AD-756 452

FEASIBILITY STUDY OF AUTOMATIC FABRICATION OF SPECTACLE LENSES IN THE FIELD (STATE-OF-THE-ART SURVEY)

J. T. Celentano

Life Systems Research Institute

Prepared for:

Army Medical Research and Development Command

January 1970

FEASIBILITY STUDY OF AUTOMATIC FABRICATION OF SPECTACLE LENSES IN THE FIELD

STATE-OF-THE-ART SURVEY

J. T. CELENTANO, M. D.
M. O. RUDD
M. GRESHES
Q. Y. CHANG

U.S. ARMY MEDICAL RESEARCH & DEVELOPMENT COMMAND
CONTRACT DADA17-69-C-9062

Approved for public release; distribution unlimited

LIFE SYSTEMS
RESEARCH INSTITUTE

AND

UNIVIS®

R

148

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)

Life Systems Research Institute
Los Angeles, California 90067

2a. REPORT SECURITY CLASSIFICATION

2b. GROUP

3. REPORT TITLE

Feasibility Study of Automatic Fabrication of Specticle Lenses in the Field (State-of-the-Art Survey)

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Technical Report - 14 April - 13 October 1969

5. AUTHOR(S) (First name, middle initial, last name)

J. T. Celentano, M.D.

6. REPORT DATE

January 1970

7a. TOTAL NO. OF PAGES

~~139~~ 148

7b. NO. OF REFS

8a. CONTRACT OR GRANT NO.

DADA17-69-C-9062

b. PROJECT NO.

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

US Army Medical Research and Development Command, Washington, DC 20314

13. ABSTRACT

A literature survey was accomplished, including library and patent searches and vendor contacts. The literature was searched for articles related to plastic lenses, ophthalmic and optical techniques and products, automated lens fabrication techniques, and plastic automation fabrication techniques. Approximately 50,000 titles were reviewed and more than 300 articles and patents considered applicable.

I-a

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
lens fabrication						
ophthalmic and optic techniques						
plastic materials						
literature survey						

I-4

69R113

FEASIBILITY STUDY OF AUTOMATIC FABRICATION OF SPECTACLE LENSES IN THE FIELD

STATE-OF-THE-ART SURVEY

J. T. CELENTANO, M. D.
M. O. RUDD
M. GRESHES
Q. Y. CHANG

U. S. ARMY MEDICAL RESEARCH & DEVELOPMENT COMMAND
CONTRACT DADA17-69-C-9062

LIFE SYSTEMS RESEARCH INSTITUTE
LOS ANGELES, CALIFORNIA
AND
UNIVIS, INCORPORATED
FORT LAUDERDALE, FLORIDA

JANUARY 1970

I-C

FOREWORD

This is the first technical report for a Feasibility Study of Automatic Fabrication of Spectacle Lenses in the Field submitted by Life Systems Research Institute and Univis, Incorporated to the U. S. Army Medical Research and Development Command in accordance with the Delivery "Item 4." page 77 of the Life Systems Research Institute and Univis, Incorporated proposal, December 27, 1968, and "Item C. (1)" of Contract DADA17-69-C-9062, 14 April 1969.

The report covers Task 1, Review State-of-the-Art, and portions of Task 3.4, Materials Test. The work was performed during the period 14 April to 13 October 1969 at Life Systems Research Institute in Los Angeles, California, and the Univis Research and Development Laboratories in Fort Lauderdale, Florida, and the Univis Applied Plastics Division in New York.

Dr. J. T. Celentano is the Principal Investigator and Project Manager for the study. Mr. M. O. Rudd is the Principal Investigator for Univis, Incorporated and Mr. M. Greshes is Associate Principal Investigator for the Applied Plastics Division of Univis, Incorporated.

ABSTRACT

This is the first technical report of a Feasibility Study of Automatic Fabrication of Spectacle Lenses in the Field, U. S. Army Medical Research and Development Command, Contract DADA17-69-C-9062, 14 April 1969. The report covers Task 1, Review State-of-the-Art, and portions of Task 3.4, Materials Test. The work was accomplished during the period 14 April to 13 October 1969.

The review concerned lens fabrication techniques, lens materials, plastic materials, and plastics fabrication techniques. A literature survey was accomplished, including library and patent searches and vendor contacts. The literature was searched for articles related to plastic lenses, ophthalmic and optical techniques and products, automated lens fabrication techniques, and plastic automated fabrication techniques. Approximately 50,000 titles were reviewed and more than 300 articles and patents considered applicable. These were acquired and reviewed. Over 500 suppliers of plastics materials and products were contacted. A software survey was established to preliminarily evaluate and screen over 100 specific plastic materials. Thirty-seven plastic materials were selected for a physical evaluation. Both evaluations were made against criteria pertinent for ophthalmic lens requirements.

The results of the literature survey are discussed. The methodology for both the software and physical evaluations are discussed and the results of the surveys presented. The results are analyzed, conclusions drawn, and recommendations made.

Appendix I contains the bibliography of articles and patents reviewed and Appendix II contains the list of vendors and suppliers contacted.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Visual defects represent almost a routine factor in the equippage of the modern soldier. When one considers that approximately thirty-three percent of Army personnel need prescription spectacles and over fifteen percent additional are allowed to wear plano-tinted spectacles, the problem is an acute one. At present there is essentially no standard for usual defects rejection if the defect can be corrected with spectacles. Thus, a rather wide range of refractions exist, although these are generally single vision problems expected in the younger age groups.

During World War II over two million pairs of glasses were furnished by the Army. In the European Theater in 1943, 30,000 lenses per month were fabricated, achieving the highest rate of the war. During World War II broken spectacles frequently meant the soldier was out of action until he could get to a supply depot or hospital where spectacles were fabricated. If he did not have his prescription, then a further wait often ensued.

Currently, an optical laboratory unit is stationed in the division area and a soldier needing spectacle repair makes his way to the detachment for service. The optical detachment must carry an extremely large inventory of lenses, over 700 different prescriptions, to meet these needs. In addition, the technicians must be highly skilled.

Eye injuries also took their toll of the combat force, many of which could have been prevented with protective eyewear. Of these, the greater percentage were evacuated and not returned to combat.

In Vietnam approximately three percent of the evacuated casualties have suffered primarily an eye injury and,of those evacuated for other reasons, another three percent would have been evacuated for eye injuries alone.

Spectacle lenses provided routinely to Army personnel today are of standard untreated, ophthalmic crown glass. Both industrial and semi-ophthalmic thickness types of heat treated (case hardened) glass are easily available at practically no greater cost than conventional glass and are being more widely used for children and individuals in only occasionally hazardous occupations. Present developments in optical plastics have far surpassed the disappointing false starts made with xylonite and methyl methacrylate which were impractically soft and subject to discoloration. The major drawback to plastic lens material is that they are still softer than glass, but considerable strides have been made in improving this characteristic. Ultimately plastic lenses may afford greater economy by eliminating all surfacing procedures.

Useful and relatively hard, thermostabile plastic lenses are now available with excellent optical characteristics and extremely high safety values. These allyl type resin lenses are of light weight, improved resistance to chemicals, reduced tendency to fogging, and pit less than glass on exposure to welder's splatter.

Fabrication of spectacles in the field is a complex affair requiring a large inventory of different items and great quantities of each in order to satisfy demands. Besides a large number of items, the fabrication process requires highly skilled technicians in numbers difficult to achieve. It would be highly desirable, therefore, to develop a system whereby spectacle lenses would be automatically fabricated in the field with minimal operator training. This feasibility study is directed toward the development of a system for the automated fabrication of spectacle lenses in the field. The goal being a system which requires little training to operate, is reliable, easily maintainable, will require only the smallest inventory, will rapidly fabricate spectacle lenses, and can be carried on a military 1/4 ton truck, will rapidly fabricate spectacles to a prescription carried by the soldier, such as on his dog tag, and have lenses of impact resistant plastic, tinted as required, and moisture and scratch resistant insofar as possible. The first task of this feasibility study was to perform a survey of the state-of-the-art of lens making and plastics molding and fabrication techniques to provide a basis for the remainder of the study and a rationale for future efforts. This report summarizes the results of the survey.

METHOD OF SURVEY

The initial effort of this project, Task 1, was a review of the state-of-the-art. The project approach is illustrated in Figure 1. Task 1 reported herein was a survey effort with the view toward providing raw data for the succeeding analyses and to delineate the feasibility study effort by determining how much of the required technology may currently exist and be in usable form. In this task the various lens fabrication techniques were assessed in respect to current lens materials and other materials perhaps not now used for making lenses. This included not only lens techniques, but techniques from other fields that perhaps may be extrapolated or converted to lens production. The material surveyed was evaluated for its specific applicability to lens fabrication and those materials and techniques of value for lens processing will be identified. The survey included the literature, universities, and industry. The survey was accomplished in two phases. One, a software evaluation in which a large number of materials and processing techniques were evaluated on the basis of technical literature and plant visits. Secondly, a physical plastics materials evaluation was accomplished. In actuality, this physical evaluation encompassed part of the materials testing program of Task 3. It was deemed the only logical approach to developing information as to some of the attributes of the plastics not readily available, especially abrasion resistance.

Initially, the review consisted of a literature search. An evaluation of a large number of abstract indexes was conducted and five were selected for indepth survey. They were the Engineering Index, the Index Medicus, the Index of Science and Technology, Plastic Abstracts, and Reader's Guide to Periodical Literature. These indexes were then searched for key categories such as spectacles, spectacle lenses, lenses, optics, ophthalmics, plastic lenses, automated processes, lens processes, etc. Reprints of articles whose abstracts appeared appropriate were secured. Each article was then thoroughly evaluated. In addition, the references or bibliography of each article was reviewed for leads to other articles not picked up in the index search.

Additionally, a search of the U. S. Patents was conducted. Approximately 50,000 titles were surveyed. Of these, over 170 articles and 100 patents were considered pertinent and copies obtained for review. Appendix I presents a list of the pertinent references in bibliographic form.

In order to evaluate the state-of-the-art of the ophthalmic and plastics industry, a list of suppliers and manufacturers of plastic and

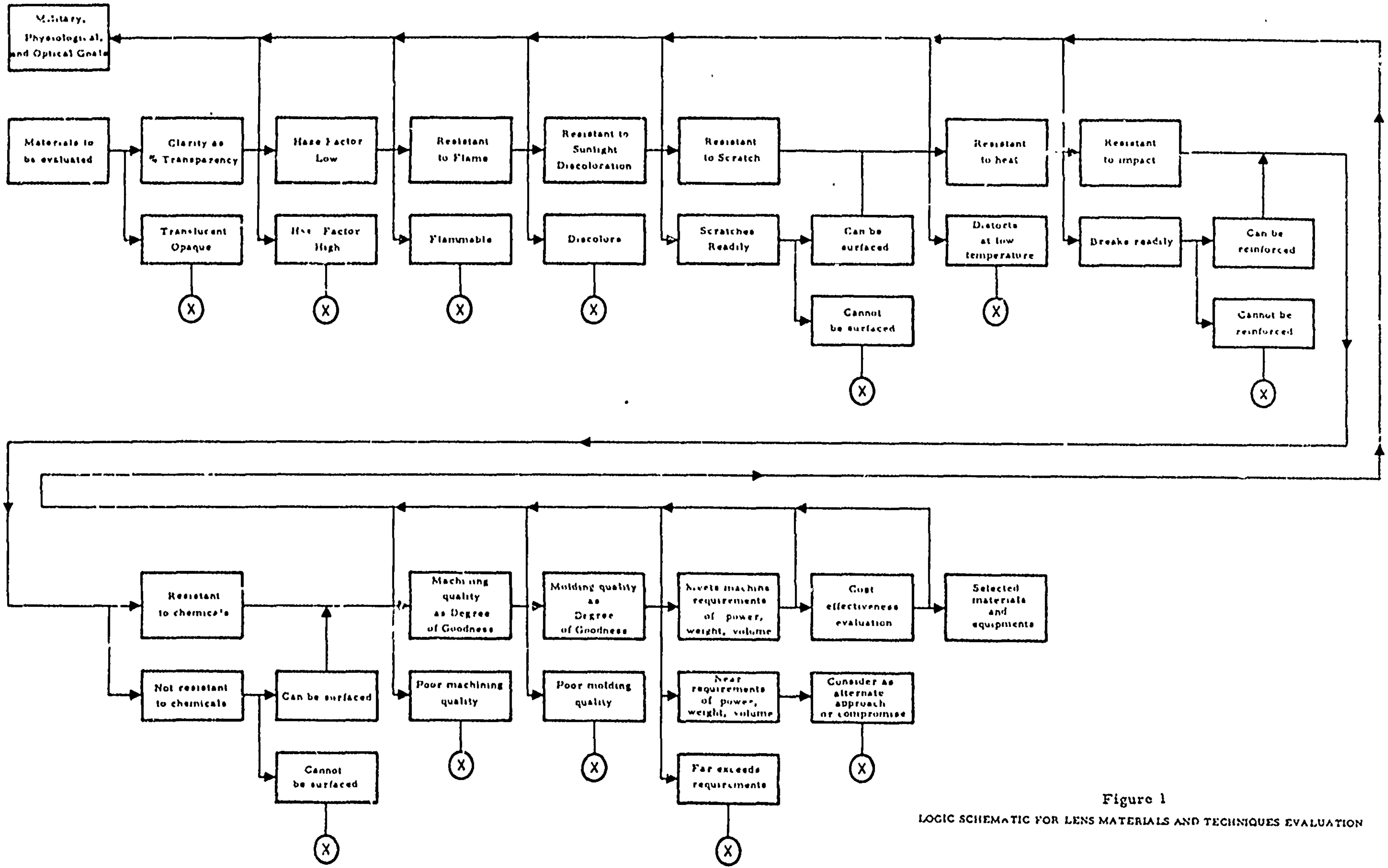


Figure 1
LOGIC SCHEMATIC FOR LENS MATERIALS AND TECHNIQUES EVALUATION

ophthalmic materials and processes was compiled. This list, provided as Appendix II, consists of 507 companies. The major ophthalmic suppliers were readily identifiable and did not represent a problem. However, the plastics industry was another matter. There were over a thousand suppliers of products in this area. Fortunately, there was some degree of categorization among these industries and the following criteria were established as a basis for determining the companies which were contacted:

- Companies manufacturing resins, molding compounds and other plastic materials were contacted, specifically those whose products include basic resins, casting resins or compounds, laminated resins or compounds, and molding or extruding compounds. Companies whose only products are organosols and plastisols, fine powders, solutions and emulsions, and electrical specialty compounds were not included.

- Foam plastics were not included because of their non-transparent properties.

- Companies specializing in modifiers and additives were searched and those producing stabilizers or ultraviolet absorbers were contacted.

- Film and sheeting manufacturers and those making fabrics, papers, and fillers only were not contacted because these products are not applicable to optical use.

- Manufacturers and suppliers of laminates and reinforced plastics only were not contacted as these materials are not applicable to optical use.

- Those companies involved in plastics machinery or equipment whose products include injection molding machines, molds and dies, compression molds, thermoforming systems, thermoset molding machines, and those manufacturing optical instruments were contacted.

- Companies specializing in dip-coating processes were contacted.

- From an initial review the plastics of interest were narrowed to the following and companies producing these were contacted--acrylics, allyl resins and monomers, cellulosic molding compounds and sheets, cellulosics, epoxy resins, fluoroplastics, nylons, phenol-formaldehydes and phenol-furfural molding compounds, phenolic cast resins, phenoxys, polycarbonates, polyesters and alkyd resins, polyethylenes, polypropylenes, polystyrene silicones, urethanes, vinyl polymers and copolymers. All these generic plastics include one or several transparent products. The other generic plastics have no transparent item.

A series of basic letters were prepared for several categories of companies: plastics manufacturers who may have a product of optical quality; plastics manufacturers or processors who may have a product or technique that could be used for opthalmic lens manufacturing; automatic machine processors who may have techniques or equipment that could be used for lens manufacturing and processing; and ophthalmic lens producers and processors. One of the letters, selected on the basis of each supplier's major capability, was mailed to all 507 suppliers. Those suppliers having especially interesting processes and techniques were requested to allow a visit by a representative of the project team.

Of the 507 letters sent over 100 were requested to provide samples of commercial materials which could be applicable to lens manufacture. The materials obtained would be candidates for the physical test and evaluation.

In addition to attempting to obtain commercially available plastics which were adaptable to this study, an attempt was made to obtain and evaluate materials which were in the development stage and which, at best, would not be commercially available for at least two to three years, if at all. Generally, one is not successful in trying to solicite information about materials in the development stage because of the confidential nature of such information. However, approximately fifteen such visits were accomplished. This phase of the investigation was intriguing because of the small potential volume of plastics which would, ultimately, be used in lens application. However, there are other end uses of plastics materials with tonnage potential which have the same basic requirement as plastic material for lens application. One such end use would be floor tiles where a clear, water white, scuff proof, weather resistant material is desirable. This portion of the study, therefore, was to search out and obtain such development materials, more so than materials for optical application of which there are very few.

The various materials obtained for the physical evaluation were primarily those materials which would be applicable for lenses rather than frames. Plastics materials adaptable for frame application are well known and only those materials which would have exotic properties were considered in the evaluation. However, one of the considerations in evaluating a lens material is its possible use as a frame material as well. The materials obtained as described above were exhaustively evaluated for all characteristics pertinent to lens application. While certain properties are more pertinent than others, all significant properties from the point of view of optics as well as esthetics were considered Thirty-seven materials were secured and each evaluated for 34 criteria. The 37 materials represented homo-polymers or coatings and were representative samples of all plastic materials which are candidates for this application. It represents samples of polyesters, silicones, fluorocarbons, polycarbonates, acetates, butyrates, acrylics, epoxys, styrenes, polyvinyl cloride, urethanes, and co-polymers of these materials.

The basis of both the software and the physical evaluation was a materials properties and machine processing matrix. The logic of this systematic evaluation is presented in Figure 2. The design goals and the materials properties set up a series of "go, no go" gates through which each material under consideration must pass. Where a circle with an "X" inside appears, this represents a "no go" situation. Materials passing through to the end were then compared and selections made. In a similar fashion, techniques were evaluated.

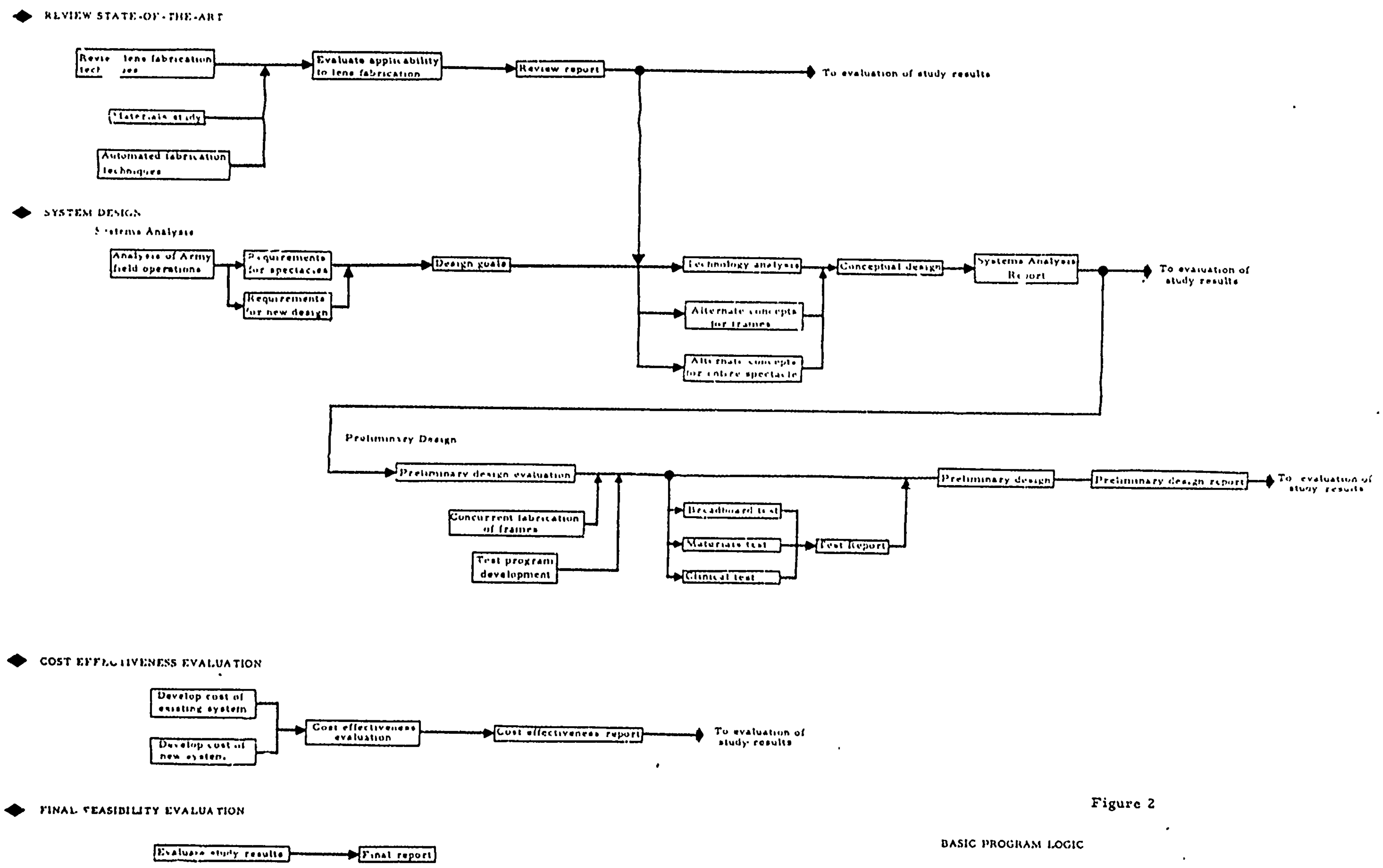


Figure 2

BASIC PROGRAM LOGIC

RESULTS OF SURVEY

GLASS LENSES

Ophthalmic Glass

To the extent that such properties can be achieved in glass, the requirements for the special glasses used for ophthalmic lenses are: abrasion resistance, impact resistance, high transparency, freedom from internal haze, bubbles, striations, etc., stability against the effects of weathering and corrosive elements. These physically desirable characteristics must be provided in glasses having a variety of tints, shapes, and thicknesses. Additionally, the optical properties of extreme homogeneity, controlled refractive index and dispersion, and consistency of color (or lack of color in the case of clear glasses) must be maintained.

The above mentioned general requirements need to be met by all glasses which are to be considered for spectacle lens use. Fused multifocal lenses require the use of additional varieties of glasses suitable for the reading segment and intermediate segment areas. Such segment glasses are required in a variety of refractive indices. Segment glasses should desirably have low dispersions (high nu values) and adequate stability. They have the further special requirement of matching the thermal expansion properties of the crown glasses to which they are to be fused.

Glass Varieties in Common Use

Table 1, abstracted from a publication entitled "Clear Ophthalmic Glass Properties," provided by the Optical Sales Department of Corning Glass Works, lists the types and optical characteristics of the glasses in common use for the volume production of single vision and multifocal lenses. A similar range of suitable glasses is also manufactured and supplied by PPG Industries. (The American Optical Company and Bausch & Lomb Optical Company also manufacture ophthalmic glasses, but their output is primarily intended for their internal use.)

The glasses listed under Group 1 in Table 1 are all known in the trade as "crown glasses" and are comprised principally of soda, lime, and silica. Practically all single vision lenses manufactured today are produced from these crown glasses, as are also the one-piece types of multifocal lenses and the major blank portions of fused type multifocal lenses. Crown glasses are relatively inexpensive, durable, and producible in high quality. Group 2 lists glasses customarily supplied

Table 1

Commonly Used Ophthalmic Glasses

Corning Glass Code	Glass Type	Index n_D	Nu
Group 1			
8361	Crown	1.523	58.6
8314	Shade A Pink	1.523	58.3
8315	Shade B Pink	1.523	58.2
8383	Shade C Pink	1.523	57.0
8044	Shade B Neutral	1.523	54.8
8364	Shade C Neutral	1.523	54.8
8384	Shade A Green	1.523	54.6
8385	Shade B Green	1.523	53.3
8386	Shade C Green	1.523	52.3
Group 2			
8323	Light Barium Flint	1.588	52.0
8304	Extra Dense Crown	1.617	49.4
8324	Dense Flint	1.653	34.0
8316	Barium Flint	1.653	42.2
8040	Dense Barium Flint	1.701	34.4
8405	Neutral Barium B	1.588	51.9
8042	Neutral Barium B	1.653	42.2
8388	Neutral Barium C	1.588	51.8
8389	Neutral Barium C	1.653	42.2
8396	Green Barium B	1.588	51.7
8398	Green Barium B	1.653	42.1
8397	Green Barium C	1.588	51.2
8399	Green Barium C	1.653	42.2

as the segment glasses in fused type multifocals. The Code 8324 Dense Flint, Index 1.653, is used as the segment glass in the widely-used Kryptok, or round segment, lens blank. The remaining glasses listed in Group 2 are primarily used as segment glasses in the "improved-type" fused multifocal or "straight-tops."

In addition to the glasses described in the table, two series of segment glasses, known as "compatible flints" and "compatible bariums" have recently been developed. These segment glasses are provided, eight to twelve types to a series, with refractive indices increasing by small, uniformly spaced differences. Such a series offers the lens manufacturer the attractive possibility of providing a large range of reading addition powers while maintaining the internal segment glass and major blank curvatures constant.

Absorptive Shades

Uncolored glass, known as "white" glass, is employed in the great majority of prescriptions. Tinted glasses in various hues and densities have been developed and accepted for use in meeting a variety of needs. Some glasses, such as the dark neutral grays and greens, serve the directly functional purpose of absorbing a large portion of the light incident upon the wearer's eye, thus avoiding discomfort and eye fatigue due to prolonged exposure to brightly illuminated or contrasting fields of view. The lighter green and pink shades are perhaps largely cosmetic in their effect, although some claim can be made for a minor increase in eye comfort from their use under some conditions. Table 2 lists the commonly prescribed absorptive shades with their respective luminous transmittances for solar light.

Table 2

Common Absorptive Glasses

Trade Name	Nominal Luminous Transmittances
Pink Shade A	87%
Pink Shade B	82%
Pink Shade C	67%
Green Shade A	67%
Green Shade B	52%
Green Shade C	37%
Neutral Shade B	31%
Neutral Shade C	20%

"Crookes glass," which is of a light blue-green hue having high absorption in the ultraviolet region, is rarely used, but affords a good protection from ultraviolet radiation while transmitting efficiently in the visual part of the spectrum. Ophthalmic glasses having a warm brown hue, incorrectly termed "tan," have gained a degree of acceptance in the market during the past few years. Typical of such glasses are products known as Cosmetan and UniTan.

A new type of glass which is of considerable technical interest is the photovariable glass developed by Corning Glass Company and termed "Photogray." This remarkable glass has the unique property of darkening when exposed to light, and recovering its initial high transmittance when withdrawn to a darkened area. While ophthalmic lenses made from Photogray glass will not replace in function the white glasses and the darker absorptive shades, Photogray does have a use in providing, to those who are abnormally sensitive to light, some degree of comfort under varying light conditions. The disadvantages of Photogray glass in its present form are those of a restricted range of transmittances and of an undesirably long recovery time back to peak transmittance after coming in from the bright sunlight.

Methods of Manufacture of Ophthalmic Glass

Substantially all of the ophthalmic glass manufactured in the United States today is produced by the "continuous melt" process. In this process, which is admirably suited to the low cost, high volume production of ophthalmic quality glass, the glass batch ingredients, in the form of powdered metallic and nonmetallic oxides, are introduced into a platinum lined tank within a gas fired furnace. After an adequate period of melting and stirring, the molten batch flows through a small outlet in the tank into a mixing chamber. From this chamber, a stream of hot viscous glass flows under gravity. By maintaining the level of the batch in the tank through the addition of replacement quantities of batch mix, the flow of glass out of the mixing chamber can be maintained almost indefinitely.

The viscous stream of glass flowing downward is sheared at precisely controlled intervals to break the flow into discreet "gobs" of the desired weight of glass. The individual gob drops onto one of a number of appropriate receptacles on a rotating, indexing table. By synchronizing the indexing of the table with the dropping of the sheared gobs, the gobs can be handled at an extremely rapid rate. As the gob is carried around by the indexing table, it is cooled until rigid enough to maintain its shape, whereupon it is ejected from its support and automatically conveyed to an annealing lehr.

The product from these continuous tank furnaces is usually provided in the form of a "hot pressing." For this purpose, the molten gob of glass drops into a mold cavity carried by the indexing table.

When the table next indexes, the cavity is closed by a plunger with a face of appropriate configuration. The pressure of the plunger forms the gob into a pressing.

The hot pressing method of making glass pressings is particularly suited to large quantity requirements. The cost of the necessary quantity of mold cavities and plungers, along with the complex set-up required, makes the employment of the hot pressing process prohibitively expensive for the production of small quantities of pressings. To service these low volume requirements, gobs from the continuous tank are, as in the hot pressing process, sheared and dropped onto the indexing table. For this use, however, the gobs are caused to fall upon flat surfaces on the table, after which they are permitted to flow unrestrained until rigid. The typical gob as formed in this manner is pancake-shaped, with a diameter from 4 to 10 times its thickness, and with a weight ranging from a few grams to over 100 grams. Such gobs are produced in relatively large quantities and are inventoried until required for re-pressing.

To meet the need for small quantities of glass pressings produced by the continuous tank process, a gob form is selected whose size, weight, and composition are suitable for the requirement at hand. The gobs are then processed through a series of hand operations. They are loaded one at a time into a furnace where they become plastic. Upon reaching the required viscosity, a gob is picked up with tongs and dropped into a mold cavity. It is then pressed into its intended shape by actuating a switch which lowers a pneumatically controlled plunger. The shaped gob, or "re-pressing," is removed from the mold, rough annealed by placing it in a cooler area of the furnace, and then loaded into another furnace for the final annealing.

Where the requirement for a particular glass type is small, the continuous tank furnace is not suited, owing to the considerable start-up costs and the large batch volume required just to charge the tank. These smaller demands are met by the use of a variation of an older process for producing optical glasses. The batch constituents are placed in a ceramic crucible and brought to the melting temperature, mixed carefully, and allowed to stand undisturbed so that bubbles and other impurities are removed from the body of the melt. The central portion of the contents of the crucible is then emptied out and passed between rotating steel rollers, causing the glass to be extruded in the form of a sheet of controlled thickness. The sheet, still plastic, drops onto a moving flat bed which provides support for the sheet until it is sufficiently rigid. Sheets produced in this manner are stocked until needed, whereupon they are sawed or broken into cubes or rectangular prisms of the desired weight. The individual bits are then manually processed into pressings in much the same manner as was described above in the description of the processing of re-pressings.

The three basic methods of providing glass pressings for use by the ophthalmic manufacturer may be summarized as follows:

> Hot pressings produced by the continuous melt method are by far the cheapest and have the best available quality. Their use presupposes an adequate quantity requirement to support the mold and set-up costs. The re-pressing of gobs is more costly, but provides good quality pressings. The use of rolled sheet to make re-pressings is appreciably more expensive than the other two methods, and results in a product of lower quality.

Lens Manufacturing

Spectacle lenses must be provided in a great variety of powers and forms. To meet the differing requirements of the individual patients, the prescription laboratory, which promptly supplies spectacles to an individual prescription, generally services a local area or region. If the requirements of this region were to be produced on a "make to order" basis, the majority of orders would require being made on a one-of-a-kind operation, with its attendant high costs. When the laboratory orders lenses from an established manufacturer, however, the lens requirements for the entire country are, in effect, pooled so that the manufacturer is enabled to produce reasonable quantities of identical lenses. The ability to produce in volume means that large outlays for capital equipment can be justified. The economics of the supply of ophthalmic lenses has thus led to the existence of a number of relatively large manufacturers who supply lens products to wholesale laboratories. These laboratories thereupon process the manufactured lenses into the completed prescription form.

Ophthalmic lenses are supplied by the manufacturer to the prescription laboratory as "uncut" lenses or as "semi-finished" lens blanks. The uncut lens has both sides polished in the final form, but the periphery of the lens is left considerably oversized to permit placing the mechanical center in accordance with the prescription, and edging the lens to fit the prescribed frame.

Semi-finished blanks have only one side finish polished. The semi-finished blank is supplied with adequate thickness to permit the prescription laboratory to grind and polish the second side in accordance with the individual prescription. Semi-finished blanks supplied for single vision requirements usually have the toric surface, front or rear, finish polished, although some blanks are provided with the convex sphere finished only. Multifocal, semi-finished blanks always have the front surface, which contains the reading segment, as the finished surface.

While most single vision lenses are supplied to the laboratory in the uncut form, almost all multifocal lens blanks are supplied in the semi-finished form. This is because the tremendous variety of multifocal blanks required to meet all of the sphere power and cylinder power corrective requirements and additionally provide cylinder axis alignments having the prescribed relation to the segment areas, would require impossibly large inventories of uncut lenses.

Manufacturing Processes

Glass blanks utilized in volume manufacturing are primarily produced as hot pressings by the continuous tank process and, hence, are suitably uniform and consistent in their dimensional properties.

Blanks to be processed are often supported in multiples on suitable holders, or "runners." The blanks are adhered to the runners by interposing a layer of either a specially formulated pitch or wax, or by the use of a low melting point alloy, commonly known as LMP. The blanks mounted on runners are precisely supported in immovable relationship to each other throughout a following sequence of operations, such as generating, grinding, and polishing. Some operations, however, are best performed by merely cradling the individual glass blank in a "spinner" which holds the blank by its edges and one surface while the other surface is being processed.

High speed generators are employed to remove the surface layer of glass from the pressing and to shape the curve roughly to the intended form, whether sphere or toric. Such generators are rugged machine tools, with considerable emphasis upon rate of output. Usually the generator is manually loaded and unloaded, but the cutting wheel is automatically fed into the glass. The cutting means is always a metal-bonded, diamond grit wheel of the cup type. Diamond grit sizes from 80 to 150 mesh are usually employed, with 120 mesh customarily used. A coolant is pumped in quantity onto the interface between the tool and glass blank. Coolants in wide use are of three types: soluble oil, kerosene-based, and ethylene glycol diluted with water.

Following the generating, or roughing, operation just described, the lens blank is smoothed to put it into a condition suitable for polishing. Smoothing is accomplished by one of three available methods, with no one method being the overwhelming choice. Smoothing may be carried out with the same type of equipment used for the rough generating, but with the diamond wheel replaced with one of much finer grit size. Grits used for smoothing are in the micron range, and vary from 10 to 30 microns average particle size depending upon the requirements of the process. Smoothing is also performed satisfactorily by the lapping technique, using a cast iron lapping tool whose curvature is the exact mate to the lens curve required, and a fine abrasive powder suspended as a slurry. Abrasives in common use are natural emery, aluminum oxide, and garnet. Suitable abrasive powders have average particle sizes ranging from 9 to 15 microns. Equipment for lapping comprises a motor-driven vertical spindle to which the workpiece or the cast iron lap is attached at the upper end. The other element, lap or workpiece, is driven, under free-floating conditions, back and forth across the mating surface beneath. The abrasive slurry is pumped onto the interface. Banks of such units are employed. The third method of smooth grinding is similar to lapping with an abrasive slurry, but a diamond grit lap is employed as the abrading means, while coolant is pumped onto the interface between workpiece and lap. The latter of the three methods is gaining in use and, as experience develops, will probably largely supplant the others.

The polishing of ophthalmic lenses is invariably accomplished by a lapping process. The equipment is similar to that used for smooth grinding with an abrasive slurry. Instead of a cast iron tool face as the lapping surface, the polishing operation requires a more resilient and softer medium. A great variety of polishing surfaces, known as "pads," have been developed. Pad materials which are widely used are: wool felt, felt impregnated with pitch, wax, or plastic, woven textiles similarly impregnated, and complex formulations of synthetic chemicals, often blended through the use of a rubber mill.

For polishing, the abrasive slurry is replaced with a polishing slurry. The polishing powders in widest use today are cerium oxide and zirconium oxide. The slurry is always a water suspension, with additives to assist in the suspension or in the maintaining of acidity. With today's equipment and polishing materials, the polishing of a single lens surface usually requires from two to ten minutes. Because of the repetitive nature of the operation, wherein one lens is loaded into a holder immediately following the removal of a polished lens, the emphasis in the polishing process is upon closely controlled smooth-grinding, to the end that the polishing cycle can consistently be at a minimum, and upon the polishing pad material, which must be durable and capable of maintaining the required curvatures under conditions of heavy pressure and fairly high speed.

Additional specialized operations are required in the manufacture of fused multifocal lens blanks. Mating sphere curves are ground and polished on the major blank of crown glass and on the segment of high index glass. After scrupulous cleaning under dust-free conditions, the segment is accurately positioned in contact with the major blank and held in this position by means of droplets of cement while the parts are being fused together. The fusing is done in the continuous-lehr type of electric furnace in which the work being fused is carried slowly through several temperature zones. The zones have their temperatures controlled by individual controllers actuated by thermocouples. Temperature stability of the order of plus or minus 5°F is required at the peak temperature where fusing takes place. In fusing furnaces of minimum complexity, the heating zones comprise (1) a rapid preheating zone, (2) a fusing zone, (3) a cooling zone, (4) an annealing zone, and (5) a further cooling zone which brings the glass load safely down to a temperature at which it may be removed from the furnace. Fusing furnaces are usually between 25 and 40 feet in length and operate at conveyor speeds of from 6 to 12 feet per hour.

The one-piece form of multifocal lens blank, examples depicted in Figure 3, has two or more spherical curvatures ground and polished on the same side of the glass blank. The processing of such multiple surfaces is a matter of considerable mechanical difficulty, requiring as it does that the function between the differently curved areas be free of even tiny chips, while at the same time requiring the forming of surfaces with quality optical performance throughout the polished areas. The equipment for such work must be of a high caliber, and is equivalent to the machine tooling used in the more demanding metal working requirements. High speed diamond grit cut wheels are widely used as the abrading means. Particular attention must be paid to providing a machine which is free of vibration. Atypically, the polishing machines used in making one-piece multifocals are carefully engineered units, providing several quite precise adjustments along with the essential freedom from vibration. Pad materials and polishing slurries are similar to those used in other types of lens manufacturing.

Manufacturing Inventories

For the reasons presented at the beginning of this section, the lens manufacturer must make and carry in inventory a great number of varieties of lens blanks. Thus, the single vision, uncut lens must be stocked in all of the combinations of sphere powers, cylinder powers, absorptive tints, and three thicknesses (regular, dress, and industrial).

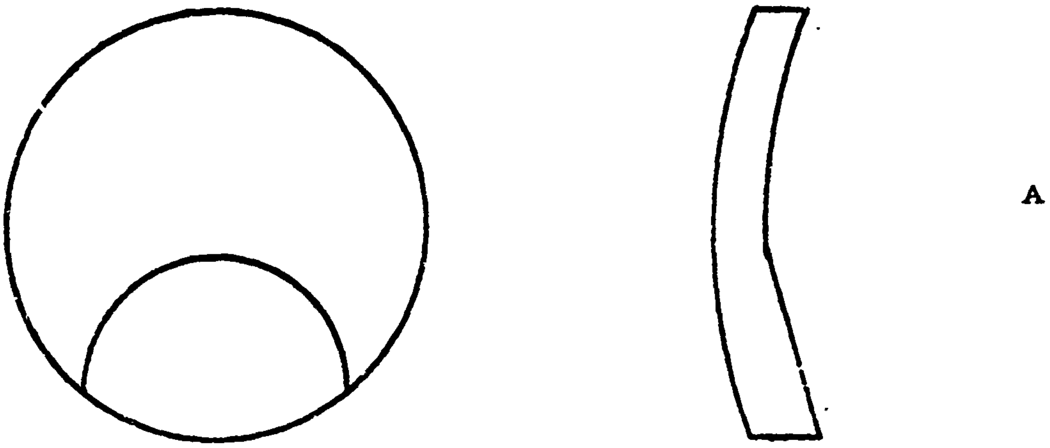
Multifocal lens blanks require inventories of even greater scope. Involved are the combinations of base curve powers, reading powers, bifocal segment styles, trifocals, absorptive tints, and the major categories: fused and one piece. Lens blank items carried in inventory by the larger manufacturers accordingly range from 5,000 to 20,000 separate items.

Glass Lens Types

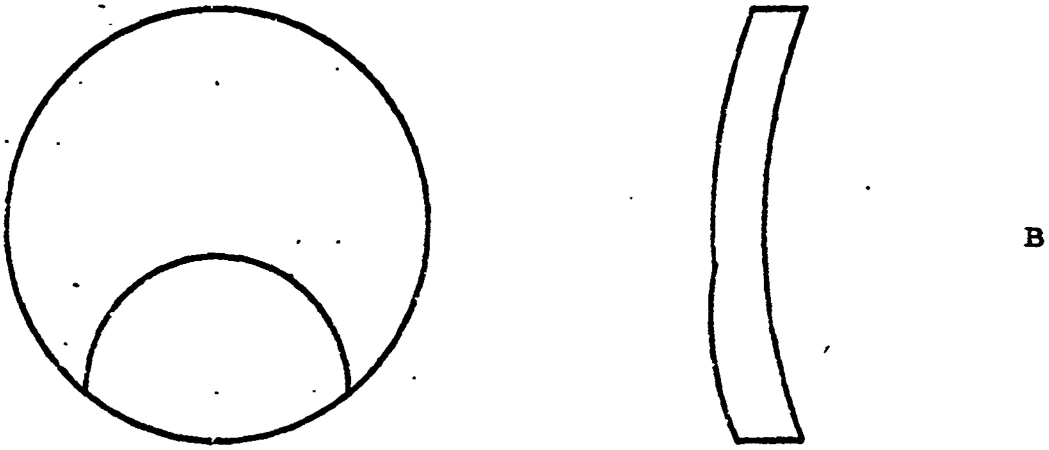
Single Vision Lenses

Single vision lenses are provided in sizes up to 62 mm diameter (smaller in the highest powers). They are available in absorptive tints: white (clear), pink - 3 shades, green - 4 shades, gray - 2 shades, brown - 1 shade, and "Photogray" - 1 shade.

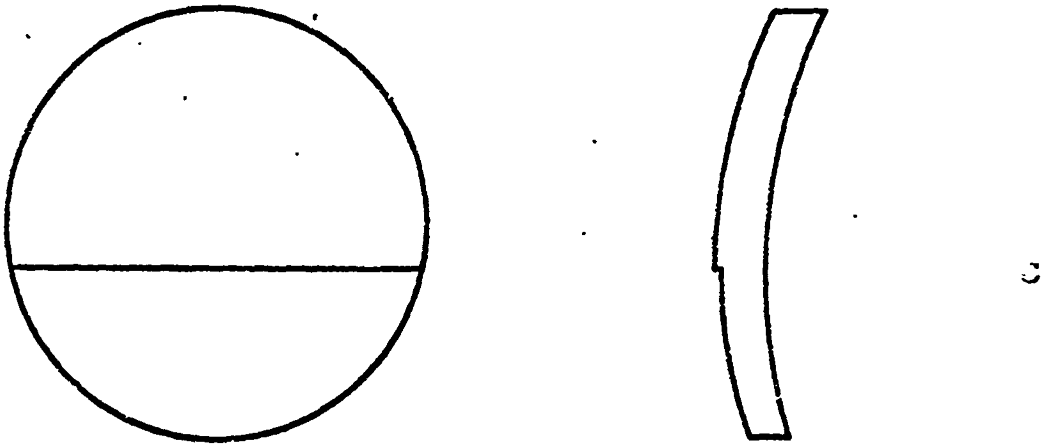
Uncut lenses are those in which both surfaces are finished and ready for edging and mounting. Forms may be provided with the toric



ULTEX



PLUS ULTEX



UNIVIS E-STYLE

FIG. 3

Multifocal Lens Styles - One Piece

surface on front (plus toric) or the toric surface on rear (minus toric). Typical available power ranges are spheres from + 7.50D to - 5.50D in 0.12D steps (0.25D steps in the higher powers), and cylinders from - 0.12D to - 3.00D in 0.12D steps (0.25D steps in the higher powers).

Semi-finished lenses are those in which the toric surface is finished and the sphere surface and edging is to be provided by the prescription laboratory. These are provided as toric front surface finished only, or sphere front surface finished only. The base curve selection of these is provided in a large variety of powers (12 or more), permitting the choosing of the proper curve for any prescribed lens power which will effectively reduce the lens aberrations at wide angles of view. With semi-finished lenses the blank dimensions and shape provide adequate glass to permit grinding a range of spheres and cylinder power requirements and to permit edging to an acceptable range of "eye sizes" and shapes

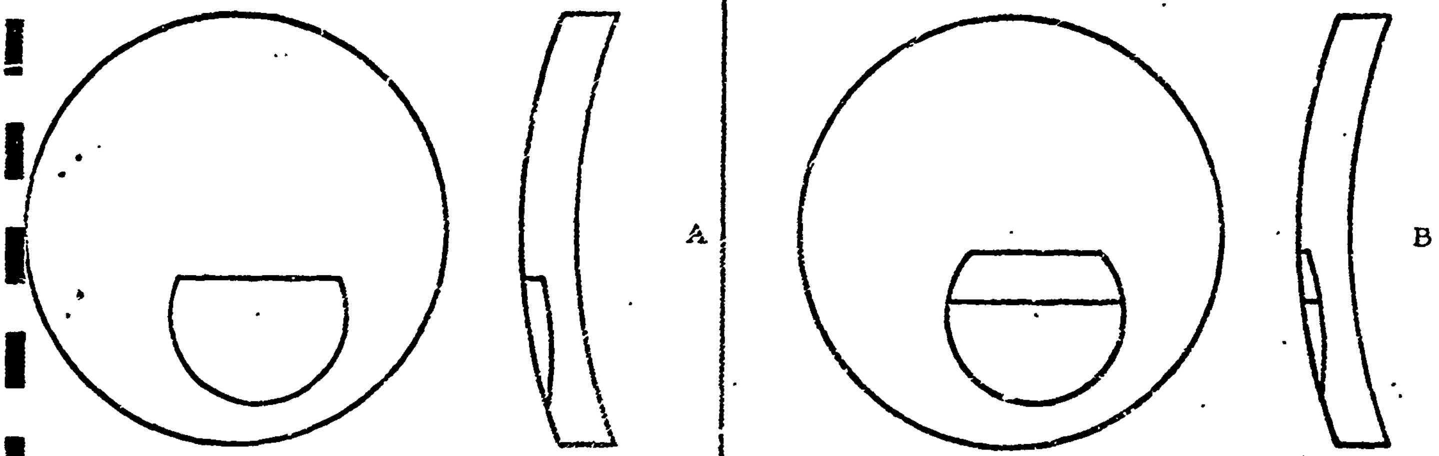
Multifocal Lenses

There are several functional types of multifocal lenses. The bifocal provides an area of additional plus power below the distance viewing area. The trifocal provides an area of "intermediate" added power below the distance area, and a "reading" area of further increased power below the intermediate area. The graduated type provides continuous increase in plus power downwardly along the vertical meridian or along the lower part of this meridian.

There are several special purpose multifocal lenses: specially formed segments of added power to meet vocational needs--special segment sizes, shapes, positions, powers, or combinations of positions and powers, i.e., the Univis DD lens style shown in Figure 5-C; cataract lenses, having exceptionally strong front surface powers; and special glasses, where unusual absorptive requirements are to be met.

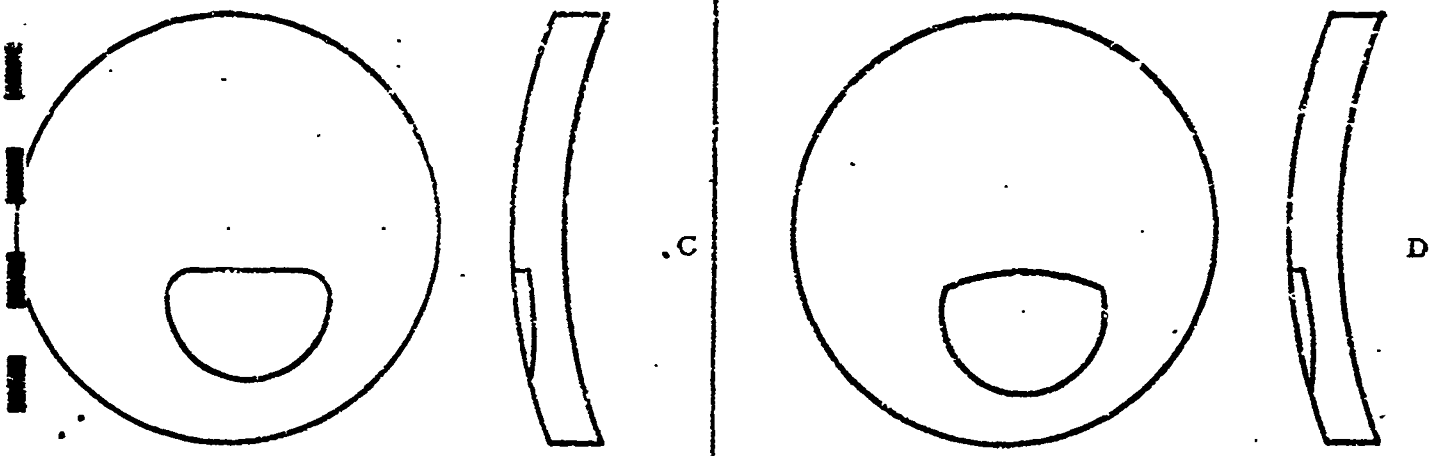
The construction of multifocal lenses is generally accomplished by two methods. These are one-piece which are made from a single piece of glass, usually crown glass of 1.523 refractive index. These have several styles: segment(s) of added power on rear surface, Ultex, (Figure 3-A); segment(s) of added power on front surface, Plus Ultex (Figure 3-B); and segment(s) of added power on front surface, bounded by straight shoulder, Univis E-Style (Figure 3-C).

There are also fused multifocal lenses. In these the major (distance) area is made of 1.523 index crown glass into which a segment of glass of a high index of refraction (1.588, 1.617, 1.653, 1.700) has been placed by fusing in an electric furnace. These fused multifocals are made in a large variety of segment shapes and sizes. Typical styles of fused multifocal lenses are shown in Figures 4 and 5.



STRAIGHT TOP BIFOCAL

TRIFOCAL



PANOPTIC

CURVED TOP

FIG. 4

Multifocal Lens Styles--One Piec

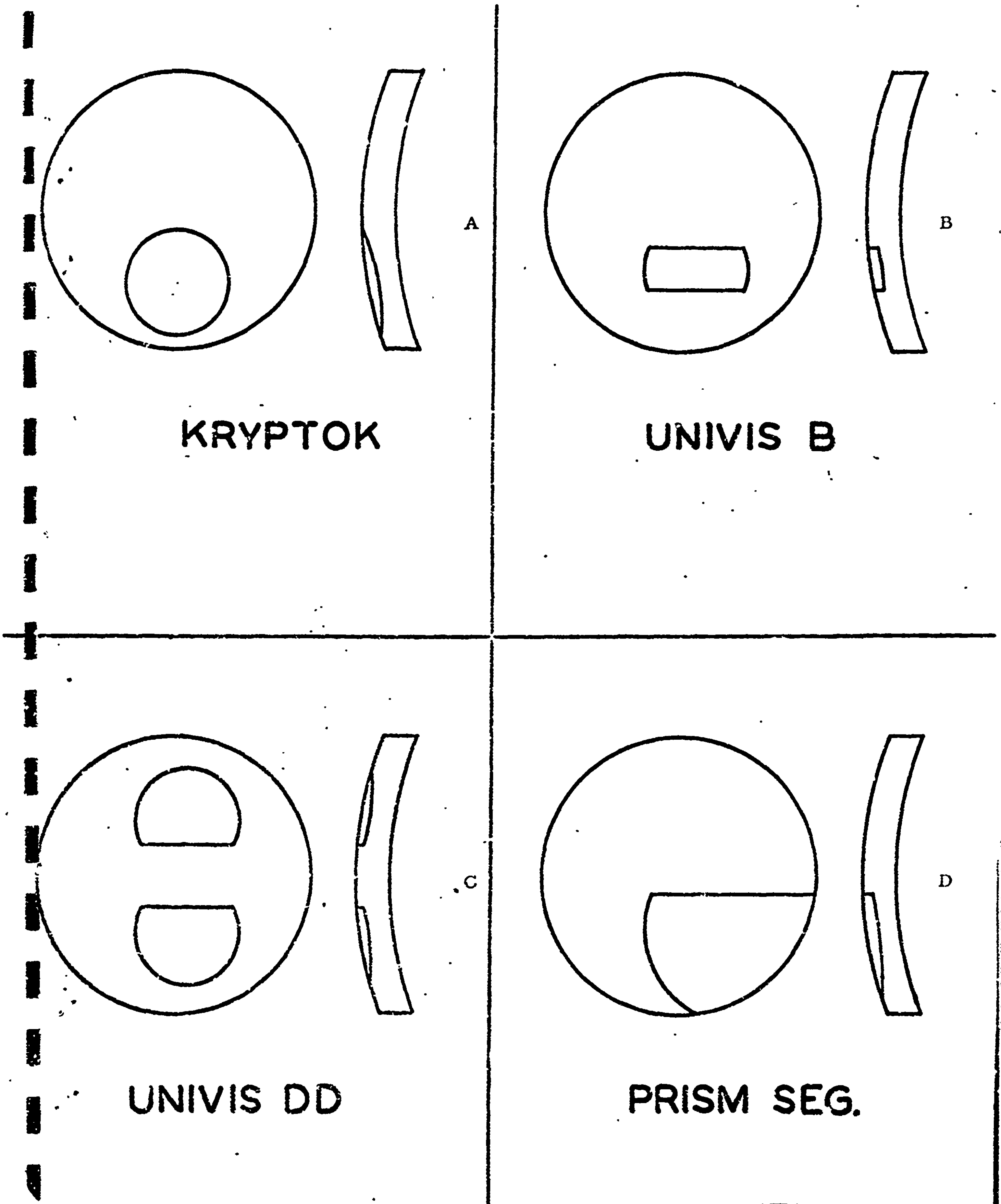


FIG. 5

Multifocal Lens Styles--Fused

Advantages and Disadvantages of Ophthalmic Glass

Advantages

As an optical material for the construction of spectacle lenses, glass has many advantages over the few other candidate materials which have acceptable transparency and homogeneity. The raw materials which comprise a batch of optical glass are relatively inexpensive. Because of the great compatibility of the glass-forming silicates with a wide variety of inorganic materials, glasses can be formulated which have properties tailored to meet the different requirements posed by corrective lenses.

Glass is an exceptionally stable material. It is almost unaffected by long exposure to bright sunlight. In the forms used for ophthalmic lenses, glass is highly resistant to deterioration from weathering and mildly corrosive elements. Glass is rigid and quite elastic. These are properties which facilitate shaping operations such as grinding and polishing, and which resist optical distortion when the lenses are mounted in a constraining frame.

The glass industry is the beneficiary of centuries of experience. This know-how results in a product which is of completely acceptable quality with regard to such essential properties as homogeneity, freedom from internal blemishes, strict refractive index tolerances, and uniformity of shade and hue in absorptive glasses.

Disadvantages

The economical forming of ophthalmic glass directly into lenses from the melt has not been achieved. Even at temperatures of the order of 1500°F, glass is a highly viscous, putty-like material, and hence unsuited to normal casting or molding techniques. While acceptable procedures are in wide use for the pressing of large quantities of identical glass pieces having relatively broad tolerances as to size and surface irregularities, the insurmountable problems involved in pressing glass precisely enough for use as a lens requires that glass be provided in a form which must receive additional shaping and polishing operations. These shaping procedures require relatively skilled workmen and expensive, specialized equipment.

Glass, when broken by impact, may produce quantities of sharp fragments which are obvious eye hazard. Because of its brittleness, the use of glass in lenses results in significant losses in processing and frequent breakage by the wearer.

The use of absorptive glasses for promoting greater comfort under conditions of strong, contrast lighting is accompanied by a difficulty when the darker shades are used with strong prescription powers. Strong powered lenses have large differences in thicknesses between center and edge, so that a considerable difference in light absorption occurs. Thus, a strong minus powered lens may well absorb many times as much light around the edge as through the center. If the central area is suitably dark to afford glare protection, the outer area may be so dark as to be, in effect, a mask.

Glass for Safety Lenses

Materials

Safety lenses, widely used in industry, are commonly of three types: laminated glass, heat-treated or hardened glass, and plastics--discussed in the next section. Laminated glass is produced by laminating two outer layers of ophthalmic glass to a middle layer of vinyl. Laminated glass, although superior from the safety point of view to plain crown glass, carries with it two rather significant disadvantages which have prevented it from attaining the general acceptance that heat-toughened glass has attained. First, in spite of advancement in edge-sealing techniques and the introduction of polyvinyl butyral as a midlayer, interlayer breakdown still occasionally occurs, with noticeable "running" rowards the edges of the lens. Secondly, on drop ball testing and on bombardment with low velocity missiles, these lenses fracture at essentially the same resistance point that ordinary crown glass does. The layers of the glass would in general bind together fairly well, but small spicules and particles would often fly from the inner surface of the lens. These particles create a definite hazard to the eye. Bausch and Lomb manufactured these lenses under the name Laminex and American Optical Company manufactured them under the name I-Safe. They are still produced under the name Motex by Optical Industries of Indianapolis.

Heat-treating or heat-toughening of glass has undergone innumerable refinements until at present a table-size heat-treating unit is available. The modern lens is heat-treated after the process of polishing and edging has taken place. It is particularly important that the polishing be carefully and accurately accomplished, because fracture systems often start in an area of surface scratching or flaws. The average heat-treated lens, depending on thickness, undergoes an increase in impact resistance of from three to seven times. Scratched or pitted safety lenses of the heat-treated variety should be removed from service because their impact resistance has been significantly decreased. Tempered lenses must not be subjected to drill holes and should be mounted in plastic rather than metal frames to increase further their shock resistance. Heat-treated lenses for industrial use must have a minimum thickness of 3 mm--Federal Specifications for Goggles GGG-G501 b July 13, 1944--and withstand a test impact of a 45 gm steel ball freely falling for 50 inches. Corrected curve blanks in prescription ranges are available to meet this 3 mm minimum specification: B & L Industrial Thickness Orthogon, Tillyer A-O Super Armor Place, Titmus Industrial. Similar properties can be given to thinner lenses for nonindustrial use, using minimum thickness blanks of 1.8 to 2.2 mm. These are lighter in weight, more attractive, more acceptable for street use, but offer slightly less impact resistance. Prescription range blanks are available to the optician in this thickness under the names Tempross Tillyer (American Optical Company), Tuffx 2 mm (Titmus), 2.1 mm Orthogon (Bausch & Lomb), or Dress Safety 2.2 mm (Shuron). Other trade names, such as Hardrx, Safe-Rex, and Tuffrx are applied to these semiophthalmic thickness lenses, by their jobbers.

Characteristics of Safety Lens Materials

The optical characteristics of heat-treated glass and laminated glass and organic plastics are all extremely satisfactory and closely parallel the characteristics of crown glass. It is not these optical characteristics, therefore, but rather the characteristics of impact-resistance and resistance to surface scratching, as well as fracture pattern upon impact, which are important.

Surface hardness or scratch resistance is a minor problem in heat-treated glass lenses, but would have to be considered a significant problem in plastic lenses. Heat-treated glass, because of decreased surface elasticity, is slightly more susceptible to scratching than ordinary crown glass. Surface scratching or abrasion in turn lowers the impact resistance as it opens an avenue for a fracture pattern to begin.

Impact resistance in ophthalmic safety materials is measured by the drop ball test, which is believed to approximate the low velocity missiles possibly encountered in civilian life. Ross and Stewart studied high velocity missiles and their results on ophthalmic safety lenses. Their results suggest that with a 1 mm missile, comparison of industrial thickness heat-treated glass with rabbit corneas reveals corneal tissue to be more resistant to penetration than the lenses. The lenses broke at velocities less than the velocity required to penetrate the cornea. Allyl resin lenses similarly bombarded showed no more than a barely visible dent. Their studies suggest that allyl resins afford the most consistent high impact resistance, while among the glass products, industrial thickness, heat-treated glass offers the greatest low impact resistance.

When one is dealing with prescription lenses, obviously the prescription strength will alter the impact resistance; thus, increasing the spherical or decreasing the cylindrical power will produce increased resistance. Similarly, more plus and less minus will have a like effect.

Fracture patterns secondary to breakage on impact are equally important as a consideration in choosing a safety lens material. Crown glass, as well as the inner layer of laminated glass, upon fracture will produce minute sharp spicules and particles capable of penetrating and perforating the afterlying globe. Similarly, case-hardened glass, although more resistant to impact, will upon fracture loose small spicules from its posterior surface. Plastic lenses, on the other hand, upon fragmentation will give off more obtuse and less damaging segments, a quality secondary to the relative softness of the plastic and which offsets the mild disadvantage of surface scratching of the plastic.

New Developments

Corning Glass Works, in Corning New York, may provide safety lens material of exceptional quality. Corning research workers have experimented with many chemical formulas in the preparation of glass, and many methods of strengthening. Their processes include rare earth barium lithium glasses which are chemically treated or heated in molten lithium and marketed under the name Chemcor. These glasses have unique properties of flexibility and impact resistance. The basic glasses are described as "flexible" because they can be bent over a modest radius of curvature before reaching the rupture point. Pilot studies have been conducted in which 236 drop ball tests were performed on 36 of these lenses (under test conditions of 72-79°F and humidity of 32 percent). Plano lenses in thickness ranges of 2.0 to 2.1 mm and 3.4 to 3.6 mm have shown uniformly excellent optical characteristics, surface curvature and consistency in lens thickness. The thinner, therefore lighter, lens (a millimeter thinner than the usual industrial standards) may exceed conventional standards for heat-treated, industrial safety lenses at least in the plano lenses.

Prescription-strength lenses made of these new materials offer reduction in both thickness and weight, with enhanced impact resistance. The designations "super grade" or "super strength" are used by Corning for their 3.4 to 3.6 mm thickness series. Unfortunately, these lenses show no birefringence pattern in polarized light and, therefore, this useful procedure both for identification and quality appraisal is not applicable.

The American Optical Company of Southbridge, Massachusetts, is undertaking distribution of Chemcor-processes lenses under the AO trade name "triple armor plate."

PLASTIC MATERIALS

Plastics Chemistry

Since the first use of plastics for optical lenses, the chemical industry has progressed a long way in making more usable and practical plastic lenses. Optical clarity, water absorption, light stability, thermal expansion, thermoplasticity, shrinkage, warping, and excessive flammability were all problems that have now been met satisfactorily. The development of optically clear and durable organic plastics such as polystyrene, polycyclohexyl methacrylate, methyl methacrylate, allyl and polyester resins has opened an entirely new field for mechanical eye protection. On the basis of certain common essential of structure, all transparent plastics show some similarity of properties. They are polymers, i. e., molecules built from comparatively simple units joined end to end so that the simplest substances consist of long carbon-carbon chains. Common examples of such linear polymers are polystyrene and methyl methacrylate. These molecules are quite long, flexible, and may contain thousands of carbon atoms in the main chain. More complex plastics have cross linked or three dimensional chains, comparable, in some ways, to an elaboration of the structural pattern in diamonds.

The past few years have seen the development of many new polymeric materials, some of them, such as polypropylene and polyisoprene rubber, being the results of completely new polymerization techniques. There have also been corresponding advances in processing techniques.

Plastics themselves can be divided into two main subgroups, i. e., thermoplastics and thermosets (or thermohardening) materials. Thermoplastics are materials which have the property of softening repeatedly on the application of heat and of hardening again when cooled, while thermosets soften once and then harden irreversibly on the application of sufficient heat (usually referred to as "curing"). When a thermosetting resin is "cured" it is insoluble in solvents.

Thermosetting materials are chemical compounds made by processing a mixture of resin with fillers, pigments, dyestuffs, lubricants, etc. in preparation for the final molding operation. These materials or molding compounds are, in most cases, in powder, granulated, or nodular form, having bulk factors from 2 to 8. A few are used in the form of slabs.

The most commonly known thermosetting materials are made from phenol-formaldehyde, urea-formaldehyde and melamine-formaldehyde resins, combined with such fillers as cotton or nylon flock, rag fibers, pieces of macerated rag, tire cord, and sisal. Other important materials are produced from alkyd or polyester resins. These materials, in the molding process, require the correlation of two factors, i. e., heat and pressure. The heat softens the compounds to a putty-like state and the pressure causes them to flow or spread out into the recesses between the two halves of the mold as they close. Further application of heat while still under pressure causes the compounds to undergo a chemical reaction called polymerization, in which they are set up to an infusible and insoluble state; hence, the name thermosetting.

Thermoplastic materials also are chemical compounds, but they have undergone all chemical reactions before being put into the mold. They usually come in granular form, with a bulk factor of approximately 2. These materials, when compression molded, become plastic under pressure and heat in a heated mold and flow out to the contour of the cavity. Molds must be arranged for rapid heating and cooling, since the molded articles cannot be removed from the mold until the material has been sufficiently cooled to harden. This process of softening the plastic by heating and hardening it by chilling can be repeated indefinitely.

Examples of thermoplastic materials are cellulose acetate, cellulose acetate butyrate, ethyl cellulose, acrylics, vinyls, polyvinyl chloride, polystyrene, styrene copolymers, nylon, polyethylene and fluorocarbons. The difference in the formation of thermoplastics and thermosetting materials can be explained by functionality theory.

Consider a monomer with functionality (f) = 2. In this case, the reaction can continue to give long-chain molecules. An example of this type is the formation of a linear polyester from a dihydric alcohol and a dibasic acid. A reactive double bond possesses a functionality of 2 since it can open in such a way that it will connect up with two other groups. The attached bond can react with other reactive groups which may be present. Many chains are in the process of formation at any instant and each chain competes for monomer with all other chains. Chain formation ceases when the supply of monomer is exhausted or when a reaction occurs with a monofunctional molecule, such as a catalyst residue, solvent molecule, or an impurity. Monofunctional compounds are also added deliberately to control the chain length, and thus the molecular weight of the polymer.

The linear polymers formed by the reaction of difunctional molecules are members of the subgroup of plastics which have already been defined as thermoplastics. The long-chain molecules are held together by relatively weak intermolecular forces and energy, in the form of heat, will cause the molecules to move relative to each other and the material will then flow. Differences in the softening point of different plastics are due to the relative strength of their intermolecular forces. Polar molecules, such as those of nylon, have greater attraction for each other than nonpolar ones such as polyethylene, and the softening point of the former is, therefore, greater than that of the latter. This is because there are bulky groups attached to the polystyrene molecule, which prevent a close approach of the polymer chains with a consequent lessening of the attractive forces between them. Less energy, heat, is necessary, therefore, to cause relative movement or slipping of the chains.

The consequence of including a material with a functionality of 3 among the reactants allows the development of a three-dimensional network. An example of this type of reaction is the formation of phenol-formaldehyde resins. The three-dimensional type of polymer typified by phenol-formaldehyde exhibits the type of behavior described earlier as thermosetting, the fully cured compound being unable to flow under the action of heat. Each carbon atom in the network is bound by primary valence bonds to other carbon atoms so that relative movement is almost impossible. In addition, such a structure prevents penetration by solvent molecules and subsequent dispersion so that although solvents may sometimes cause swelling of thermosets, they cannot produce a solution.

Depending on composition, polymers may be either homopolymers or copolymers. Homopolymers are composed of single, repeating monomer units which make up the molecule. Copolymers are composed of two or more different chemical monomer units which are reacted to form the polymer chain. In some cases an unsaturated polymer is cross linked by blending with an unsaturated copolymerizable monomer providing a material of considerably different physical properties, especially increased structural strength. One sample of this is the cross linking of a polyester with an allyl to give a thermosetting material, allyl diglycol carbonate, or CR39, having much increased surface hardness over the basic polymer.

The notion of molecule length or size immediately raises the question of quantifying this characteristic so that it may be significantly discussed in terms of effects on properties. The accepted procedure for referring to this property is through the molecular weight (MW) or degree of polymerization (DP). The latter is simply defined as the number of monomer units in the polymer molecule. Its relationship to molecular weight is as shown in the following expression:

$$\text{MW (polymer)} = \text{DP} \times \text{MW (monomer)}$$

Since every polymer sample actually consists of a mixture of molecular weights, the concern is really with the average molecular weight. The DP or the molecular weight can have an important effect on properties. As either increases, the molecular size increases and provides greater opportunity for molecular interactions.

Two characteristic temperatures associated with polymers which are most useful in understanding their behavior are the glass transition (Tg), often called second order, and the melt transition (Tm), often called first order. The Tg is usually defined as the temperature below which molecular chain motion is frozen in. Above this temperature there is sufficient energy to permit motion and undulations in the chain. In amorphous polymers this chain motion is associated with plastic or elastic characteristics. Below the Tg, these materials are stiff and hard, and often brittle. The first order, or melt temperature (Tm) is the temperatur at which the crystalline volume elements in a polymer system are in equilibrium with the molten state. Melting usually occurs over a range of temperatures; one does not observe the relatively sharp "point" observed in the melting of low molecular weight crystalline materials. The range of melting is due to the variation in degree of perfection of the crystalline regions of the polymers. Highest melt temperature is associated with greatest crystalline perfection.

Commercial Plastic Lenses

Materials

Modern optical plastics, introduced over thirty-five years ago, are generally classified according to molecular linkage into linear polymers which are thermoplastics, or cross linked polymers with three-dimensional structure which are thermosetting.

The long, flexible, linear polymers, such as the methacrylates and polystyrenes of which Plexiglas and Lucite are examples, have excellent refractive characteristics, but are too soft for practical lens use. Less expensive and industrial lenses, such as Optilite B, Dockson No. 11, Watchemoket 440C, I-Gard, made from the methacrylates have not proved durable.

The considerably harder, cross linked resin, allyl diglycol carbonate (CR39), has been much more widely used in the development of harder resin lenses such as Armorlite, Enduron, Optilite A, Plastough, Plastolite, Plasticor, AOlite, and Telor Orma 1000.

A basic polymer when processed by different manufacturers will often end up with altered mechanical characteristics, though the reproducibility of optical properties from batch to batch with any one producer's methods is quite good. Accuracy of plus or minus 0.001 should be expected in the refractive index.

Plastic resin lenses of the allyl type in ophthalmic thickness are indicated for corrections other than high minus cylinders. These lenses are especially indicated in high minus spheres. Their light weight and unusually fine appearance are relative indications in positions where mechanical hazards may be encountered infrequently or routinely.

Plastic resin lenses of the allyl type in industrial thickness are indicated in hazardous occupations, violent sports, and minus cylinder corrections except where heavy grime or perspiration would necessitate frequent wiping. Considerations of their thickness are outweighed by remarkable lightness, clarity, extremely high safety values, and lower transmittances of ultraviolet and infrared energy. They offer slight advantage over glass in areas where temperature changes give rise to fogging.

Methyl methacrylate, cellulose acetate, and polystyrene, though possessing useful optical qualities, are unsuitable as lens materials principally because of their softness. Thermolability and somewhat greater susceptibility to chemical attack are further disadvantages. Various new formulations, especially of methyl methacrylate, are somewhat harder and more resistant to scratch.

Plastic Lens Types

Single Vision Lenses. With the exception of the availability of absorptive tints, the varieties of single vision plastic lenses which are obtainable from manufacturers today correspond closely with those discussed under the heading "Glass Lens Types."

Plastic lenses, unlike glass lenses, are almost always provided by the manufacturer to the processing laboratory in white (clear) tint only. Requirements for absorptive tints are provided by the processing laboratory through a simple dyeing procedure, utilizing a dyestuff of the required tinting properties. This manner of supply of absorptive tints reduces greatly the inventory of blanks required by the processing laboratory and also provides flexibility in the coloration and transmittance of the dyed lenses.

Multifocal Lenses. The functional types of plastic lenses now available are restricted relative to the availability of glass lens types. Bifocal and trifocal lenses which are the counterparts of the one-piece glass lenses of the Univis E-Style, Figure 3, are manufactured, as are the Kryptok, straight top bifocal, and straight top trifocal styles, Figure 4.

No graduated or special purpose types of plastic lenses are normally available. However, one special type of product is available to the laboratory in plastic which is not supplied in glass. This is the strongly plus powered cataract lens which has the front convex surface aspherically curved to provide a reduction in marginal lens aberrations.

Almost all plastic ophthalmic lenses produced today, whether in the uncut or semi-finished form, are made by casting a liquid monomer between molds, curing, and removing the lens blank from the molds. Accordingly, all multifocal lens forms are of a one-piece construction in plastic.

Advantages and Disadvantages of Commercial Plastic Lenses

Advantages. The plastic lenses have greater impact resistance, especially in the cross linked allyl resin lenses, to both larger, low velocity and smaller, high velocity missiles than glass lenses.

Fragmentation, when it does occur, usually yields larger and more obtuse segments than occur when conventional glass or heat-treated glass lenses are broken. The weight is 50 to 60 percent less than glass (specific gravity of the useful optical plastics varies between 1.13 and 1.19). Radiation filters for sun use are easily made in uniform density by application of a surface dye to the molded plastic. Light transmission in the visible spectrum is slightly better than glass. There is less tendency to fogging due to lower thermal conductivity. The thinner the plastic lens, the less the tendency to fog. Plastic lenses withstand thermal shock of hot metal which will shatter glass lenses because hot metal has less tendency to adhere to plastic than to glass. There are fewer "rings" apparent in the periphery of strong minus lenses. Production by molding or casting eliminates surfacing procedures and may make for a more economical lens. Replacement, usually because of surface abrasions, is not an emergency matter as with broken glass. Extreme perfection of polishing is not necessary to achieve high impact resistance as in glass lenses.

Disadvantages. The principal disadvantage has been their softness, which has been somewhat overcome through the development of allyl resin lenses. All current plastic lenses still scratch more easily than glass, but other disadvantages are not serious. Another major disadvantage from the viewpoint of a field lens system is the cure time. The cross linked allyl carbonate, CR-39, type material requires at least twelve hours to cure. There is no way to reduce this practically with this type of material. Thermoplastics may be distorted by heat, as when an oven door is opened, but generally withstand any temperature that the body can endure. Thermosetting plastics avoid this disadvantage. Plastics have somewhat greater susceptibility than does glass to attack by chemicals. The index of refraction (1.45 to 1.51) in the more frequently used optical plastics is slightly less than that of crown glass (1.51 to 1.53) and a small correction factor is required when using a Geneva lens measure. Usual edge grinding machines are not efficient on the softer of these lenses, but water-free instruments are available and efficient for this specific purpose. Resurfacing is not a practical procedure and in general the plastic lens program is designed to eliminate all surfacing procedures. Plastic lenses are flammable but are ignited with difficulty by matches and burn more slowly than plastics usually used in commercial spectacle frames. Optical plastics have less heat absorption than glass due to their generally high (eighty to eighty-five percent) transmittances in the infrared region. Metal coatings such as aluminum, copper or "Iconel," which are effective infrared barriers, cannot at present be satisfactorily bonded to plastic lenses. Discoloration or yellowing, which earlier was a serious obstacle, has been largely overcome.

Materials Survey

Due to the complex problem of development for an automated lens fabricator and the disadvantages of current commercial optical plastics, especially the long cure time of CR-39, the material survey had to be quite extensive.

This section summarizes the results of the plastic materials software survey. This included the literature search, vendor supplied information, visits, and theoretical analysis.

Materials Properties

Those properties of plastic materials that make for good spectacle lenses have to do with the optical qualities and resistance to environmental factors. Most significant from the viewpoint of developing an automated system for field fabrication of lenses is the capability to be easily and rapidly fabricated. The optical properties of interest are light transmission and clarity, haze, and refractive index. The most fundamental quality of protective material in the prevention of eye injuries is mechanical impact resistance. Hardness is also important from the viewpoints of practicality and serviceable life of the protective materials. This quality has become more pivotal as plastic materials have gained popularity. Thermal and chemical resistance are of further concern in special occupations and environments. Abrasion resistance of particular concern for ophthalmic applications is a complex factor. It is probably related to a combination of the properties of hardness and impact resistance, but is not readily quantifiable on this basis. The routine measurement technique is not applicable for ophthalmic purposes.

There are presently at least twenty-one generic plastics possessing the optical properties to be good spectacle lens material. Since, in many ways, there is no practical commercial item, the evaluation was based upon the commercial or development items, not on the generic classes. The twenty-one generic plastics are listed below. Where there is more than one subgroup, those having a transparent member are indicated.

Acrylic	Cast methyl methacrylate
	Molded methyl methacrylate
	MMA alphamethylstyrene copolymer
	Acrylic multipolymer
Allyl Resins	Cast allyl
Cellulosic Molding Compound	
	Cellulose acetate
	Cellulose propionate molding compound
	Cellulose acetate butyrate

Epoxy Resins	Cast resins, no filler Cast resins, flexibilized Phenol novolac epoxy resins
Fluoroplastics	FEP fluoroplastic Polychlorotrifluoroethylene Polyvinylidene fluoride
Ionomers	
Nylons	Type 12, unfilled
Phenol formaldehyde and phenol furfural molding compounds	No filler
Phenolic Cast Resins	No filler
Phenoxy	
Phenylene Oxide	Polyphenylene oxide, modified phenylene oxide, unfilled
Polycarbonate	Unfilled
Polyester and Alkyd Resins	Cast polyester
Polyethylene	Polyethylene cross linkable compounds Ethylene vinyl acetate copolymer Low, medium and high density
Polypropylene	Unmodified
Polystyrene	Polystyrene molding compounds, unfilled Special heat and chemical resistant type Styrene-acrylonitrile copolymer, unfilled
Polysulfone	
Silicones	Cast resins
Styrene-butadiene	
Urea-formaldehyde Molding Compounds	Alpha cellulose filler
Urethanes	Urethane elastomers

Vinyl Polymers and Copolymers	Polypropylene modified polyvinyl chloride Vinyl chloride and vinyl chloride-acetate molding compounds, rigid and flexible unfilled Vinylidene chloride molding compound Vinyl formed molding compound

Software Evaluation

During the survey, specifications and other technical data for a rather large number of plastic materials were acquired. A matrix was made of the significant information and the matrix analyzed in the manner described in the section on methodology. Within the group of generic plastics listed above, two hundred commercial and development items were identified for evaluation. The charts on the following pages summarize the significant data concerning these items. The criteria for evaluation were selected as those properties basic to ophthalmic lens materials for combat personnel and potential field fabrication. The criteria for screening are listed in the left column in order of importance from the top. Generally, these properties are based upon ASTM methods. Ophthalmic plain crown and safety lens glass are included for comparison.

In order to evaluate these materials, some method of rating had to be used. Since the items must pass each criteria in order of importance, additional weighting was not necessary. That is, a number representing a total point score would serve no purpose if, for example, an item had good ultraviolet resistance qualities but was highly flammable. Rather than use such an arbitrary rating scale, a minimum level of acceptability was chosen below which a material could not be practically considered for ophthalmic lens use. Below is a list of these criteria, together with their definition for this evaluation and the acceptable limits. Due to the complexity of certain of the measurements, as, for example, chemical resistance, only a relative rank is shown on the chart--excellent, good, fair, poor. In other cases only a qualitative rating could be obtained.

Light transmission indicates the transmittance of light measured in percent from a white light source considered as 100%. Clear plateglass is 92%.

Haze is the amount of dispersion of the light beam due to distorting elements within or marks and scratches upon the surface. It is measured as a percent distortion of the light beam.

Abrasion resistance is an indication of the material's ability to withstand scratching that would seriously affect the optical qualities. This was entirely an estimate in the initial evaluation since most of the materials do not test for optical qualities. It

	MATERIAL EVALUATED			
PROPERTIES	Adhesive Products Allpex	Airco Chem & Plastics Airco 400-B981	Airco Chem & Plas Airco 400-7003	Allied Chemical Aclar 22-C
Material	polyest/acrylic cast	PVC, propylene mod.	PVC, propylene mod.	fluoroplastic, CTFE
Thermoplast(P)Thermoset(S)	S	P	P	P
Light transmission (%)	85	84	81	80
Haze (%)	4	0.5	0.5	4.0
Abrasion resistance(%haze)(1)				
Plain	F	P	P	F
Coated		G	G	G
Color(2)	C	CC	CC	CC
Hardness (3)	B46	M24, R107	M39, R115	D50
Impact resistance(ft-lb/in)				
Plain	5.4	18	0.5	1.5
Coated				
Flame resistance (4)				
Plain	NF	NF	SE	NF
Coated				
UV resistance	G	F	P	E
Chemical resistance				
Plain	E	F	G	E
Coated				
Heat resistance(°F) (5)	F300 D168	F350 D158	F350 D153	F368 D250
Weathering resistance	F-G	G	G	F
Water immersion resistance(%)	0.2	0.1	0.1	0.0
Boiling water resistance	F	F-G	F-G	E
Molding quality & process time	F/P	E/F	E/F	G/F
Machining quality	G	E	E	E
Machine requirements (6)	C-heat cured	CM, IM	CM, IM	CM, IM
Mold shrink (in/in)		0.002	0.002	0.03
Compression mold temp. (°F)	CT150	290	290	600
Compression mold press(psi)		1000	1000	2000
Specific gravity	1.12	1.31	1.31	2.11
Refractive index	1.54	1.50	1.50	1.35

(1) E - Excellent
G - Good
F - Fair
P - Poor

(2) CC - water white (crystal clear)
C - white (clear)
SA - slightly amber
A - amber
Y - yellow

(3) Rockwell - E, L, M, R.
Shore - A, D
Barcol - B

(4) NF - not flammable
SE - self-extinguishing
Burns at in/min

(5) F - Flow
D - Deflection
B - Brittle

(6) C - Cast
CM - Compression mold
IM - Injection molding
VF - Vacuum forming

Table 3. Plastics Properties--Software Evaluation

	MATERIAL EVALUATED			
PROPERTIES	Allied Chemical Aclar 22A	Amer. Cyanamid Acrylite Type 12	Amer. Cyanamid Acrylite Type 15	American Optics Aolite (Ophthalmic)
Material	fluoroplastic, CTFE	acrylic molding comp	acrylic molding comp	allyl diglycol carbon.
Thermoplast(P) Thermoset(S)	P	P	P	S
Light transmission (%)	90	92	92	92
Haze (%)	1.0	3.0	3.0	1.0
Abrasion resistance (Sharegi)				
Plain	F	F	F	G
Coated	G	C	G	
Color (2)	CC	C	C	CC
Hardness (3)	D65	M102	M101	M95
Impact resistance (ft-lb/in)				
Plain	3.0	0.[illegible]	0.3	0.4
Coated				
Flame resistance (4)				
Plain	NF	0.004	NF	SE
Coated		NF		
UV resistance	F	E	E	G
Chemical resistance				
Plain	E	G	G	G
Coated				
Heat resistance (°F) (5)	F368 D260	F300 D189	F300 D192	D120
Weathering resistance	F-G	F-G	F-G	G
Water immersion resistance (%)	0.0	0.03	0.03	0.2
Boiling water resistance	E	F-G	F-G	G
Molding quality & process time	G/F	G-F	G-F	E-P
Machining quality	F	G	G	G
Machine requirements (6)	CM, IM	CM, IM	CM, IM	C
Mold shrink (in/in)	0.003	0.004	None	
Compression mold temp. (°F)	600	300	300	
Compression mold press (psi)	2000	2000	2000	
Specific gravity	2.08	1.18	1.18	1.35
Refractive index	1.35	1.49	1.49	1.50

	MATERIAL EVALUATED			
PROPERTIES	Americal Optical Plastelite (Indust.)	American Optical Plasticor, Tillyer	American Polymers Ampol	Applied Plastics AP7(proprietary)
Material	allyl diglycol carbon.	allyl diglycol carbon.	cellulosic, acetate	allyl/acrylic coating
Thermoplast(P)Thermoset(S)	S	S	P	S
Light transmission (%)	90-92	90	85	92
Haze (%)	1.0	1.0	3.0	0.3
Abrasion resistance(%haze)(1)				
Plain	G	G	F	
Coated				G
Color (2)	CC	CC	C	CC
Hardness (3)	E42, M100	E46, M100	R110	D40
Impact resistance (ft-lb/in)				
Plain	0.4	0.45	0.5	
Coated				
Flame resistance (4)				
Plain	SE	SE	SE	
Coated				NF
UV resistance	G	G	G	G
Chemical resistance				
Plain	G	G	F	
Coated			G	E
Heat resistance(°F) (5)	D190	D190	F260 D160	
Weathering resistance	G	G	G	G
Water immersion resistance(%)	0.2	0.2	1.7	
Boiling water resistance	G	G	F-G	F
Molding quality& process time	E/P	E/P	E/F	-/F
Machining quality	G	G	E	
Machine requirements	C	C	CM, IM	Dip and cure
Mold shrink (in/in)			0.002	
Compression mold temp. (°F)			260	
Compression mold press.(psi)			100	
Specific gravity	1.35	1.35	1.28	
Refractive index	1.50	1.50	1.48	1.50

PROPERTIES	MATERIAL EVALUATED			
	Armorlite Armorlite(ophthalmic	Bausch & Lomb Ortholite(ophthalmic)	Bee Chemical Urethane X1409	Cadillac Plastics Rigid Vinyl Chloride
Material	allyl diglycol carbon.	allyl diglycol carbon.	urethane coating	PVC
Thermoplast(P)Thermoset(S)	S	S	S	P
Light transmission (%)	92	92	92	86
Haze (%)	1.0	1.0	0.1	1.0
Abrasion resistance(%haze)(1)				
Plain	G	G		F
Coated			F	
Color(2)	CC	CC	SA	CC
Hardness (3)	E42, M95	M95	80D	85D
Impact resistance(ft-lb/in)				
Plain	0.4	0.3		1.0
Coated			5.0	
Flame resistance (4)				
Plain	SE	SE		SE
Coated			SE	
UV resistance	G	G	G	G
Chemical resistance				
Plain	G	G		F
Coated			G	
Heat resistance(°F) (5)	D190	D190	F300, D250	F295 D175
Weathering resistance	G	G	F	G
Water immersion resistance(%)	0.2	0.2	0.1	0.1
Boiling water resistance	G	G	G	F
Molding quality& process time	E/P	E/P	-/F	E/F
Machining quality	G	G		E
Machine requirements	C	C	Dip	CM, IM
Mold shrink (in/in)				0.001
Compression mold temp. (°F)				285
Compression mold press.(psi)				750
Specific gravity	1.35	1.35	1.30	1.40
Refractive index	1.50	1.50	1.55	1.53

PROPERTIES	MATERIAL EVALUATED			
	Celanese Plastics Cellulose CA928H2	Celanese Plastics Cellulose XA947	Celanese Plastics 1PX	Celanese Plastics Forticel W60010-A
Material	cellulosic	cellulosic	cellulosic	cellulosic cellulose proprionate
Thermoplast(P)Thermoset(S)	P	P	P	P
Light transmission (%)	86	87	87	88
Haze (%)	1.0	1.0	1.0	1.0
Abrasion resistance(%haze)(1)				
Plain	F	F	F	F
Coated				
Color (2)	C	C	C	CC
Hardness (3)	R115	R115	R115	R115
Impact resistance (ft-lb/in)				
Plain	0.4	0.4	0.4	0.8
Coated				
Flame resistance (4)				
Plain	SE	SE	SE	1.0
Coated				NF
UV resistance	G	G	G	G-with uv additive
Chemical resistance				
Plain	F	F	F	F
Coated				G
Heat resistance(°F) (5)	F260 D195	F260 D195	F260 D195	F380 D160
Weathering resistance	G	G	G	G
Water immersion resistance(%)	1.7	1.7	1.7	2.0
Boiling water resistance	F-G	F-G	F-G	G
Molding quality& process time	E/F	E/F	E/F	E/F
Machining quality	E	E	E	E
Machine requirements	CM, IM	CM, IM	CM, IM	CM, IM
Mold shrink (in/in)	0.003	0.003	0.003	0.003
Compression mold temp. (°F)	260	260	260	265
Compression mold press.(psi)	100	100	100	100
Specific gravity	1.28	1.28	1.28	1.23
Refractive index	1.48	1.48	1.48	1.47

PROPERTIES	MATERIAL EVALUATED					
	Celanese Plastics Acetate 0-11891-A	CIBA Aroldite 502	CIBA EPM 1138	Combined Optical Indust. Igard	Diamond Plastics PP9620L	Dockson No. 11 (Ophthalmic)
Material	cellulosic, acetate	epoxy, rigid	epoxy, rigid	acrylic-MM coat w/AM	polypropyl, cast sheet	acrylic-plexiglas IIUVA
Thermoplast(P)Thermoset(S)	P	S	S	P	P	P
Light transmission (%)	87	83	70	92	88	92
Haze (%)	1.0	less than 1.0	less than 1.0	1.0	1.5	1.0
Abrasion resistance(%haze)(1)						
Plain	F	G	G	F	F	F
Coated					G	G
Color(2)	C	SA	A	CC	C	CC
Hardness (3)	D72, R115	B32	B40	E5	R110	M105
Impact resistance (ft-lb/in)						
Plain	0.4	0.3	0.5	0.3	0.5	0.4
Coated						
Flame resistance (4)						
Plain	SE	1.0	SE	1.0	1.0	1.0
Coated					NF	NF
UV resistance	G	None	None	F	G-with uv add.	G
Chemical resistance						
Plain	F	G	G	G	G	F
Coated						
Heat resistance(°F) (5)	F260 D195	F550 D300	F550 D300	F300 D180	F350 D140	F300 D200
Weathering resistance	G	G	G	F-G	F	G
Water immersion resistance(%)	1.7	0.1	0.1	0.2	0.01	0.3
Boiling water resistance	F-G	G-E	G-E	F/G	G	F-G
Molding quality& process time	E/F	E/F	E/F	G/F	E/F	G/F
Machining quality	E	G	G	G	G	G
Machine requirements	CM, IM	C	C	CM, IM	CM, IM	CM, IM
Mold shrink (in/in)	0.003	0.001	0.001	0.003	0.01	0.001
Compression mold temp. (°F)	260			300	340	300
Compression mold press.(psi)	100			2000	500	2000
Specific gravity	1.28	1.25	1.25	1.18	0.91	1.18
Refractive index	1.48	1.58	1.58	1.49	1.49	1.49

PROPERTIES	MATERIAL EVALUATED			
	Dow Chemical Styron Veralite 674	Dow Chemical Tyril 770	Dow Chemical Polyglycol Diamine Epoxy	Dow Corning Silicone X32059 (developmental)
Material	polystyrene	polystyrene, acrylonitr	epoxy	silicone, flexibl
Thermoplast(P)Thermoset(S)	P	P	S	S
Light transmission (%)	90	88	85	83
Haze (%)	1.0	1.0	3.0	18
Abrasion resistance(%haze)(1)				
Plain	F	E	F	F
Coated	G	G		
Color (2)	CC		C	C
Hardness (3)	M71	M80	D87	A35
Impact resistance (ft-lb/in)				
Plain	0.2	0.4	0.5	
Coated				
Flame resistance (4)				
Plain	1.0	0.8	0.1	SE
Coated	NF	NF		
UV resistance	E-with uv additive	E-with uv additive	E	E
Chemical resistance				
Plain	G	G	G	P
Coated				
Heat resistance(°F) (5)	F265 D177	F265 D212	F350 D250	D200 B-100
Weathering resistance	G	G	G	G
Water immersion resistance(%)	0.03	0.28	0.1	0.1
Boiling water resistance	F-G	G	G-F	E
Molding quality & process time	E/F	E/F	G/P	E/P
Machining quality	F	F	E	
Machine requirements	CM, IM	CM, IM	C-heat cure	C
Mold shrink (in/in)	0.001	0.003	0.001	
Compression mold temp. (°F)	265	265	CT225	
Compression mold press (psi)	1000	1000		
Specific gravity	1.05	1.07	1.25	1.05
Refractive index	1.59	1.59	1.58	1.43

PROPERTIES	MATERIAL EVALUATED			
	Dow Corning Silicone 806A (development)	Dupont Abcite(development)	Dupont ABC (development)	Dupont Surlyn
Material	silicone coating	acrylic sheet	silicone, glass resin ct	ionomer resin
Thermoplast(P)Thermoset(S)	S	P	S	P
Light transmission (%)	92	92	92	85
Haze (%)	1.0	1.0	1.0	4.0
Abrasion resistance(%haze)(1)				
Plain		G	G	E
Coated	F			
Color(2)	C	CC	CC	C
Hardness (3)		M90	B70	D65
Impact resistance (ft-lb/in)				
Plain		0.4	0.4	6.0
Coated				
Flame resistance (4)				
Plain		NF	NF	1.0
Coated	NF			
UV resistance		G	G	G-with uv additive
Chemical resistance				
Plain		G	G	F
Coated				
Heat resistance(°F) (5)		F300 D180		F300 D120
Weathering resistance		G	G	G
Water immersion resistance(%)				0.2
Boiling water resistance				P
Molding quality& process time	-/F	G/F	-/F	E/F
Machining quality		G	G	G
Machine requirements		CM, IM	Dip	CM, IM
Mold shrink (in/in)		0.003		0.003
Compression mold temp. (°F)		300		300
Compression mold press.(psi)		2000		100
Specific gravity		1.18	1.05	0.94
Refractive index		1.49	1.43	1.51

PROPERTIES	MATERIAL EVALUATED			
	Dupont Lucite	Dynamit Sales Trogamid T	Eastman Chemical Tenite acetate 081	Eastman Chemical Tenite butyrate 201
Material	acrylic resin	nylon, high impact	cellulosic, acetate	cellulosic, butyrate
Thermoplast(P)Thermoset(S)	P	P	P	P
Light transmission (%)	92	80	88	88
Haze (%)	3.0	4	1.0	1.0
Abrasion resistance(%haze)(1)				
Plain	F	P	F	F
Coated	G		G	G
Color (2)	C		C	C
Hardness (3)	M95	M31, R106	R109	R113
Impact resistance (ft-1b/in)				
Plain	0.3	2.0	1.3	0.8
Coated				
Flame resistance (4)				
Plain	1.0	1.0	1.0	1.0
Coated	NF		NF	FN
UV resistance	G-with uv additive	F	G	G-with uv additive
Chemical resistance				
Plain	G	G	F	F
Coated			G	G
Heat resistance(°F) (5)	F300 D198	F360 D131	F347 D162	F347 D202
Weathering resistance	F-G	G	G	G
Water immersion resistance(%)	0.3	0.25	2.1	2.2
Boiling water resistance	F/G	P	F	F
Molding quality& process time	G/F	P/G	G/F	G/F
Machining quality	G	G	E	E
Machine requirements	CM, IM	IM	CM, IM	CM, IM
Mold shrink (in/in)	0.001	0.003	0.002	0.002
Compression mold temp. (°F)	300	360	350	350
Compression mold press.(psi)	2000	9200	500	500
Specific gravity	1.18	1.01	1.30	1.22
Refractive index	1.49	1.50	1.48	1.47

PROPERTIES	MATERIAL EVALUATED			
	Eastman Chemical Tenite propionate 307	Eastman Chemical U vex (sheet)	Eastman Chemical Acetate 37195	Eastman Chemical Acetate 4000H
Material	cellulosic, proprionate	cellulosic, acetate but	acetate cellulosic	acetate cellulosic
Thermoplast(P)Thermoset(S)	P	P	P	P
Light transmission (%)	88	90	90	90
Haze (%)	1.0	1.0	1.0	1.0
Abrasion resistance(%haze)(1)				
Plain	F	F	F	F
Coated	G			
Color(2)	C	C	C	C
Hardness (3)	R116	R88	R100	R100
Impact resistance (ft-lb/in)				
Plain	1.1	0.8	1.0	1.0
Coated				
Flame resistance (4)				
Plain	1.3	1.9	1.0	1.0
Coated	NF			
UV resistance	G-with uv additive	G	G	G
Chemical resistance				
Plain	F	F	F	F
Coated	G			
Heat resistance(°F) (5)	F365 D213	F260 D152	F260 D195	F260 D195
Weathering resistance	G	G	G	G
Water immersion resistance(%)	2.6	1.6	1.7	1.7
Boiling water resistance	G	P	F-G	F-G
Molding quality& process time	G/F	P-G	E/F	E/F
Machining quality	E	E	E	E
Machine requirements	CM, IM	Thermoforming	CM, IM	CM, IM
Mold shrink (in/in)	0.002		0.003	0.003
Compression mold temp. (°F)	365		265	265
Compression mold press.(psi)	500		100	100
Specific gravity	1.23	1.20	1.28	1.28
Refractive index	1.47	1.47	1.48	1.48

PROPERTIES	MATERIAL EVALUATED			
	Eastman Chemical Acetate 37038	Ethyl Corporation Ethyl 5012	Ethyl Corporation Ethyl 7036	Fenwal Tru Cast 110
Material	acetate cellulosic	PVC	PVC	epoxy, resin
Thermoplast(P)Thermoset(S)	P	P	P	S
Light transmission (%)	90	88	88	85
Haze (%)	1.0	1.0	1.0	3.0
Abrasion resistance(%haze)(1)				
Plain	F			F
Coated				
Color(2)	C	C	C	C
Hardness (3)	R110	D70	D80	D87
Impact resistance (ft-lb/in)				
Plain	1.3	0.6	3.0	0.5
Coated				
Flame resistance (4)				
Plain	1.0	SE	SE	0.1
Coated				
UV resistance	G	G	G	E
Chemical resistance				
Plain	F	G	G	G
Coated				
Heat resistance(°F) (5)	F260 D195	F285 D142	F300 D155	F350 D250
Weathering resistance	G	G	G	G
Water immersion resistance(%)	1.7	0.2	0.2	0.1
Boiling water resistance	F-G	F	F	G
Molding quality& process time	E/F	E/F	E/F	G/P
Machining quality	E	E	E	E
Machine requirements	CM, IM	CM, IM	CM, IM	C-heat cure.
Mold shrink (in/in)	0.003	0.001	0.001	0.001
Compression mold temp. (°F)	265	285	300	CT225
Compression mold press.(psi)	100	750	750	
Specific gravity	1.28	1.37	1.31	1.25
Refractive index	1.48	1.53	1.53	1.58

PROPERTIES	MATERIAL EVALUATED			
	Freeman Chemical Nupol 46-4005	General Electric Lexan 243	General Electric Silicone 0063-285-193 (development)	General Electric RTV 615
Material	acrylic resin	polycarbonate, resin	silicone cast, elastomr	dimeth RTV, silic cast, elastom
Thermoplast(P)Thermoset(S)	S	F	S	S
Light transmission (%)	92	85	90	90
Haze (%)	1.0	2.0	1.0	1.0
Abrasion resistance(%haze)(1)				
Plain	F	F		
Coated	G	G		
Color(2)	C	SA	C	C
Hardness (3)	B48	M70	A60	A35
Impact resistance(ft-[illegible]				
Plain	0.33	1.8		
Coated				
Flame resistance (4)				
Plain	1.0	SE	SE	SE
Coated	G			
UV resistance	E	G	G	E
Chemical resistance				
Plain	G	G		G
Coated				
Heat resistance(°F) (5)	F400 D276	F500 D265 B-135		D600 B-75
Weathering resistance	G	G		G
Water immersion resistance(%)	0.3	0.15		0.12
Boiling water resistance	G	G		G
Molding quality& process time	G/P	E/F	G/F	G/F
Machining quality	G			
Machine requirements	C-heat cure	CM, IM	C-heat cure	C-heat cure
Mold shrink (in/in)		0.005		
Compression mold temp. (°F)	CT200	500	CT212	CT258
Compression mold press (psi)		1000		
Specific gravity	1.23	1.20	1.02	1.02
Refractive index	1.48	1.59	1.43	1.43

PROPERTIES	MATERIAL EVALUATED			
	General Electric Silicone 391-15-170 (development)	General Electric Lexan 9030	General Mills Milvex 1525	B. F. Goodrich Urethane 161-11-111- (development)
Material	silic cast rigid & coat.	polycarbonate sheet	nylon resin, sheet	urethane sheet
Thermoplast(P)Thermoset(S)	S	P	P	P
Light transmission (%)	90	84	90	72
Haze (%)	1.0	1.0	1.0	3.0
Abrasion resistance(%haze)(1)				
Plain	G	F	F	F
Coated		G		
Color (2)	C	C	C	SA
Hardness (3)	B-70	M70, R118	M31, R106	D30
Impact resistance (ft-lb/in)				
Plain	0.3	16.0	2.0	5.0
Coated				
Flame resistance (4)				
Plain	NF	SE	SE	SE
Coated				
UV resistance	E	G-with uv additive	G	G
Chemical resistance				
Plain	G	G	G	G
Coated				
Heat resistance(°F) (5)	D500 B-100	F500 D275 B-135	F400 D130	D250
Weathering resistance	G	G	G	F-G
Water immersion resistance(%)	0.1	0.58	0.8	0.1
Boiling water resistance	G	G	F	
Molding quality& process time	E/F	E/F	P/G	G/F
Machining quality			G	G
Machine requirements	C-heat cure	CM, IM, VF	IM	CM, IM, VF
Mold shrink (in/in)		0.0005	0.003	0.009
Compression mold temp. (°F)	CT212	500		300
Compression mold press (psi)		1000		100
Specific gravity	1.05	1.20	1.01	1.18
Refractive index	1.43	1.59	1.52	1.55

	MATERIAL EVALUATED			
PROPERTIES	B.F. Goodrich Urethane 58104-9D (development)	B.F. Goodrich Plastisol 131-11-54-2	B. F. Goodrich Plastisol 131-11-54-3	Gulf Research & Development Experimental Polymer X-202-100
Material	urethane sheet	urethane58dop/100pvc	urethane75dop/100pvc	acryl/ethylene copolyr
Thermoplast(F)Thermoset(S)	P	S	S	P
Light transmission (%)	78	88	86	86
Haze (%)	1.4	19	16	2.1
Abrasion resistance(%haze)(1)				
Plain	F	F	F	F
Coated				G
Color (2)	CC	CC	CC	Sa
Hardness (3)	D25	D25	D20	D52
Impact resistance (ft-lb/in)				
Plain	5.0	5.0	5.0	
Coated				
Flame resistance (4)				
Plain	SE	SE	SE	1.0
Coated				G
UV resistance	G	G	G	F-G
Chemical resistance				
Plain	G	G	G	
Coated				
Heat resistance(°F) (5)	D250	D250	D250	F370 D120
Weathering resistance	F-G	F-G	F-G	
Water immersion resistance(%)	0.1	0.1	0.1	
Boiling water resistance				
Molding quality& process time	G-F	G/P	G/P	
Machining quality	G	G	G	
Machine requirements	IM, CM, VF	C	C	CM
Mold shrink (in/in)	0.009			
Compression mold temp. (°F)	300			
Compression mold press (psi)	100			
Specific gravity	1.18	1.30	1.30	0.95
Refractive index	1.55	1.55	1.55	1.51

PROPERTIES	MATERIAL EVALUATED			
	Hughson Chemical Chemglaze Z053	ICI America TPX Methylpentenc Polymer	Isochem Isochemrez. Trans.	Lentile Ophthalmiqu Rationelles Telor Orma 1000
Material	polyurethane coat.	methylpentene polymer	epoxy resin	allyl diglycol carbonat
Thermoplast(P)Thermoset(S)	S	P	S	S
Light transmission (%)	90	90	85	92
Haze (%)		4.0	4.0	1.0
Abrasion resistance(%haze)(1)				
Plain	F	F	G	G
Coated				
Color(2)	C	C	C	CC
Hardness (3)	D50	L70	D88	E30, M95
Impact resistance(ft-lb/in)				
Plain		1.3	0.4	0.4
Coated				
Flame resistance (4)				
Plain	SE	1.0	0.5	0.3
Coated				
UV resistance	G	P	E	G
Chemical resistance				
Plain	E	G	G	G
Coated				
Heat resistance(°F) (5)		F465 D350	F550 D228	D190
Weathering resistance	F	F-G	G	G
Water immersion resistance(%)	0.8	0.01	0.08	0.2
Boiling water resistance		E	G	G
Molding quality& process time	-/G	G/F	G/F	E/P
Machining quality	G	G	G	G
Machine requirements	Dip and Cure	CM, IM, VF	C-heat cure	C
Mold shrink (in/in)		0.015		
Compression mold temp. (°F)		550	CT200	
Compression mold press.(psi)		500		
Specific gravity	1.18	0.83	1.12	1.35
Refractive index	1.55	1.47	1.58	1.50

	MATERIAL EVALUATED			
PROPERTIES	Marblette Maraglas 658	Marblette Crystle	Mobay Merlon	Mobay Texin 480
Material	epoxy, rigid	phenolic, cast resin	polycarbonate	urethane film, elasto
Thermoplast(P)Thermoset(S)	S	S	P	P
Light transmission (%)	88	85	90	87
Haze (%)	3.0	4.0	1.0	
Abrasion resistance(%haze)(1)				
Plain	G	F	F	F
Coated			E	
Color (2)	C	C	CC	C
Hardness (3)	M90	M95	R115	M28, R60
Impact resistance (ft-lb/in)				
Plain	0.4	0.4	14.0	does not break
Coated				
Flame resistance (4)				
Plain	0.1	0.1	SE	SE
Coated				
UV resistance	E	F-G	E-with uv additive	G
Chemical resistance				
Plain	G	G	G	F
Coated				
Heat resistance(°F) (5)	F550 D250	D175	F425 D280 B-150	F300 D200
Weathering resistance	F-G	F-G	G	F-G
Water immersion resistance(%)	0.1	0.3	0.14	0.8
Boiling water resistance	G	F-G	G	G
Molding quality& process time	E/F	E/F	G/F	G/F
Machining quality	G	E	E	G
Machine requirements	C	C	CM, IM	CM, IM
Mold shrink (in/in)			0.005	0.009
Compression mold temp. (°F)			480	300
Compression mold press (psi)			1000	100
Specific gravity	1.25	1.31	1.20	1.18
Refractive index	1.58	1.62	1.59	1.55

PROPERTIES	MATERIAL EVALUATED			
	Molded Products Co. Urethane MP-1485	Molded Products Co. Urethane MP-950	Molded Products Co. Urethane MP-850	Owens Illinois Glass resin coating
Material	urethane sheet	urethane sheet	urethane sheet	silicone gl. res. coat.
Thermoplast(P)Thermoset(S)	P	P	P	S
Light transmission (%)	80	80	80	92
Haze (%)				1.0
Abrasion resistance(%haze)(1)				
Plain	E	E	E	
Coated				G
Color(2)	SA	SA	SA	CC
Hardness (3)	D30	D40	D30	B70
Impact resistance (ft-lb/in)				
Plain	5.0	5.0	5.0	0.4
Coated				
Flame resistance (4)				
Plain	0.5	SE	SF	NF
Coated				
UV resistance	G	G	G	G
Chemical resistance				
Plain	F	F	F	G
Coated				
Heat resistance(°F) (5)	D190	D190	D190	
Weathering resistance				G
Water immersion resistance(%)	0.8	0.8	0.8	
Boiling water resistance	G	G	G	
Molding quality& process time				-/F
Machining quality				G
Machine requirements	CM, IM	CM, IM	CM, IM	Dip
Mold shrink (in/in)	0.008	0.008	0.008	
Compression mold temp. (°F)	300	300	300	
Compression mold press.(psi)	100	100	100	
Specific gravity	1.20	1.20	1.20	1.05
Refractive index	1.5	1.5	1.5	1.43

PROPERTIES	MATERIAL EVALUATED			
	Pennwalt Kynar 400 Homopolymer	Phillips Petroleum K-Resin, BDS Polymer (development)	Pioneer Scientific Enduron	Pittsburgn Plate Glass CR-39
Material	fluoroplastic, PVF	butadiene styrene copo	allyl diglycol carbon.	allyl diglycol carbon.
Thermoplast(P)Thermoset(S)	P	P	S	S
Light transmission (%)	90	90	92	92
Haze (%)		2.0	1.0	1.0
Abrasion resistance(%haze)(1)				
Plain	G	F	G	G
Coated				
Color (2)	C	C	CC	CC
Hardness (3)	D75	D75	E35	M95
Impact resistance (ft-lb/in)				
Plain	3.8	0.4	0.3	0.4
Coated				
Flame resistance (4)				
Plain	SE	0.5	0.35	0.35
Coated				
UV resistance	E	G	E	E
Chemical resistance				
Plain	G	P	G	G
Coated		F		
Heat resistance(°F) (5)	F340 D195 B-80	F300 D150	F300 D190	F300 D190
Weathering resistance	E		E	E
Water immersion resistance(%)	0.04	0.2	0.2	0.2
Boiling water resistance	E	P	G	G
Molding quality& process time	G/F	G/F	E/P	E/P
Machining quality	E	P	G	G
Machine requirements	CM	CM, IM	C-heat cure	C-heat cure
Mold shrink (in/in)	0.03	0.001		
Compression mold temp. (°F)	450	250		
Compression mold press.(psi)	500	100		
Specific gravity	1.76	1.02	1.32	1.32
Refractive index	1.42	1.53	1.50	1.50

PROPERTIES	MATERIAL EVALUATED			
	Reichhold Chemical Polyester 32-036	Reichhold Chemical Polyester 32-033	Reichhold Chemical Polyester 32-032	Ren Plastics Ren DC80-65
Material	polyester cast resin	polyester cast resin	polyester cast resin	epoxy cast resin
Thermoplast(P)Thermoset(S)	S	S	S	S
Light transmission (%)	85	85	85	88
Haze (%)	1.0	1.0	1.0	
Abrasion resistance(%haze)(1)				
Plain	F	F	F	G
Coated	G	G	G	
Color(2)	CC	CC	CC	CC
Hardness (3)	M90	M90	M90	M86
Impact resistance (ft-lb/in)				
Plain	0.4	0.4	0.4	0.4
Coated				
Flame resistance (4)				
Plain	1.0	1.0	1.0	0.5
Coated				
UV resistance	G	G	G	E
Chemical resistance				
Plain	P	P	P	G
Coated	G	G	G	
Heat resistance(°F) (5)	D200	D200	D200	F500 D146
Weathering resistance	F-G	F-G	F-G	F-G
Water immersion resistance(%)	0.2	0.2	0.2	0.55
Boiling water resistance	G	G	G	F-G
Molding quality& process time	E/P	E/P	E/P	E/P
Machining quality	G	G	G	G
Machine requirements	C	C	C	C-heat cure
Mold shrink (in/in)				0.008
Compression mold temp. (°F)				CT200
Compression mold press.(psi)				
Specific gravity	1.25	1.25	1.25	1.25
Refractive index	1.55	1.55	1.55	1.57

PROPERTIES	MATERIAL EVALUATED			
	Ren Plastics Ren DC22-63	Reichhold Chemical Phenolic Molding	Richardson R 570	Rohm & Haas Plexiglas V(811)-100
Material	epoxy cast resin	phenolic mold. comp.	polysty. meth meth copc	acrylic molding
Thermoplast(P)Thermoset(S)	S	S	P	P
Light transmission (%)	88	80	90	91
Haze (%)		4.0	1.0	2.0
Abrasion resistance(%haze)(1)				
Plain	G		F	F
Coated			G	G
Color (2)	CC	C	CC	CC
Hardness (3)	M94	M100	M75	M97
Impact resistance (ft-lb/in)				
Plain	0.4	0.35	0.3	0.4
Coated				
Flame resistance (4)				
Plain	0.5	0.3	0.5	0.7
Coated				
UV resistance	E	F	E	E
Chemical resistance				
Plain	G		F	F
Coated			G	G
Heat resistance(°F) (5)	F500 D133	D320	F300 D205	F320 D198
Weathering resistance		F-G	E	E
Water immersion resistance(%)	0.4	0.40	0.15	0.3
Boiling water resistance	F-G	G	G	F-G
Molding quality& process time	E/P	E/F	G/F	G/F
Machining quality	G	E	G	
Machine requirements	C	C-heat cure	CM, IM	CM, IM
Mold shrink (in/in)		0.004	0.002	0.001
Compression mold temp. (°F)			300	350
Compression mold press.(psi)			1000	2000
Specific gravity	1.15	1.39	1.09	1.19
Refractive index	1.57	1.62	1.57	1.49

PROPERTIES	MATERIAL EVALUATED			
	Rohm & Haas Plexiglass VS-100	Rohm & Haas Plexiglass V(415)-100	Rowland Products Polycarbonate	Shell Chemical Crystal Polystyrene
Material	acrylic molding	acrylic molding	polycarbonate	polystyrene
Thermoplast(P)Thermoset(S)	P	P	P	P
Light transmission (%)	92	91	85	85
Haze (%)	1.0	3.0	1.0	2.0
Abrasion resistance(%haze)(1)				
Plain	F	F	F	F
Coated	G	G	G	G
Color(2)	CC	CC	CC	C
Hardness (3)	M84	M96	M70	M70
Impact resistance (ft-lb/in)				
Plain	0.4	0.4	12.0	0.30
Coated				
Flame resistance (4)				
Plain	0.7	0.7	SE	0.5
Coated				
UV resistance	E	E	G	G
Chemical resistance				
Plain	F	F	P	F
Coated	G	G	G	G
Heat resistance(°F) (5)	F270 D167	F340 D190	F480 D275	F265 D200
Weathering resistance	E	E	G	F-G
Water immersion resistance(%)	0.3	0.3	0.15	0.03
Boiling water resistance	F-G	F-G	E	F-G
Molding quality& process time	G/F	G/F	G/F	G/F
Machining quality	G	G	G	G
Machine requirements	CM, IM	CM, IM	CM, IM	CM, IM
Mold shrink (in/in)	0.001	0.001	0.005	0.001
Compression mold temp. (°F)	300	370	500	265
Compression mold press.(psi)	2000	2000	1000	1000
Specific gravity	1.18	1.19	1.20	1.06
Refractive index	1.49	1.49	1.59	1.59

PROPERTIES	MATERIAL EVALUATED			
	Shell Chemical Epoxy Resin	Sierracin Sierracin 311	Sierracin Sierracin 900	Sinclair-Koppers Styrene Polymer 230
Material	epoxy resin	silicone, glass res. ct.	pol,ester sheet	polystyrene
Thermoplast(P)Thermoset(S)	S	S	S	P
Light transmission (%)	85	92	91	90
Haze (%)	3.0			1.0
Abrasion resistance(%haze)(1)				
Plain	G	G	F	F
Coated		G	G	G
Color (2)	C	CC	CC	C
Hardness (3)	M90	D60	M90	M70
Impact resistance (ft-lb/in)				
Plain	0.5		0.4	0.30
Coated				
Flame resistance (4)				
Flain	0.5	NF	1.0	0.5
Coated				
UV resistance	E	E	G	G
Chemical resistance				
Plain	G	G	P	F
Coated				G
Heat resistance(°F) (5)	F550 D250	D 300 B -65	D250	F265 D200
Weathering resistance	F-G	G	F-G	F-G
Water immersion resistance(%)	0.08	0.1	0.2	0.03
Boiling water resistance	E	E	G	F-G
Molding quality& process time	G/P	E/P	E/P	G/F
Machining quality	G	G	G	F-G
Machine requirements	C	Dip and cure	C	CM, IM
Mold shrink (in/in)	0.001			0.001
Compression mold temp. (°F)				265
Compression mold press.(psi)				1000
Specific gravity	1.25	1.25	1.28	1.06
Refractive index	1.58	1.43	1.56	1.59

PROPERTIES	MATERIAL EVALUATED			
	Spencer Kellog Urethane 692-U-2	Spencer Kellog Urethane Epoxy	Societa Italiana Resin Surfen	Societa Italiana Resin Sarit
Material	urethane coating	urethane/epoxy coat.	phenolic resin	urea formalde., mld. re
Thermoplast(P) Thermoset(S)	S	S	S	S
Light transmission (%)	90	90	85	50
Haze (%)	1.0	1.0	4.0	
Abrasion resistance (%haze)(1)				
Plain				F
Coated	F	F		G
Color (2)	CC	CC	C	C
Hardness (3)	D70	M80	M95	M110
Impact resistance (ft-lb/in)				
Plain			0.35	0.35
Coated				
Flame resistance (4)				
Plain			0.2	SE
Coated	NF	NF		
UV resistance	G	G	F	F
Chemical resistance				
Plain			F-G	P
Coated	G	G		
Heat resistance (°F) (5)	D200	D200	D170	F275 D260
Weathering resistance	F-G	F-G		
Water immersion resistance(%)	0.02	0.05	0.3	0.4
Boiling water resistance	G	G	P	F
Molding quality & process time	-/P	-/P	E/P	E/P
Machining quality	E	G	E	
Machine requirements	Dip and cure	Dip and cure	C	C
Mold shrink (in/in)				
Compression mold temp. (°F)				
Compression mold press (psi)				
Specific gravity	1.30	1.30	1.31	1.49
Refractive index	1.55	1.57	1.53	1.55

PROPERTIES	MATERIAL EVALUATED			
	Standard Brand Chem. Tylac 112	Thermoset Plastics Thermoset 609	Thiokol Corp. Solithane 113	Thiokol Corp. Solithane 291
Material	styrene butadiene elas.	epoxy cast resin	urethane cast resin	urethane resin coat.
Thermoplast(P)Thermoset(S)	P	S	S	S
Light transmission (%)	80	88	80	80
Haze (%)				
Abrasion resistance(%haze)(1)				
Plain	E	G	G	
Coated				G
Color(2)	C	CC	A	SA
Hardness (3)	A60	D83	D60	A85
Impact resistance (ft-lb/in)				
Plain	no break	0.45	5.0	
Coated				5.0
Flame resistance (4)				
Plain	0.5	0.5	SE	
Coated				SE
UV resistance	G	E	G	G
Chemical resistance				
Plain	P	G	P	
Coated				P
Heat resistance(°F) (5)	F250 D150	F550 D250	F350 D300	F350 D200
Weathering resistance	F-G	F-G	F-G	F-G
Water immersion resistance(%)	0.20	0.28	0.5	0.5
Boiling water resistance	P	E	E	E
Molding quality& process time	E/F	E/P	E/P	-/P
Machining quality	P	G	E	E
Machine requirements	CM, IM	C-heat cure	C-heat cure	Dip and cure
Mold shrink (in/in)	0.001			
Compression mold temp. (°F)	250	CT250	CT300	CT300
Compression mold press.(psi)	100			
Specific gravity	1.00	1.25	1.07	1.23
Refractive index	1.53	1.57	1.55	1.55

PROPERTIES	MATERIAL EVALUATED			
	Union Carbide	Union Carbide	Vistron	Watchmocket
	Phenoxy	Polysulfone	Silmar S40	Watchmocket 440C
Material	phenoxy	polysulfone	polyester cast. resin	acrylic(plexiglas IIUVA
Thermoplast(P)Thermoset(S)	P	P	S	P
Light transmission (%)	80	80	85	91
Haze (%)		5.0		1.0
Abrasion resistance(%haze)(1)				
Plain	G	G	F	F
Coated				G
Color (2)	C	C	C	CC
Hardness (3)	R115	M69	B43	E31
Impact resistance (ft-lb/in)				
Plain	1.5	1.2	0.4	0.30
Coated				
Flame resistance (4)				
Plain	0.5	SE	SE	0.7
Coated				
UV resistance	F	F	G	E
Chemical resistance				
Plain	F	E	F	F
Coated	G			G
Heat resistance(°F) (5)	F300 D175	F550 D345	F400 D250	F270 D165
Weathering resistance	F-G	G	F-G	E
Water immersion resistance(%)	0.13	0.22	0.2	0.3
Boiling water resistance	P	E	G	F-G
Molding quality& process time	G/F	G/F	F/P	G/F
Machining quality	E	E	G	G
Machine requirements	CM, IM	CM, IM	C-heat cure	CM, IM
Mold shrink (in/in)	0.003	0.007		0.001
Compression mold temp. (°F)	300	550	CT90	300
Compression mold press.(psi)	1000	1000		2000
Specific gravity	1.17	1.24	1.19	1.18
Refractive index	1.60	1.63	1.56	1.49

	MATERIAL EVALUATED			
PROPERTIES	Willson Plastough	Younger-Med Optics Younger K-Optics (spectacle shield)	Crown Glass Ophthalmic	Crown Glass Heat Treated Indust. (safety)
Material	allyl diglycol carbon.	acrylic(meth meth)	2.0 mm thickness	3.5 mm thickness
Thermoplast(P)Thermoset(S)	S	P		
Light transmission (%)	92	90	92	92
Haze (%)	1.0	1.0	0.5	0.5
Abrasion resistance(%haze)(1)				
Plain	G	F	E	E
Coated		G		
Color(2)	CC	CC	CC	CC
Hardness (3)	F46	M85		
Impact resistance(ft-lb/in)				
Plain	0.35	0.4	0.45 - shatters	0.30 - splinters
Coated				
Flame resistance (4)				
Plain	0.5	1.0	NF	NF
Coated				
UV resistance	G	E	E	E
Chemical resistance				
Plain	G	F	E	E
Coated		G		
Heat resistance(°F) (5)	F300 D190	D200	F2600 D1100	F2600 D1100
Weathering resistance	E	E		
Water immersion resistance(%)	0.2	0.3		
Boiling water resistance	G	G		
Molding quality& process time	E/P			
Machining quality	G			
Machine requirements	C-heat cure			
Mold shrink (in/in)				
Compression mold temp. (°F)				
Compression mold press.(psi)				
Specific gravity	1.32	1.18	2.550	2.480
Refractive index	1.50	1.49	1.523	1.523

was based upon the material, hardness, and impact resistance, and was fully explored in the physical evaluation. Poor abrasion resistance may be improved by a coating in which case this is indicated and an essential where indicated.

Color is of little importance except as it pertains to light transmission.

Hardness is an arbitrary rating indicating the resistance of a material to penetration, or its brittleness. There are several quantitative scales used: Rockwell, Durometer and Barcol. The higher the hardness number the harder the material.

Impact resistance is a measure of the relative toughness of a material and its resistance to breakage or penetration from a blow. It is typically determined by the Izod test in which a notched specimen is subjected to a blow sufficient to break it. It is measured in ft - lb per inch of notch. The higher the rating the greater the impact strength. Some materials can be reinforced to improve impact strength; however, this must not interfere with light transmission.

Flame resistance is a measure of the material's inability to combust when exposed to a flame. The measurement is made in terms of the material's flammability. Materials may be nonflammable (NF), self-extinguishing (SE), or have a burning rate measured in inches/minute. Materials that are inherently flammable may be provided a nonflammable coating.

Ultraviolet resistance indicates the material's ability to withstand the discoloration or hazing when exposed to ultraviolet, especially of the sun over prolonged periods. It is usually measured in terms of percent of haze or transmittance loss over several months exposure. Ultraviolet stabilizers may be added to the plastic formulation to increase ultraviolet resistance.

Chemical resistance indicates the material's ability to withstand a variety of chemicals. Most commercial plastics are subjected to a large variety of chemicals. These can be generally grouped into weak acids, weak alkalis, strong acids, strong alkalis, and organic solvents. Further groupings include common household materials and industrial petroleum products. The measurement indicates whether or not, and to what degree, the plastic may be attacked by the particular agents. Plastics with poor chemical resistance may be coated for a more usable product.

Heat resistance and cold resistance is a measure of the plastic's response to extremes of temperature. This is indicated by determining three critical temperature points: flow temperature (F) is the temperature at which flows begin; deflection temperature is the temperature at which the deformation or distortion occurs when subjected to a load; brittle point is the low temperature at which the plastic becomes brittle. Temperatures are given in °F.

Weather resistance is indication of the plastic's ability to withstand prolonged exposure to weather. This usually is demonstrated by determining the amount of light transmission loss, haze, and impact strength loss after a period of exposure to normal weathering or accelerated weathering in environmental test chambers.

Water immersion resistance is a measure of the plastic's water absorption qualities. It is measured by determining the amount of water absorbed by a specimen immersed in water for 24 hours. It may be measured as an increase in size in inches or percent of an increase in weight.

Boiling water resistance is an indication of the material's ability to withstand boiling water or autoclave cycles without deforming, losing light transmission, or hazing.

Molding quality indicates the relative ease with which the plastic may be formed. Simple, rapid casting or low temperature, low pressure compression molding on one extreme to high temperature, high pressure molding on the other. Where it is known, the minimum average time for molding or curing is indicated.

Machining quality indicates the relative ease with which the plastic may be worked once formed. This includes the ability to be cut, shaped, drilled, and cemented.

Machine requirements indicates the practical formulation techniques: casting (C), compression molding (CM), injection molding (IM).

The last five properties are not actually part of the evaluation, but are reflected in properties already listed. They are included for completeness as they are important considerations for the design analysis.

Mold shrink indicates the linear shrinkage the plastic undergoes in the molding process. It is measured in inches of shrink per inch of plastic molded. This is important in mold design.

Compression mold temperature is the average low temperature required for compression molding at the average low pressure.

Compression mold pressure is the average low pressure required for compression molding at the average low temperature.

Specific gravity is most frequently given indicating the density of the material.

Refractive index indicates the index of refraction using a sodium light (D band) of wavelength 589.3 millimicrons. Ophthalmic crown glass is 1.523.

Analysis of Data. As discussed under methodology, analysis of this large number of materials demanded the establishment of criteria for evaluation and selection:

- Light transmission - minimum 80%, desirable 85%
- Haze - minimum 4%, desirable 1 %
- Abrasion resistance - good minimum, excellent desirable
  - Excellent - better than CR-39 to glass
  - Good - same as CR-39
  - Fair - methyl methacrylate to CR-39
  - Poor - less than methyl methacrylate
- Color - minimum slight amber, water white (crystal clear) desirable
- Hardness - minimum Rockwell M90, desirable M100
- Impact resistance - minimum 0.4, desirable 1.0
- Flame resistance - SE minimum, NF desirable
- Ultraviolet resistance - good minimum, excellent desirable
  - Excellent - none
  - Good - slight yellowing
  - Fair - yellowing and slight brittleness
  - Poor - brittle
- Chemical resistance - good minimum, excellent desirable
  - Excellent - no effect except specific solvents
  - Good - no effect with common household, industrial, and military materials; attacked by strong alkalis, acids
  - Fair - no effect with common household, industrial, and military materials; attacked by acids, alkalis, and organic solvents
  - Poor - affected by common household, industrial, or military materials
- Heat and cold resistance - minimum D175, B-60, desirable, D220, B-120
- Water immersion resistance - minimum 0.2, desirable 0.1
- Boiling water resistance - good minimum, excellent desirable
  - Excellent - no effect prolonged boiling or numerous autoclave cycles
  - Good - no effect short duration boiling or several autoclave cycles but discolors or becomes brittle after this
  - Fair - discolors or becomes brittle
  - Poor - becomes opaque or softens
- Molding quality and time - good minimum, excellent desirable
  - Excellent - cast, compression mold temperature below 310°F and pressure below 1100 psi, time below 10 minutes

Molding quality and time (cont.)
Good - compression mold temperature below 610°F and pressure below 2100 psi, time below 30 minutes
Fair - compression mold temperature below 1100°F and pressure below 5100 psi, time below 2 hours
Poor - compression mold temperature above 1100°F and pressure below 5100 psi, time above 2 hours

Machining quality - good minimum, excellent desirable
Excellent - easily drilled, cut, shaped and cemented
Good - difficult to drill, cut or shape, easy to cement
Fair - need special tools for drilling, cutting, or shaping, easy to cement
Poor - as fair but difficult or impossible to cement

Machine requirements - desirable are casting, compression molding or other low weight, volume, power techniques; injection molding, extrusion molding, or other processes requiring high weight, volume, and power are undesirable.

The main purpose of the software survey was to identify potential materials to fit the criteria for a plastic lens fabricator. Suitable materials would be further subjected to a physical evaluation. Of the 200 materials surveyed, approximately 50 could meet the criteria. Forty of these were obtained for physical evaluation. Many of these materials were development items with special formulations. Although the discussion here is by generic category, special formulations indicated the physical characteristics were different enough to be evaluated further.

Acrylics - The acrylics have poor abrasion resistance, poor hardness, and are flammable. With a coating, these could be acceptable due to their clarity. They were selected for physical evaluation as a good optical substrate for a resistant coating and as a standard for comparison. Molded methyl methacrylate appears to offer the best characteristics.

Allyl resins - The allyl resins, of which allyl diglycol carbonate, CR- , is the material of principal interest, have relatively good properties with moderate abrasion resistance. The mold cure time of twelve hours for CR-39 makes this totally unacceptable and there is no way to greatly improve this time. However, when used as a cross linking material or additive, the allyls are very important. CR-39 was included in the physical evaluation as a standard for comparison since it is well known and commercially acceptable.

Cellulosics - The cellulosics have good properties except they burn and absorb water to an unacceptable degree. As a substrate for a resistant coating, they may be valuable. In addition, several development formulations were uncovered. It was on this basis that several cellulosics were available for physical evaluation.

Epoxies - On the basis of survey data, the epoxy cast resins appear to have excellent qualities for lens applications. The only problem here is that there is no commercial material suitable nor has a development material been identified, although one epoxy developer indicated interest in an R & D contract to attempt such a development.

Fluoroplastics - The fluoroplastics have both flexible and rigid members. The flexibles have good to excellent properties except they are soft and, as such, probably are not suitable for an entire lens; however, they may be good as a coating or substrate. Polyvinylidene fluoride appears to have good properties and was included in the physical evaluation.

Ionomers - The ionomers generally have poor hardness and poor thermal resistance and, as such, are unacceptable.

Nylons - The nylons, Type 12 unfilled and 6/12 copolymer, have very low deflection temperatures and, as such, would be subject to deformation under conditions of routine use. In addition, they are primarily for injection molded products.

Phenol formaldehydes and phenol furfurals - The transparent members darken with prolonged exposure to sunlight and burn readily--as such they are unacceptable.

Phenolic cast resins - These burn readily, discolor with exposure to sunlight, distort at a low temperature, and are readily soluble in many organic solvents. As such, these are unacceptable.

Phenoxys - The phenoxys discolor on exposure to sunlight and burn readily. As such, they are unacceptable.

Phenylene oxides - The phenylene oxides at this time have no transparent members. In addition, they have poor chemical resistance and are primarily candidates for injection molding.

Polycarbonates - The polycarbonates appear to offer excellent characteristics and, as such, were included in the physical evaluation.

Polyester and alkyd resins - The cast polyester, the transparent member, has generally good properties except for chemical resistance. With a cross linking additive or coated, these may be very good materials. As such they were included in the physical evaluation.

Polyethylenes - The basic polyethylenes have very low light transmission and are unacceptable. The cross linkable compounds and vinyl acetate, copolymers are flexible and have poor heat resistance. Since, as a substrate or surface coating they may be acceptable, they were included in the physical evaluation.

Polypropylenes - The available transparent members have poor light transmittance, high haze, and burn readily. As such, these are not acceptable at this time.

Polystyrenes - The transparent, unfilled molding compounds burn readily and yellow when exposed to sunlight and, as such, are unacceptable. The acrylonitrile copolymers also burn readily and are unacceptable. There are heat and chemical resistant molding compounds that appear to possess acceptable characteristics and were included in the physical evaluation.

Polysulfones - The available polysulfones have poor transmittance and high haze. As such, they are unacceptable.

Silicones - The silicones have a number of transparent commercial and development materials available. All possess excellent characteristics with the exception that some are flexible. In this respect, they are unacceptable alone but may be excellent for coatings or substrates. These were included in the physical evaluation.

Styrene butadiene - This material is soft, deforms at low temperatures, and has poor chemical resistance and, as such, is unacceptable.

Urea formaldehydes - These transparent molding compounds have poor light transmittance and discolor with prolonged exposure to sunlight. As such, they are unacceptable.

Urethanes - The urethane elastomers have excellent characteristics except they are flexible and, as such, unacceptable alone. However, as coatings or substrates, they may be very acceptable and were included in the physical evaluation.

Vinylpolymers and copolymers - Most of these transparent materials available deform at a relatively low temperature and have poor light transmittance and, as such, are unacceptable. Rigid PVC does appear to possess acceptable qualities and was subjected to physical evaluation.

<u>Phototropic Lenses.</u> Much work has been done during the past twenty-five years on protective devices which would suddenly change their optical density on abrupt exposure to high light levels. In this area are triphenylmethane dyes which show phototropic properties, but their reactions are generally slow and their optical densities not high. Electromechanical goggles have been devised, with explosive dimple motors, which provide rapid protection, are cumbersome, weighing approximately eight ounces, and require nearly eight ounces of miniaturized electronics. Electrochemical processes, such as high-speed electroplating, have also been studied, but have not afforded the rapid changes necessitated.

The problem has been partly solved in the area of infrared absorption with the retention of high visible light transmission with methyl methacrylate combined with tris-p-diethyl aminophenyl ammonium fluoroborate. Ultraviolet protection can also be achieved. The visible spectrum, with its potential for severe retinal burns, has not been adequately met.

The Pittsburgh Plate Glass Company has sponsored studies at the Mellon Institute in which fairly good phototropic, optical pumping, responses to sunlight are achieved by incorporating cerium or europium in a dilution of 100 parts per million to initial glass melts. This tends to produce an amethyst or purplish density on exposure to bright sunlight, reducing transmittance by approximately 40 percent. Reductions up to 90 percent can be achieved under laboratory conditions, by exposure to mineralite at 2,537 angstrom units.

Corning Glass has added photochromic silver halides to more conventional silicate glasses, producing color reversibility. Though the rate of darkening is insensitive to temperature, the rate of fading slows with decreased temperature. Darkening increases over a period of approximately 60 seconds, though high-intensity discharges of 3 milliseconds will produce 25 percent reductions in transmittance after several seconds. Clearing is slower, depending on temperature, and requires several hours at low temperature. There is no fatigue to this reaction and the color of the darkened lens is neutral grey or grey brown. Photochromic materials now under study by Corning are dispersed crystals of silver halide in concentration by volume of 500 parts per million. A mildly phototropic "eye comfort" glass lens has been developed by Corning that varies in transmission from 17 to 70 percent depending on illumination.

Photochromic coated, plastic lenses developed by Nuclear Research Associates have been produced under the name "Rayex." Photochromic coatings are produced by American Cyanamid, but their reactions are slow and fatigue rapidly in bright sunlight.

The problem then is primarily the development of a darkening material with rapid response and, especially, rapid return. Although no phototropic lens is currently available, such practical developments may not be far off.

Physical Evaluation

Based upon the software survey, including numerous supplier visits, a number of materials were selected for physical evaluation. Samples were obtained and the test protocol established.

The various material obtained for evaluation were primarily those which would be suitable for lenses rather than frames. Plastics materials adaptable for frame fabrication are well known and only those materials which would have exotic properties were considered in the evaluation. However, one of the considerations in evaluating a lens material is its possible use as a frame material as well. The materials obtained were exhaustively evaluated for all characteristics pertinent to lens application. While certain properties are more pertinent than others, all significant properties from the point of view of optics as well as esthetics were considered. Thirty-seven materials were each evaluated for 34 criteria. The 37 materials were homopolymers or coatings and were representative samples of the various generic plastic materials which were deemed candidates for this application by the software survey. The test samples included specimens of these generic materials: acrylics, allyl resins, cellulosics, fluoroplastics, polycarbonates, polyesters, polyethylenes, polystyrenes, silicones, urethanes, and vinyl polymers. The results of the physical evaluation are presented in Table 4.

Light transmission - This criteria was determined by a Gardner Light Meter. This is a commercially available instrument for this measurement and has a reliability well within 1 percent. Light transmission is affected by both the amount of color in the material and the index of refraction of the material. A light transmission of 82% or greater would not seriously distract from the proper ophthalmic functioning of any lens product.

Haze - This criteria was determined on a Gardner Light Meter. This is a commercially available instrument for this measurement and has a reliability well within 1 percent. An inherent haze content of 4 percent would not be excessive in a lens product. This is the accepted criteria of the Army Chemical Corps in their M-17 gas mask lens. Several of the materials tested, such as the polyurethanes, had a high inherent haze value. Some of the materials, while having high haze content, were poorly made samples. The amount of haze indicated is only for that particular sample and need not be inherent in the product. These products, probably, have an inherent haze value of less than 1 percent.

PROPERTIES	MATERIAL EVALUATED			
	Airco Chemical Polyethyl. PUC 7008	Allied Chemical ACLAR 22C	Applied Plastics AP7 Coating	Bee Chemical Urethane X1409 Coat
1. Light transmission (%)	84	91	92	92
2. Haze (%)	0.5	1.0	0.3	0.1
3. Abrasion resistance(%haze)	22	23	14	12
4. Color	crystal	transparent crystal	crystal	crystal
5. Hardness	14-12	62 Duro	--	49-42
6. Impact resistance	Passable	passable-impact	passable	passable-impact
7. Flame resistance	self-extinguishing	not flammable	not flammable	not flammable
8. UV resistance				
Color	dark amber	crystal(turned brittle)	crystal	slightly amber
Light transmission (%)	42	88	92	90
9. Chemical resistance				
Gasoline	no change	no effect	no change	no change
Transmission fluid	no change	no effect	no change	no change
Alcohol	no change	no effect	no change	no change
Perchlorethylene	no change	no effect	no change	no change
Me Et Ketone	soluble	no effect	soluble	attacks coating
10. Heat resistance-Color	translucent white	crystal	crystal	crystal
Light transmission (%)	49	91	90	91
Surface	no change	no change	no change	no change
Abrasion resis. (% haze)	(30) 10	24	15	25
11. Accelerated weathering				
Color	slightly amber	crystal	crystal	crystal
Craze	none	none	none	none
12. Water immersion				
Blushing	no change	none	no change	no change
Adhesion	--	--	excellent	excellent
Abrasion resis. (% haze)	--	--	26	18
13. Humidity I				
Abrasion resis. (% haze)	11	11	21	22
Adhesion	--	--	poor	excellent
Craze	--	--	none	none
14. Humidity II				
Abrasion resis. (% haze)	--	--	37	21
Adhesion	--	--	poor	excellent
Craze	--	--	none	none
15. Boiling water				
Abrasion resis. (% haze)	--	--	22	24
Adhesion	--	--	poor	excellent
Craze and blush	blush	no effect	no change	no change
16. Adhesion	--	--	excellent	excellent

Table 4. Plastics Properties--Physical Evaluation

PROPERTIES	MATERIAL EVALUATED			
	Cadallac Plastics Rigid Vinyl Chloride	Celanese Plastics Forticel, Cellulosic	Celanese Plastics Acetate 12-11891A	CIBA Arodite 502 Epoxy
1. Light transmission (%)	86	86	87	83
2. Haze (%)	1.0	1.0	1.0	less than 1.0
3. Abrasion resistance(%haze)	22	18	17	14
4. Color	transparent crystal	transparent crystal	transparent crystal	slightly amber
5. Hardness	Barcol 14-10	72 Duro	72 Duro	B32
6. Impact resistance	passable impact	passable impact	passable impact	fair-good
7. Flame resistance	not flammable	supports combustion	supports combustion	slow
8. UV resistance				
Color	dark amber	very slight amber	very slight amber	slightly amber
Light transmission (%)	35	86	87	81
9. Chemical resistance				
Gasoline	no effect	no effect	no effect	none
Transmission fluid	no effect	no effect	no effect	none
Alcohol	no effect	no effect	no effect	none
Perchlorethylene	no effect	no effect	no effect	none
Me Et Ketone	craze	soluble	soluble	none
10. Heat resistance-Color	dark amber	crystal	crystal	slightly amber
Light transmission (%)	26	86	86	80
Surface	no change	material distorted	material distorted	no change
Abrasion resis. (% haze)	23	18	16	14
11. Accelerated weathering				
Color	dark amber	crystal	crystal	no change
Craze	none	none	none	no change
12. Water immersion				
Blushing	none	none	none	none
Adhesion	--	--	--	--
Abrasion resis. (% haze)	--	--	--	--
13. Humidity I				
Abrasion resis. (% haze)	--	--	--	--
Adhesion	--	--	--	--
Craze	--	--	--	--
14. Humidity II				
Abrasion resis. (% haze)	--	--	--	--
Adhesion	--	--	--	--
Craze	--	--	--	--
15. Boiling water				
Abrasion resis. (% haze)	--	--	--	no effect
Adhesion	--	--	--	--
Craze and blush	blush	blush and distortion	blush and distortion	--
16. Adhesion	--	--	--	--

PROPERTIES	MATERIAL EVALUATED			
	CIBA EPM 1138 Epoxy	Dow Corning X32059 Silicone	Dow Corning 806A Silicone Coating	Eastman Chemical Uvex-acetate butyrat
1. Light transmission (%)	70	83	92	89
2. Haze (%)	less than 1.0	18*	0.4	1.0
3. Abrasion resistance(%haze)	16	(23) 5	27	28
4. Color	amber	crystal	crystal	transparent crystal
5. Hardness	B40	20	--	72 Durometer
6. Impact resistance	fair-good	good tensile	--	passable impact
7. Flame resistance	self-extinguishing	not flammable	not flammable	supports combustion
8. UV resistance				
Color	no change	very slight amber	crystal	crystal
Light transmission (%)	no change	82	92	88
9. Chemical resistance				
Gasoline	none	no change	attacks coating	no effect
Transmission fluid	none	no change	no change	no effect
Alcohol	none	no change	no change	no effect
Perchlorethylene	none	no change	no change	no effect
Me Et Ketone	none	no change	attacks coating	craze
10. Heat resistance-Color	no change	crystal	crystal	crystal
Light transmission (%)	70	76	91	89
Surface	no change	no change	no change	no change
Abrasion resis. (% haze)	16	(24) 4	25	23
11. Accelerated weathering				
Color	no change	crystal	crystal	crystal
Craze	no change	none	none	none
12. Water immersion				
Blushing	none	slight blush	no change	none
Adhesion	--	--	excellent	--
Abrasion resis. (% haze)	--	--	37	--
13. Humidity I				
Abrasion resis. (% haze)	--	--	32	--
Adhesion	--	--	excellent	--
Craze	--	--	none	--
14. Humidity II				
Abrasion resis. (% haze)	--	--	50	--
Adhesion	--	--	excellent	--
Craze	--	--	none	--
15. Boiling water				
Abrasion resis. (% haze)	no effect	--	34	--
Adhesion	--	--	excellent	--
Craze and blush	--	slight blush	no change	blush
16. Adhesion	--	--	excellent	--

PROPERTIES	MATERIAL EVALUATED			
	Eastman Chemical Acetate 37195	Eastman Chemical Acetate 40000H	Eastman Chemical Acetate 37038	General Electric Silicone RTV-615
1. Light transmission (%)	91	91	91	91
2. Haze (%)	0.2	0.3	0.3	1.0
3. Abrasion resistance(%haze)	18	29	27	0.5
4. Color	crystal	crystal	crystal	transparent crystal
5. Hardness	60 Durometer	65 Durometer	40 Durometer	10 Durometer
6. Impact resistance	passable	passable	passable	good tensile
7. Flame resistance	supports combustion	supports combustion	supports combustion	supports combustion
8. UV resistance				
Color	very slight amber	crystal	crystal	crystal(turned brittl
Light transmission (%)	88	91	92	91
9. Chemical resistance				
Gasoline	no change	no change	no change	sl. swell, no oth. att
Transmission fluid	no change	no change	no change	no effect
Alcohol	range peel	blush	orange peel	no effect
Perchlorethylene	no change	no change	no change	sl. swell, no oth. att
Me Et Ketone	soluble	soluble	soluble	blush but no attack
10. Heat resistance-Color	crystal	crystal	crystal	crystal
Light transmission (%)	90	90	90	91
Surface	softened	softened	softened	no change
Abrasion resis. (% haze)	25	25	17	0.2
11. Accelerated weathering				
Color	crystal	crystal	crystal	crystal
Craze	none	none	none	none
12. Water immersion				
Blushing	no change	no change	no change	none
Adhesion	--	--	--	--
Abrasion resis. (% haze)	--	--	--	--
13. Humidity I				
Abrasion resis. (% haze)	--	--	--	--
Adhesion	--	--	--	--
Craze	--	--	--	--
14. Humidity II				
Abrasion resis. (% haze)	--	--	--	--
Adhesion	--	--	--	--
Craze	--	--	--	--
15. Boiling water				
Abrasion resis. (% haze)	--	--	--	--
Adhesion	--	--	--	--
Craze and blush	blush	blush	blush	no effect
16. Adhesion	--	--	--	--

	MATERIAL EVALUATED			
PROPERTIES	General Electric Silicone 0063-285-193	General Electric Silicone 391-15-170	B. F. Goodrich Urethane 161-11-111-1	B. F. Goodrich Urethane 58104 9D
1. Light transmission (%)	92	90	72	78
2. Haze (%)	1.0	1.0	31	64
3. Abrasion resistance(%haze)	0.4	14	(29) 0	(61) 0
4 Color	transparent crystal	transparent crystal	sl. amber translu.	sl. amber translu.
5 Hardness	17 Durometer	70 Durometer	31 Durometer	25 Durometer
6. Impact resistance	good tensile	slightly brittle	excellent tensile	good tensile
7. Flame resistance	supports combustion	not flammable	self-extinguishing	self-extinguishing
8. UV resistance				
Color	crystal(turned brittle	crystal	sl. amber translu.	--
Light transmission (%)	92	91	72	--
9. Chemical resistance				
Gasoline	sl. swell, no oth.att.	no effect	no change	no change
Transmission fluid	no effect	no effect	no change	no change
Alcohol	no effect	no effect	no change	no change
Perchlorethylene	no effect	no effect	no change	no change
Me Et Ketone	no effect	no effect	no change	soluble
10. Heat resistance-Color	crystal	crystal	sl. amber translu.	sl. amber translu.
Light transmission (%)	92	90	52	50
Surface	no change	no change	no change	no change
Abrasion re. is. (% haze)	0.2	13	(47) 0	(20) 0
11. Accelerated weathering				
Color	crystal	crystal	sl. amber translu.	--
Craze	none	none	none	none
12. Water immersion				
Blushing	none	none	no change	no change
Adhesion	-	--	--	--
Abrasion resis. (% haze)	--	--	--	--
13. Humidity I				
Abrasion resis. (% haze)	--	--	--	--
Adhesion	--	--	--	--
Craze	--	--	--	--
14. Humidity II				
Abrasion resis. (% haze)	--	--	--	--
Adhesion	--	--	--	--
Craze	--	--	--	--
15. Boiling water				
Abrasion resis. (% haze)	--	--	--	--
Adhesion	--	--	--	--
Craze and blush	no effect	blush	blush	no change
16. Adhesion	--	--	--	--

PROPERTIES	MATERIAL EVALUATED B. F. Goodrich Plastisol 131-11-54-2	 B. F. Goodrich Plastisol 131-11-54-3	 Mobay Chemical Texin 480 Urethane	 Molded Products Urethane MP-1485
1. Light transmission (%)	88	86	86	86
2. Haze (%)	19*	16*	24	59
3. Abrasion resistance(%haze)	(26) 7	(27) 11	(22) 0	(59) 0
4. Color	crystal	crystal	sl. amber translu.	sl. amber translu.
5. Hardness	26 Durometer	20 Durometer	20 Durometer	30 Durometer
6. Impact resistance	good tensile	good tensile	excellent tensile	excellent tensile
7. Flame resistance	self-extinguishing	self-extinguishing	self-extinguishing	supports combustion
8. UV resistance				
Color	slightly amber	slightly amber	translucent amber	--
Light transmission (%)	81	84	86	--
9. Chemical resistance				
Gasoline	no change	no change	no change	--
Transmission fluid	no change	no change	no change	--
Alcohol	blush, brittle	blush, brittle	no change	--
Perchlorethylene	no change	no change	no change	no change
Me Et Ketone	craze	no change	--	--
10. Heat resistance-Color	amber	amber	sl. amber translu.	--
Light transmission (%)	73	68	90	--
Surface	no change	no change	no change	no change
Abrasion resis. (% haze)	15	--	(27) 7	--
11. Accelerated weathering				
Color	slightly amber	slightly amber	amber	--
Craze	none	none	none	none
12. Water immersion				
Blushing	severe blush	severe blush	no change	no change
Adhesion	--	--	--	--
Abrasion resis. (% haze)	--	--	--	--
13. Humidity I				
Abrasion resis. (% haze)	--	--	--	--
Adhesion	--	--	--	--
Craze	--	--	--	--
14. Humidity II				
Abrasion resis. (% haze)	--	--	--	--
Adhesion	--	--	--	--
Craze	--	--	--	--
15. Boiling water				
Abrasion resis. (% haze)	--	--	--	--
Adhesion	--	--	--	--
Craze and blush	blush	blush	no change	blush
16. Adhesion	--	--	--	--

PROPERTIES	MATERIAL EVALUATED			
	Molded Products Urethane MP-950	Molded Products Urethane MP-850	Owens-Illinois Glass Resin Coating	Pennsalt Chemical Rynar Flucroplastic
1. Light transmission (%)	80	77	92	69
2. Haze (%)	63	34	0.1	62
3. Abrasion resistance(%haze)	(67) 0	(28) 0	7	27% additional
4. Color	sl. amber translu.	sl. amber translu.	crystal	translucent white
5. Hardness	40 Durometer	33 Durometer	--	75 Durometer
6. Impact resistance	excellent tensile	excellent tensile	passable impact	passable impact
7. Flame resistance	self-extinguishing	self-extinguishing	not flammable	self-extinguishing
8. UV resistance				
Color	sl. amber translu.	sl. amber translu.	crystal	translucent white
Light transmission (%)	81	78	90	64
9. Chemical resistance				
Gasoline	--	no change	no change	no effect
Transmission fluid	no change	no change	no change	no effect
Alcohol	no change	no change	flaked surface	no effect
Perchlorethylene	no change	no change	flaked surface	no effect
Me Et Ketone	no change	no change	attacks coating	no effect
10. Heat resistance-Color	sl. amber translu.	--	crystal	translucent white
Light transmission (%)	69	--	91	69
Surface	no change	no change	no change	no change
Abrasion resis. (% haze)	(63) 0	--	25	62
11. Accelerated weathering				
Color	sl. amber translu.	sl. amber translu.	crystal	translucent white
Craze	none	none	none	none
12 Water immersion				
Blushing	no change	no change	no change	no change
Adhesion	--	--	poor	--
Abrasion resis. (% haze)	--	--	16	--
13. Humidity I				
Abrasion resis. (% haze)	--	--	12	--
Adhesion	--	--	poor	--
Craze	--	--	none	--
14. Humidity II				
Abrasion resis. (% haze)	--	--	16	--
Adhesion	--	--	poor	--
Craze	--	--	none	--
15. Boiling water				
Abrasion resis. (% haze)	--	--	distorted	--
Adhesion	--	--	poor	--
Craze and blush	no change	blush	coating distorted	no effect
16. Adhesion	--	--	poor	--

PROPERTIES	MATERIAL EVALUATED			
	Pittsburgh Plt. Glass CR-39(al. digly. carb)	Proprietary Material ABC Coating	Reichhold Chemical Polyester 32-036	Reichhold Chemical Polyester 32-033
1. Light transmission (%)	92	92	88	87
2. Haze (%)	1.0	1.0	1.0	1.0
3. Abrasion resistance(%haze)	12	9	22	27
4. Color	crystal	translucent crystal	translucent crystal	transparent crystal
5. Hardness	M95	--	Barcol 40-36	Barcol 40-36
6. Impact resistance	good	passable impact	passable impact	passable impact
7. Flame resistance	self-extinguishing	not flammable	supports combustion	supports combustion
8. UV resistance				
Color	slightly amber	--	slightly amber	slightly amber
Light transmission (%)	92	coating	86	84
9. Chemical resistance				
Gasoline	none	no effect	no effect	no effect
Transmission fluid	none	no effect	no effect	no effect
Alcohol	none	no effect	no effect	no effect
Perchlorethylene	none	no effect	no effect	no effect
Me Et Ketone	none	no effect	mp effect	no effect
10. Heat resistance-Color	crystal	crystal	amber	amber
Light transmission (%)	92	92	85	85
Surface	no change	no change	no change	no change
Abrasion resis. (% haze)	12	8	22	24
11. Accelerated weathering				
Color	slightly amber	crystal	amber	amber
Craze	none	none	none	none
12. Water immersion				
Blushing	none	none	none	none
Adhesion	--	excellent	--	--
Abrasion resis. (% haze)	12	9	--	--
13. Humidity I				
Abrasion resis. (% haze)	12	9	--	--
Adhesion	--	excellent	--	--
Craze	none	none	--	--
14. Humidity II				
Abrasion resis. (% haze)	12	12	--	--
Adhesion	--	excellent	--	--
Craze	none	none	--	--
15. Boiling water				
Abrasion resis. (% haze)	12	14	--	--
Adhesion	--	excellent	--	--
Craze and blush	--	no effect	no effect	--
16. Adhesion	--	excellent	--	--

PROPERTIES	MATERIAL EVALUATED			
	Reichhold Chemical Polyester 32-032	Rohm & Haas Plexiglas U415-100	Rowland Products Cast acrylic sheet	Rowland Products Polycarbonate
1. Light transmission (%)	87	92	93	85
2. Haze (%)	1.0	0.2	0.1	1.0
3. Abrasion resistance(%haze)	23	20	16	26
4. Color	transparent crystal	crystal	crystal	transparent crystal
5. Hardness	Barcol 43-38	Barcol 45-36	Barcol 49-42	Barcol 16-12
6. Impact resistance	passable impact	passable	passable impact	passable impact
7. Flame resistance	supports combustion	supports combustion	supports combustion	self-extinguishing
8. UV resistance				
Color	amber	very slightly amber	crystal	very slightly amber
Light transmission (%)	85	91	93	87
9. Chemical resistance				
Gasoline	no effect	no change	no change	no effect
Transmission fluid	no effect	no change	no change	no effect
Alcohol	no effect	no change	no change	no change
Perchlorethylene	no effect	no change	no change	no effect
Me Et Ketone	no effect	slightly soluble	no change	soluble
10. Heat resistance-Color	amber	crystal	crystal	crystal
Light transmission (%)	87	92	91	85
Surface	no change	softened	no change	no change
Abrasion resis. (% haze)	23	--	16	30
11. Accelerated weathering				
Color	amber	crystal	crystal	crystal
Craze	none	none	none	none
12. Water immersion				
Blushing	none	no change	no change	none
Adhesion	--	--	--	--
Abrasion resis. (% haze)	--	--	--	--
13. Humidity I				
Abrasion resis. (% haze)	--	--	--	--
Adhesion	[illegible]	--	--	--
Craze	--	--	--	--
14. Humidity II				
Abrasion resis. (% haze)	--	--	--	--
Adhesion	--	--	--	--
Craze	--	--	--	--
15. Boiling water				
Abrasion resis. (% haze)	--	---	--	--
Adhesion	--	--	--	--
Craze and blush	--	distorted	no change	no effect
16. Adhesion	--	--	--	--

	MATERIAL EVALUATED			
PROPERTIES	Sierracin Sierracin 311 Coat.	Sinclair-Koppers Styrene 230	Spencer Kellog Urethane 692-V-2 Ct	Spencer Kellog Urethane epoxy coat
1. Light transmission (%)	89	90	92	92
2. Haze (%)	1.0	0.4	0.2	0.1
3. Abrasion resistance(%haze)	14	24	18	18
4. Color	transparent crystal	crystal	crystal	crystal
5. Hardness	--	Barcol 35-32	--	--
6. Impact resistance	passable impact	passable	--	--
7. Flame resistance	not flammable	supports combustion	not flammable	not flammable
8. UV resistance				
Color	--	slightly amber	crystal	crystal
Light transmission (%)	coating	87	92	92
9. Chemical resistance				
Gasoline	no effect	no change	no change	no change
Transmission fluid	no effect	craze	no change	no change
Alcohol	no effect	no change	no change	no change
Perchlorethylene	no effect	soluble	no change	no change
Me Et Ketone	no effect	no change	attacks coating	attacks coating
10. Heat resistance-Color	crystal	crystal	crystal	crystal
Light transmission (%)	89	88	91	91
Surface	no change	no change	no change	no change
Abrasion resis. (% haze)	12	27	27	17
11. Accelerated weathering				
Color	slightly amber	crystal	slightly amber	slightly amber
Craze	none	none	none	none
12. Water immersion				
Blushing	none	no change	no change	no change
Adhesion	good	--	poor	excellent
Abrasion resis. (% haze)	11	--	19	34
13. Humidity I				
Abrasion resis. (% haze)	11	--	20	23
Adhesion	good	--	poor	poor
Craze	none	--	none	none
14. Humidity II				
Abrasion resis. (% haze)	12	--	34	27
Adhesion	good	--	poor	excellent
Craze	none	--	none	none
15. Boiling water				
Abrasion resis. (% haze)	14	--	20	24
Adhesion	good	--	poor	fair
Craze and blush	some coat lifting	no change	no change	no change
16. *Adhesion*	*good*	*excellent*	*poor*	*excellent*

Abrasion resistance - It was not possible to evaluate abrasion resistance by means of the standard abrasion test procedures such as the Tabor Abrasion Tester because the various samples received were of varying sizes and the standard test procedures require a minimum 5" square. Also, it was difficult to establish a uniform technique for evaluating abrasion resistance for materials as varied as styrene and glass. Therefore, the test procedure outlined below was established, allowing the use of test specimens as small as 1" in diameter and of any degree of abrasion resistance including that of glass. This test procedure is quantitative in that it measures abrasion by means of the amount of haze produced. It is qualitative in that it establishes the haze reference points for such known ophthalmic plastic materials such as glass, CR-39, and methyl methacrylate polymer.

The test procedure used readily distinguishes between glass, which is the universal material; CR-39, which has been found by the U. S. Army aviation personnel to be an acceptable plastic lens material; methyl methacrylate, which is often used as a lens material but is readily abraded if extensive case is not utilized in wiping the lenses; and cellulose acetate, which is also used as a lens material but is abraded in spite of care in wiping. Degrees of abrasion resistance between these materials is also evident by this test procedure.

The equipment used to test for abrasion resistance was a circular device which could be rotated around a radius of approximately 17/32". To this device was fixed a narrow specimen of 3M Tri-M-Ite Fre-Cut finishing paper, silicon carbide 360 grit and approximately 5/16" wide. A weight of 670 grams was added to the device and the device placed over the specimen and rotated two revolutions.

As standards, various specimens of glass, CR-39, and methyl methacrylate polymer were repeatedly tested with this technique and extremely reproducible results were obtained. On this basis, it has been established that glass so tested would achieve 0.2 percent haze, CR-39 10 percent haze, and methyl methacrylate polymer 19 percent haze. All tests thus performed were within plus or minus 2 percent of the established standard for CR-39 and methyl methacrylate; for glass, the results were within plus or minus 0.10.

Color - The color of the material was determined visually. The relative degree of color was determined by comparison with established Applied Plastics Plant standards for acceptable color on commercial ophthalmic lenses. The designations used are:

Transparent crystal - water white appearance
Very slight amber - acceptable commercial ophthalmic quality
Slight amber - less than acceptable color cosmetically but
more than adequate optically

Amber - obvious yellow discoloration though the resultant
transmission would not interfere with the lens use
Dark amber - unsatisfactory cosmetically and optically

The color of the plastic material, in itself, has very little significance optically. Discoloration, such as yellowing, distracts cosmetically from the appearance of the lenses but does not affect the optical functioning of the product. The criteria for the amount of color which optically is in excess is represented by the amount of light absorption it causes. Therefore, color is merely a cosmetic consideration.

Hardness - Depending on the nature of the material, the hardness was tested either with the Shore D Durometer Hardness Tester or the Barcol Hardness Tester. The evaluation for hardness is merely to indicate the physical nature of the material. Material under a durometer of 30 is soft and flexible. Between 30 and 65 durometer, the material is flexible but semi-rigid. Materials with a durometer of greater than 65 and any degree of Barcol hardness are fairly rigid and inflexible.

Impact resistance - Because of the varying thicknesses of the samples received for evaluation, it was not possible to run comparative impact resistance tests. However, based on experience with various plastic materials, it was possible to establish by the nature of the various materials whether they would survive the standard impact test of a 30 inch drop of a 7/8 inch diameter ball. Where the materials were rubbery in nature, comment was made on the relative tensile strength of the material. The various materials were evaluated for their acceptance as a lens material even under battle conditions. No attempt was made in this evaluation to quantitatively evaluate impact resistance.

Flame resistance - Since the samples of the materials received were of varying thicknesses, a test to determine relative rates of burning was not feasible. The only relevant testing which could be accomplished was to subject a corner of each specimen to a lighted match for approximately 30 seconds and then determine whether (a) the material would burn, (b) it burned but was self-extinguishing, or (c) it was not flammable at all.

Ultraviolet resistance - The specimens were placed under a prescription sun lamp, approximately 6 inches under the lamp, and irradiated for 6 days. At the end of that time, notation was made with regard to color change which results in a change of light transmission. This is an accelerated test for evaluating the effects of sunlight and outdoor exposure. The effects of sunlight on plastics is generally a discoloration.

Chemical resistance - Specimens were subjected to typical environmental solvents for a period of 30 minutes. At the end of that time, the specimens were examined and solvent attack, if any, was noted. Coated specimens were tested by applying a saturated tissue on the coating while solid specimens were immersed in the solvent for the prescribed period of time. While the number of chemicals to which the plastics materials could have been subjected are endless, for this evaluation the testing was limited to five chemicals. These were either universal solvents such as MEK or perchlorethylene and chemicals to which the lenses might be subjected in normal Army usage.

Heat resistance - In the procedure for determining heat resistance, the specimens were subjected to temperatures of 225°F for 6 days. In previous test simulations with the Army Chemical Corps, this was found to be the equivalent of an accelerated desert storage test of 9 weeks duration at 170°F. At the conclusion of the test period, the specimen was re-evaluated for color, transmission, surface optics, and abrasion resistance. Any difference as a result of the test on any of these criteria was duly noted. This accelerated test tends to indicate the maximum degree of shelf life deterioration which could be expected. After being subjected to extreme heats, which were certainly not indicative of actual application, the material was evaluated for the criteria which could be affected by the test conditions. These were color, transmission, surface, and abrasion resistance.

Accelerated weathering - Experience has shown this test to be equivalent to 200 hours on the standard Fadometer Test. Specimens of each material were placed under a Westinghouse sunlamp at a distance of approximately 12 inches for 6 days. At the end of that period of time, specimens were examined to determine whether there was any resultant color change, surface craze, or other induced factors.

Water immersion - Specimens were immersed in water at room temperature for 48 hours. At the end of that time, the specimens were removed from the water and examined to determine whether they had absorbed sufficient water to cause blushing of the material or, in the case of coated specimens, whether the adhesion and/or abrasion had been affected. This extensive test of water immersion is to evaluate the effects of immersion on the various plastics tested. While this is not a normal situation in spectacle wear, it was included as a possibility, though remote.

Humidity I (110°F, 95% relative humidity) - Samples of coated materials were subjected to elevated temperatures and high relative humidity. This test was for a period of 24 hours. At the end of the test period, the specimens were examined again for abrasion resistance, adhesion, and craze or blush of the coating.

This test was instituted to indicate any effect on coated material which would occur should they be subjected to this extreme, though possible, condition in usage.

Humidity II (180°F, 95% relative humidity) - This is an accelerated test to determine the effects of heat and humidity on coated material. This test indicates the maximum deterioration, but is by no means a practical indication of what is to be expected in utilizing the coating. This test was for a period of 24 hours. At the end of the test period, the specimens were examined again for abrasion resistance, adhesion, and craze or blush of the coating.

Boiling water - All specimens were subjected to 2 hours of exposure to boiling water. At the end of that time, specimens were examined for blush or craze and, in the case of coated specimens, for adhesion and loss of abrasion resistance, if any. This test indicates the deterioration, if any, of the lens materials when subjected to boiling water for purposes of decontamination or other therapeutic requirements.

Adhesion - Adhesion was determined only on those specimens which were coatings on other plastic substrata. The technique for determining the degree of adhesion was to score the coating with a razor blade into three tic-tac-toe patterns in line. A piece of scotch tape was placed over these patterns and firmly pressed onto the coating. The tape was literally ripped from the coating and the coating examined to determine whether any coating was removed by the tape. This procedure was repeated three times. The adhesion of the coating was rated (a) excellent if there was no coating removed after three pulls of the tape; (b) good if there was partial removal of coating after three pulls, but none after the first pull; (c) fair if there was partial removal of the coating after one pull of the tape; and (d) poor if there was complete removal after the third pull of the tape. Adhesion, as it applies to coated material only, was considered in this evaluation, though it is not particularly pertinent. While certain materials showed poor adhesion, this applied only to the technique of application of the coating. Should such materials indicate attractive properties, improved adhesion could be developed. The purpose of evaluating adhesion was to determine, on those materials which had good to excellent adhesion, whether this adhesion was affected in subsequent testing.

Analysis of Test Results

The criteria for judging each of the materials tested is necessarily the same as that for the software evaluation. Listed and verbally averred specifications or qualities so frequently differ from results physically determined so that the software evaluation served primarily to identify materials available and to screen them grossly for physical evaluation. A discussion of the results is made here by generic class of material with several specific materials of most importance set forth separately.

Acrylics. These are unacceptable except as a coated base material due to poor abrasion resistance. One sample tested was primarily a standard for comparison.

Allyl Resins. These are unacceptable due to cure time. Only a standard for comparison. The sample tested for comparison standard only. Allyl resins may, however, be used as additives, especially to coatings to provide abrasion resistance without increasing cure time.

AP7. AP7 is a proprietary coating of Applied Plastics Division of Univis, Inc. While its abrasion resistance is somewhere between that of acrylic and CR-39, there are current developments which indicate the possibility of increasing this abrasion resistance to at least that of CR-39. Here, too, the material is applied to a substrate which is capable of being fabricated in a very short period of time, having all the desired properties required of an ophthalmic lens except for a high degree of abrasion resistance.

Cellulosics. Six cellulosic materials were tested, primarily for a number of development items. All had poor abrasion resistance and burn. All are unacceptable.

Fluoroplastics. Two were tested. Both had poor abrasion resistance and one very high haze. Neither are acceptable items.

Polycarbonates. Two were tested. Both show good properties except for abrasion resistance. For this reason, they are unacceptable except as a coated lens, for which they are an excellent candidate. There is some indication, however, that proprietary developments may provide a polycarbonate with abrasion resistance close to CR-39.

Polyesters. Three polyesters were evaluated and all showed poor abrasion resistance and, as such, were unacceptable. Their other good qualities may allow use as a substrate, however.

Polyethylenes. One was tested and is unacceptable due to poor abrasion and heat resistance.

Polystyrenes. One was tested and is unacceptable due to poor abrasion and heat resistance.

Silicones. There were eight silicone materials evaluated. Silicone #615, #193, and RTV are casting materials which can be fabricated in a relatively short period of time. They are elastomeric and, therefore, have extremely good abrasion resistance. However, the elastomeric properties, while excellent for abrasion resistance, gives the product a tacky surface which tends to collect dirt and make the product somewhat difficult to clean. Elastomers are unacceptable alone but could be an excellent base or coating material. They are primarily unacceptable because a flexible lens would cause distortion if bent or flexed while wearing. A rigid frame might alleviate this problem and should be considered.

Silicone #170 is a rigid transparent silicone which is also readily fabricated by casting and has abrasion resistance almost equal to that of CR-39. However, it is brittle and this precludes its use as a lens material.

Glass resin, Sierracin 311, and ABC coating materials are all silicone based derivatives. They all have equivalent or better than CR-39 abrasion resistance and have excellent-to-satisfactory stability under the various accelerated tests performed. It may be possible to develop further, by means of this family of coating materials, a coating far superior to that of CR-39 and more closely approaching that of glass. These are the first of the family of silicone coating materials and it is quite possible that they can be improved upon. These materials, of course, would be deposited on acceptable substrates.

Urethanes. Twelve urethanes were evaluated. Urethane coating #1409 has an extremely good degree of abrasion resistance. This abrasion resistance tails off, however, under conditions of accelerated and excessive testing. However, the chemical company has indicated that this is only one of a series of urethane coatings that they have and there are others in their catalog which are far superior in abrasion resistance. Of all the materials tested, urethane sheets have, by far, the greatest degree of abrasion resistance. The degree of abrasion resistance, as a matter of fact, is close to or equal to that of glass. In addition, the urethane material is an extremely tough and resiliant material. Unfortunately, it has a high degree of haze and, therefore, is not readily usable as a lens material. It may be possible to develop a technique for applying a thin film (0.001" thick) onto a plastic substrate, in which case, one would have an unbreakable, unscratchable, indestructible lens.

Epoxies. Two epoxies were evaluated. While the software evaluation indicated epoxies might be a good candidate the physical evaluation did not show this to be the case. Besides being yellow, one had poor light transmission and the other only passable. In addition, they had only fair abrasion resistance. Such being the case, they would be poor for a single lens material and for a coated lens other materials have better all-round qualities. Further commercial development, however, might provide a suitable epoxy material.

PLASTIC FABRICATION TECHNIQUES

Thermosetting Techniques

Casting

This procedure requires the use of a liquid monomer of suitable viscosity. The catalyzed monomer is poured into the cavity formed by two highly polished lens molds which are separated by a gasket of proper thickness, the mold and gasket assembly being held together by clamping, with moderate pressure. Curing must be carefully controlled as to time and temperature so that at no time does the generated heat cause the monomer to boil. The mold surfaces are specially coated to ensure that the lens and molds can be separated at the proper time.

Materials which are considered suitable for simple casting are epoxys, polyesters, and urethane elastomers. The casting process affords these relative advantages: reasonably good abrasion resistance; no heavy equipment required; cure time 10 to 60 minutes, depending upon lens thickness; lower temperature requirements; simpler equipment; and ease of incorporating tints and ultraviolet absorbers. The relative disadvantages are: difficulty in achieving water-white transparency; and lengthy cure time on strong prescriptions.

Pressure Casting. This procedure is similar to that described under "Casting," above, except that the mold assembly is held together with a pressure of 60 to 250 psi. This pressure acts to elevate the boiling point of the monomer so that higher curing temperatures may be used. This shortens greatly the curing time required and permits the use of materials which would otherwise not be practical for the present requirement. Materials which are considered suitable for the pressure casting of lenses are: acrylic monomers and polymers, and allyls. Pressure casting process affords these advantages: pressure equipment is smaller and lighter than that needed for injection molding; tints and ultraviolet absorbers can be added; excellent optical quality; whiter than cast product; and 5 to 30 minute cycles are possible. The major disadvantage, in addition to those of casting, is the requirement for heavier equipment than for casting. Wherein materials are available for fast cure, obviously casting is one technique of choice since power and size are minimal. As with other molding techniques, a number of molds may be required and this poses a distinct design problem.

Compression Molding

In compression molding, molding powder or gel is placed into an open mold which is normally preheated. On closing the mold, pressure is applied, usually in the range of 0.5 to 3 tons/sq. inch. The whole operation is carried out in a compression press, which consists basically of a ram in a cylinder which can be hydraulically operated. The hydraulic power is delivered either by means of a central accumulator system or by separate pumps attached to each press. Heat is also essential with this molding process and, when used in conjunction with pressure, the molding material will soften and flow within the mold cavity and assume the required shape. Correctly designed molds minimize flash and thus little or no finishing operations are usually necessary. Thermosetting molding materials undergo a chemical change whereby their structure becomes cross linked and the material hardens to a permanent shape. To ensure that the curing action is complete, it is necessary to maintain the molding pressure for a period.

Materials suitable for compression molding are allyls, cellulosics, polycarbonates, polystyrenes, and silicones. Advantages of this method are: short cycle time; good optical quality; good abrasion resistance; and existing techniques available. Disadvantages are: higher molding pressures with heavier molds and heavier equipment than casting; relatively long curing time; higher molding temperatures. Along with casting, this is the technique of major consideration.

The major problem with all these techniques is the requirement for a mold for each prescription required. This, however, will be a problem with any technique and is itself an area under study.

An example of a simple system, readily transportable, would use a small press, such as the Carver Laboratory Press, to provide the pressure required for a methyl methacrylate lens. The Carver Laboratory Press, a hydraulic press capable of exerting controlled pressures up to 24,000 pounds for specified period of time, is available with electric hot plates which can be channelled for water cooling.

The high pressures utilized raise the boiling point of the monomer, which minimizes its tendency to bubble due to vaporization and permits the use of higher curing temperatures, which in turn reduce the curing time. Gases trapped or dissolved in the casting slurry are forced into solution and do not show up as bubbles.

A methyl methacrylate monomer containing an inhibitor to prevent polymerization during storage is used. Low inhibitor level monomers can be used successfully and produce crystal clear products which are indistinguishable from those made from uninhibited monomer. If the inhibitor is removed, the monomer must be used promptly or stored at a temperature of 40°F or less. A liquid methyl methacrylate polymer with good storage capability is used.

The polymer and monomer are mixed and stirred continuously to ensure complete wetting of each polymer particle and to permit it to swell sufficiently to prevent settling.

When a slurry is formed, which takes about 10 to 15 minutes, it is poured and allowed to stand until it gels. The gel will be full of air bubbles, but these disappear when the mass is cured under pressure. These gels can be kept for hours before use, so that it is feasible to make a day's supply at one time.

To form a lens, the gel is placed between lens molds and placed in the press. The pressure is slowly brought up to 14,000 pounds and the heat is turned on.

When the temperature reached 240°F the heat is turned off, and the mold is allowed to cool. Water cooling is not turned on until the temperature falls to at least 150°F. The finished lens is removed from the press ready for mounting or coating, depending upon the type of material.

Transfer Molding

Transfer molding, used for complex components, also involves the application of heat and pressure to the molding powder before it is forced into the mold cavity, which overcomes some of the disadvantages associated with the compression technique. The process consists of charging a known amount of molding powder into a heated chamber outside the mold, and when the powder has reached a sufficiently plastic state it is then forced under high pressure through a suitable narrow opening, called a "gate," into a closed mold. The technique can be likened to the injection molding of thermoplastics. In both processes the material is "plasticized" in one chamber and then, while in a fluid state, forced through a "runner" into a mold cavity.

Since the molding powder is fluid when it enters the mold cavity, intricate sections can be molded, and faster cycles are possible due to the local heating produced from the frictional heat during the molding cycle. As the nature of field lens fabrication precludes the need for intricate shapes, the additional weight and size of transfer molding equipment is not warranted.

Injection Molding

Injection molding is discussed under the heading of "Thermoplastic Techniques;" however, some thermosets are now being injection molded with special equipment.

Preforming

Preforms are cold-compressed tablets of thermosetting molding materials used, instead of loose powder, for loading compression and transfer molds, for the reasons given below. They are often referred to as pills, tablets, biscuits, premolds, etc. A preform can be of almost any shape or size, and is generally designed to fit the cavity of the mold. Preforms are produced in machines designed for the purpose, in which loose powder is dispensed, usually automatically, by volume, to provide units of the desired weight, and these units are compacted under high pressure in cavities of the desired shape. Preforming, either on a daily basis or unit to unit basis, could immeasurably aid in the development of a field lens fabrication system based on a thermosetting technique.

The principal purposes and advantages of preforming may be summarized as follows: to shorten the cycle of molding; to control the weight of the charge; to facilitate handling of the molding material; to facilitate preheating by decreasing the bulk of the charge; to save material; to obtain thinner cutoff through control of weight; and to simplify construction of molds. The reasons for not preforming are: the cost of preforming is not always justified; some materials cannot be preformed because of high bulk factor; some molds of intricate shape are more effectively filled by powder; and for multi-colored articles, powder often gives a better pattern of flow.

Thermoplastic Techniques

Injection Molding

The injection molding process consists essentially of softening the material in a heated cylinder and injecting it under high pressure into a relatively cold mold where it hardens. The molded article is then ejected from the mold by means of ejector pins, compressed air, a stripper plate, or some other device. The process is a versatile one and can be applied to the production of articles ranging in weight from a fraction of an ounce to several pounds. Injection molding machines are characterized by their shot capability, plasticizing capacity, rate of injection, injection pressure, and clamp pressure (mold locking force).

The range of injection molding machines is an extremely wide one. Apart from the different sizes, ranging from those with a shot capacity of a fraction of an ounce to several pounds in one operation, there are machines with or without pre-plasticization, automatic and semi-automatic types, and fixed or rotary machines. Materials of optical grade which can be injection molded are cellulosics, fluoroplastics, polycarbonates, and polystyrenes. In addition, materials such as nylon for frames can only be practically injection molded. The advantages of injection molding in relation to the other methods described are: affords possibility of casting lens and frame integrally; optical grade lenses should be able to be produced from a material--polycarbonate--which cannot be handled with the other method; the product is almost indestructable; the injection molding of lenses is well-known technique, with millions of lenses being molded annually; short cycle time; and the suggested materials have reasonably good to good abrasion resistance. The disadvantages are: extremely heavy and complex equipment is required although the use throughout a molding machine of light weight alloys might partly overcome this objection; and a new and perhaps difficult technique would have to be developed to offer a molding process which would permit the molding of one lens, followed by a necessary "downtime," in relation to the relatively continuous molding process which is essential for success with the present machinery and procedures.

The disadvantages of large power and massive equipment precludes the use of injection molding as a practical technique for field lens fabrication.

Extrusion

The basic extrusion process is designed to convert, continuously, a thermoplastics material into a particular form. Extrusion is an extremely versatile process and the final shape or forms which can be produced include pipes, films or sheets, fibers, profiles, coatings for paper and other substrates, and coverings for wires and cables. Extruders are also used to feed blow molding machines which produce bottles and other hollow articles. Extrusion is not a pertinent technique for lens manufacture.

Blow Molding

The blow molding process is versatile and not confined to the production of containers. Automobile and engineering components have been manufactured by blow molding techniques. The principles employed in blow molding are essentially the same as those used in the production of glass bottles. Air under pressure is forced into a sealed, molten body, surrounded by a cold mold. The air causes the molten material to expand and take up the shape of the mold, being cooled--at the same time--by contact with the cold surface of the mold. The mold is then opened and the bottle ejected. This is not a technique of particular interest for lens fabrication.

Thermoforming

In thermoforming, a heat-softened plastic sheet is formed either into or around a mold. The simplest example of this technique is "bubble blowing" polymethyl methacrylate sheet to form aircraft canopies, but there are now many variations both in basic techniques and in their degree of automation. In general, thermoforming techniques are best-suited for producing moldings of large areas, for very thin-walled moldings, or where only short runs are required.

Of all the thermoplastic techniques, thermoforming may be one of the most promising due to reduced power, weight, and volume requirements. It does not have high production capability, but this may not be of importance in field lens fabrication. Sheets also may be more practical than molding compound.

Thermoforming may be divided into three main types:

Vacuum Forming. In its simplest form, the method consists of clamping the sheet in a frame attached to the mold box. The sheet is heated until rubbery and a vacuum is drawn between the sheet and the mold. Atmospheric pressure above the sheet forces the sheet onto the mold where it is cooled sufficiently to retain its shape.

Pressure Forming. This is the same as vacuum forming with the exception that a positive air pressure is applied to the sheet from above, which again has the effect of forcing the softened sheet onto the mold. The pressure which can be applied to the sheet is not limited to atmospheric pressure which is, of course, the case with vacuum forming.

Matched Molds Forming. As the name implies, the heated sheet is pressed into shape by trapping it between matched male and female molds.

Molds

Plastic lenses must be molded between optically surfaced molds if full advantage is to be taken of the use of plastics in fabrication. There are several materials and methods for surfacing them which are acceptable. Molds should be so designed that they will produce a uniformly good formed article with unskilled labor, from blanks of economical size and thickness, at an economical rate. This involves correct choice of method and machine; molds of proper shape and accuracy, made of materials compatible with the plastic to be formed; and the rate and quantity of production.

Molds made of hard crown glass offer many advantages. Techniques of grinding and polishing are fully developed. Under the conditions of intended use, glass is exceptionally resistant to staining and corrosion. It is light in weight and, so far as is known, is lighter than any available metal which is hard enough to resist scratching and to develop a full optical polish readily. While glass is brittle and easily damaged, the glass mold can be bonded with a suitable solder to a surrounding protective cell of metal.

Chemically hardened glass produces a mold surface that is harder and tougher, so that molds are not as easily damaged. The use of a thin mold plate of such glass provides a fairly flexible mold surface. This flexibility may be a desirable property for some casting techniques. A special glaze, readily available from either of two sources, is needed for molds which are to be chemically hardened. After grinding and polishing the optical surface with the same methods used with ordinary glass, the mold is immersed in a bath of molten salts. The molecular exchange results produces a glass mold which is extremely tough, while having no effect on the quality or accuracy of the optical surface.

Glass molds are most frequently used for the manufacture of plastic lenses and have a number of distinct advantages. They are hard, lightweight, and do not scratch easily. In addition, when they occur, scratches can be easily identified. Chipping and breakage are the major disadvantages. For field lens fabrication, unless a means of eliminating the requirement for a large number of molds is developed, glass molds are more acceptable than steel.

Metal molds may be used for lens fabrication; however, weight, wear, and ease of scratching are distinct disadvantages. Only if a system design specifically requires metal molds should they be considered for field lens fabrication. Steel is most commonly used for molds for plastics. It will polish in direct proportion to its hardness, and where extremely high luster or optical finish is required, a hardness of at least Rockwell C54 is mandatory. This is easily attained by quenching and tempering the high-carbon steels. Although chromeplating is common practice in the plastics industry, it will not increase the ability of a steel to be polished, or rectify defects in the finishing, but serves only to accentuate the existing finish. Stellite and certain stainless steels are the most promising of readily available metals for use in mold production. Strength and durability are the factors wherein such metals are superior to glass. Techniques for the grinding and polishing of hard metals are not as straightforward as those used with glass, but present no real problem.

For the intended application, a thin layer of a hard relatively heavy metal would be bonded to a thick backup plate of a lightweight metal. The hard cover layer would then be ground and optically polished. The two metals must have similar temperature coefficients of expansion, and this will greatly limit the selection of metals. An alloy of beryllium and copper is frequently used instead of steel for the making of molds, particularly for injection molding, but offers no advantage for lens fabrication.

Top quality optical surfaces can be produced on suitably prepared blanks of anodized aluminum. High purity aluminum, EC grade, must be used. Blanks of the desired size and shape are forged from ingots. The intended optical surface is first smooth-machined to the required curvature, employing a shaped single diamond as a cutting tool. The aluminum blank is now anodized to a depth of about 0.001 inches in a sulphuric acid type anodizing bath. Temperatures and current density are controlled to obtain a hard, dense, anodized layer. The anodized blank may now be optically polished in much the same manner as glass. The result is an optical surface of an extremely hard and stable material, inseparably bonded to a lightweight metal.

Additional Operations

Machining and Finishing

The operations of machining and finishing include filing, drilling, tapping, turning, sawing, piercing, trimming, routing, tumbling, grinding, sanding, ashing, polishing, buffing, transparent coating, polishing by solvent, and also annealing and postbaking.

As will be desirable in the development of a field lens fabrication system, many finishing operations on molded articles can be avoided by careful design of the mold, placing flash lines and gates so as to simplify the finishing. Lenses may require some degree of finishing to remove flash and gates, or to cut and shape.

Inserts

The use of inserts in molding operations presents certain difficulties. Where inserts are required for purposes of adding to the strength of the hold-down screws, or adding to the life of the screw thread, it must be realized that the addition of inserts will slow down the molding cycle and will increase the cost factor. However, for field lens fabrication systems, proper design may eliminate the need for inserts or metal parts may be added subsequent to molding by automatic means at a rate faster than is possible by incorporating such parts in the molding operation. Very often a tapped hole in the plastic, with a drive screw, a self-tapping screw, or bolt and nut, can be used with resultant saving in the cost of the molded article.

Cementing and Welding

Thermoplastic materials may be bonded by at least two techniques which are not applicable to thermosetting plastics and which take advantage of the relatively higher solubility and thermosensitivity of thermoplastics. Specific solvents and solvent-dispersed dope adhesives may be used, as well as various thermobonding or welding techniques.

The cementing of thermosetting materials to themselves, or to other materials, poses problems which are not inherent in the cementing of thermoplastics. The insolubility of thermosetting materials makes it impossible to use the solvent techniques used with thermoplastics, and the smoothness of surface of molded thermosetting plastics adds to the difficulty of cementing them. The surfaces to be joined must mate perfectly, unless a gapfilling cement can be used. The smooth surface must be sanded if machining is not required for mating. This removes the gloss and also the mold-release agent. However, where the specific adhesive strength to the plastic is high, sanding occasionally reduces net bond strength by providing nuclei for cohesive failure of the plastic. Welding by heat provides an advantageous means of joining most thermoplastics. The strength of the weld, however, differs widely among the various plastics. Thermoplastics with the highest degree of polymerization generally provide the strongest and clearest welded joints. Residual monomer, and some plasticizers, may tend to volatilize during the welding. This is difficult to prevent, and the resulting creation of bubbles impairs the strength and appearance of the joint.

Development Techniques

The major fabrication problem is the requirement for a large number of prescriptions, each requiring a separate mold if ordinary fabrication techniques are to be used. The concepts of a moldless or variable mold system are extremely attractive if feasible.

Machined Lenses

Univis, Inc. is studying the feasibility of machining a plastic material to prescription. This moldless technique requires a transparent plastic that can be buffed clear. The process includes a lathe-type device automatically adjustable to the prescription curves which would shape the lens, followed by a buffing operation to produce an optically clear surface.

Variable Membranes

Another moldless concept has been developed by Marks Polaroid with a license agreement to Univis, Inc. This technique involves the use of two stretchable membranes inside a chamber. The membranes form the curvature for both surfaces of the lens. By vacuum application to one side and pressure or vacuum to the other, any combination of shape can be made. The exact expansion of the membranes would be optically controlled. A catalyzed polymer would be forced into the space between the membranes, and the mass molded to prescribed lens shape. The polymer would soften the membranes, allowing them to be stretched. The membrane could become part of the finished lens or be made of expandable, insoluble plastic, such as mylar or rubber, and stripped off.

Variable Molds

Life Systems Research Institute is studying the feasibility of a concept discussed in the beginning of this project. This concept involves the electrostatic or electromagnetic variation of two-mold surfaces automatically to prescription shape either by a flexible surface or a surface of a variety of shapes, or a combination of both. Several alternate subsequent steps can be applied: a thermoset catalyzed polymer forced into the adjusted mold cavity and cured by casting or compression molding; a thermoform material molded under heat and pressure; a thermoform sheet vacuum shaped to the mold face and filled with a catalyzed polymer, which sheet may or may not become part of the lens.

One other concept which is being evaluated by Life Systems Research Institute is the possibility of varying the index of refraction of a fluid substrate inside a rigid surface material of fixed shape to provide varying refractions. This could be used alone or in combination with the variable mold.

Frames

Commonly, nine different frame sizes are stocked to accommodate the general population as discussed under the section on ophthalmic and optical considerations. If the frames are not fabricated at this point of usage this number may be reduced by adopting a frame on which the bridge opening can be controlled through the use of adjustable pads. Adjustable pads require skill in fitting, are less comfortable, and are liable to damage or distortion.

The decentering of the optical center of a lens to account for pupillary distance is readily accomplished if the lens is edged to its final size from an oversized blank. However, edging is undesirable for use in the field as it requires considerable maintenance and repair, appreciable weight, and operator skill. Edging can be avoided if plastic lenses are molded to their finished diameters. The prescribed pupillary distance can be maintained in the majority of cases by producing the lenses in centered form and mounting them in a frame which permits adjusting lens separations to meet requirements. With such an approach, however, there will be a small proportion of prescriptions which still require special attention. For example, a pupillary distance of 60 millimeters will not be achievable in a centered lens unless: use of a lens diameter of about 40 mm is made; a larger size lens is used providing improved appearance and a larger field of view, in this case both 40 mm lenses and lenses of the larger diameter will have to be molded which will double the number of molds required; lenses might be decentered, when necessary, by manually grinding the nasal side of the lens sufficiently to clear the patient's nose.

There is a further small lens requirement. From 1 percent to 3 percent of patients are found to require a prism correction, carried out by producing a lens which is greater in thickness on one side than on the other by a calculated amount. Such requirements obviously cannot be met with the use of centered lenses.

The requirements of temples to provide comfortable and stable fit can best, perhaps, be handled by stocking three lengths of skull temples. Large stock could be kept in a relatively small package of little weight. Attention should be given to the consideration of a temple which is easily formed to shape, after which any excess length would be removed. This approach would permit the stocking or fabrication of only one form of temple, but would require considerable skill in fitting to achieve patient comfort.

The same molding techniques can be considered for fabricating frames under field conditions as those for forming lenses: casting, compression molding, and thermoforming. However, there is no particular materials problem since the properties of transparency, abrasion resistance, and even impact resistance, are not as dominant as they are in the choice of lens materials.

Assembly of the lens and frame affords no particular problem other than the automatic orientation of the lens with respect to the frame. Integral frame and lens assembly is also being evaluated.

CONCLUSIONS AND RECOMMENDATIONS

MATERIALS

The crux of the problem of the feasibility of a system for fabricating spectacle lenses in the field is materials. For the reasons indicated, glass lenses are unacceptable and should not be considered further.

Commercial plastic lenses are made almost exclusively of allyl diglycol carbonate (ADC). This material is unsuitable due to its long cure time. Abrasion resistance is the most pressing problem and even ADC is just passable. There were over one hundred commercial and developmental items identified and screened throughout the software survey and thirty-seven items selected and procured for the physical evaluation. There are many materials with as good properties as ADC except for abrasion resistance. Elastomers of silicone and urethane have excellent abrasion resistance but these are flexible and alone unacceptable. One rigid silicone of General Electric Company has excellent properties except for some degree of brittleness. Urethane sheets of Goodrich, Mobay, and Molded Products have the greatest abrasion resistance but, at present, have a high haze factor.

Those epoxies that are available have poor transmission and abrasion resistance. Polycarbonates have poor abrasion resistance, but otherwise possess excellent properties, and can be rapidly compression-molded.

There are several coating materials which impart an abrasion resistance as good as ADC or better. Silicone and silicone glass coatings of Owens-Illinois, Sierracin and DuPont all provide a highly acceptable lens. The basic material can be polycarbonate, acrylic, or polyester. All have coatings of Bee, Spencer-Kellog and Molded Products and also have excellent properties but need further development. A Univis coating with an ADC additive also provides excellent protective properties. The most significant problem with coated lenses is the time of drying which significantly increases the time of lens production.

At present, a lens of a single material with only fair abrasion resistance will have to be accepted. On the other hand, coated lenses can have excellent resistance to abrasion and other environmental stresses. New developments, or extensions of those underway, could eliminate the need for a coating. With the rapidity of change in the plastics industry, this is to be expected, since no breakthroughs are involved.

It is recommended that materials evaluation continue with the intent that a single material will become available with adequate abrasion resistance. Investigation should be concentrated on epoxies, polycarbonates, silicones, and urethanes.

It is recommended that investigation of a coated lens be pursued as the near term goal, and that decreasing the time of curing be an important consideration.

TECHNIQUES

Of all the techniques for processing plastics, only a few have merit for a field lens fabrication system. Casting and compression molding are the only acceptable methods of processing thermosetting materials. The epoxies, allyl additives, silicones, and urethanes are candidates for casting and compression molding. Thermoplastic materials are usually injection molded; however, this process is unacceptable for field lens fabrication. Some thermoplastics can be compression molded and this is one important avenue to be pursued. In addition, thermoforming techniques are promising.

The urethanes are candidate for compression molding, as well as coated acrylics and polycarbonates. The number of molds required represents a major problem. There are several concepts of moldless or variable mold systems, each directed toward the elimination of multiple molds.

It is recommended that the investigation pursue a system utilizing casting or compression molding as the fabrication technique of choice. This may utilize preformed dough as a means of reducing cure time. In addition, the coating may be applied prior to compression.

It is recommended that investigation of moldless or variable mold systems be pursued at least to establish feasibility. While materials for frames represent no problem, the process of assembly presents a practical problem. It is possible to develop an integral lens and frame--one that is molded in one piece. The complexity of this operation may push the limit of simple and unencumbered equipment.

It is recommended that frames be fabricated concurrently with the lens or stocked separately and then the spectacles be automatically assembled. This represents an interim stage with the integral lens-frame unit as a longterm endpoint.

To pursue a multi-mold system, it is recommended that a tolerance of 1/2 Diopter (±1/4 Diopter) be considered and that ±6 Diopters be the prescription limits. In addition, only one shape of lens is recommended--preferably circular. In this way the complexity of the field lens fabrication system will be reduced due to the lesser number of molds. Consequently, size, automation complexity, and repair and maintenance requirements will be reduced considerably.

This sytem would be suitable for combat use and would represent the near term goal with a much expanded capability as a longterm endpoint.

SYSTEM DEVELOPMENT PLAN

It is estimated that a satisfactory coated lens can be available by mid-1970 with development continuing for another year. An uncoated lens of good abrasion resistance, with other qualities adequate for a combat situation, should be available by mid-1971 with a commercial grade available about one year later. A prototype automated field lens fabrication system suitable for combat forces can be developed by the end of 1971 with a system capable of handling a variety of shapes and all prescriptions by mid-1973.

Two development paths can be followed in developing a prototype. One, in which the combat system is the near term goal, with a system having a larger capability as a second endpoint. The other, in which the maximum capability system--all lens prescriptions and shapes--is the first endpoint. This second path will not measurably save any time.

It is recommended that a pre-prototype or prototype multi-mold system be developed for combat service primarily and that the materials development be concurrently pursued during the early part of this development. The system will be initiated on the basis of coated lenses but will provide for the noncoated lens as materials become available. Although the initial concept will depend on multiple molds, the feasibility of a moldless or variable mold system should be evaluated during the early development period: and, if found to be feasible, a breadboard or pre-prototype model should be made.

APPENDIX I

99-9

BIBLIOGRAPHY

Abbey, A. Improvements in or Relating to Casting Devices for Optical Elements. British Patent No. 796,825, October 4, 1955.

______________. Acrylic lenses. Plastics World 22:13, February 1964.

______________. All-plastic dark glasses. Plastics World 23:67, September 1965.

______________. Allyl ester lenses. Plastics World 22:14-15, September 1964.

American Optometric Association, Ophthalmic Optics--Prescription Standards--Allowable Tolerances. St. Louis, Mo., Rev. 1953.

American Standards Association, American Standard Safety Code for Head, Eye, and Respiratory Protection. . . approved November 27, 1959. New York, 1960. Z2.1-1959.

Arbital, Irving, Industrial visual screening in the Air Force, J. Am. Optom. Assn., 29(10):637-640, 1957-58.

Armstrong, C. W. Coatings applied with epoxy powder. Proc. Soc. Plastics Industry, Inc. --Natl. Plastics Conf. 1963, Sec. 1-C, pp. 1-8.

Aronson, A. N. Advanced multi-station coating machine. Modern Packaging. 38(12):139-40, 142, 195, 197, August 1965.

Bardin, P. C. Color coating clear glass permanently. Ind. Finishing 43:68-70, November 1967.

Barnett, G. Review of developments in coating materials and methods. Trans. Plastics Inst. 33(104):29-37, April 1965.

Bauer, La Verne N., et al. Copolymers from allyl esters and methacrylic esters. U.S. Patent No. 2,600,383. June 17, 1952.

Beattie, John O. Apparatus for the manufacture of plastic lenses from monomeric materials. U.S. Patent No. 2,745,138, May 15, 1956.

Bechtold, E. W. The aberrations of ophthalmic lenses. Am. J. Optom. and Arch. Am. Acad. Optom. 35(1):10-24, 1958.

Bedini, S. Lens making for scientific instrumentation in the seventeenth century, Applied Optics 5, 687-694, 1966.

Beech, S. R. Improvements in or relating to the production of optical elements. British Patent No. 920,608, June 21, 1961.

Belyr, V. A., Yurkevich, O. R. and Mirokovich, L. I. Analysis of certain methods of applying thin-layer polymer coatings. Soviet Plastics (English translation of Plasticheskie Masgy) 2:31-34, February 1966.

Bennett, R. Acrylic optics come of age. Res. Develop. 17:22-25, October 1966.

Bewley, L.A. Spectacle frames reduce the field of vision: a driving hazard. Journal of the American Optometric Assoc. Vol. 40, No. 1, January 1969. pp. 64-69.

Binda, F. J. Process of manufacturing glass-coated plastic material. U. S. Patent No. 2,287,546, June 23, 1942.

Birch, M. H. Improvements in or relating to lenses, British Patent No. 798, 877, October 9, 1956.

Blaurock, E. E. Apparatus for molding. U.S. Patent No. 2,661,498, December 8, 1953.

Blout, E. B., et al. Optical filter and method of manufacture. U. S. Patent No. 2,440,070. April 20, 1948.

Boenig, H. V., Scratch and wear resistant cured polyester surfaces. U. S. Patent No. 3,318,727, May 9, 1967.

Bongiovanni, G. and Clerico, M. Understanding plastic wear. Mod. Plastics 44:126, May 1967.

Bowser, G. H. Process of casting resinous lenses in thermoplastic cast replica molds. U. S. Patent No. 3,422, 168, January 14, 1969.

Bowser, G. H. Process for casting resinous lenses in thermoplastic cast replica molds, U. S. Patent No. 3,423,488, January 21, 1969.

Brandt, W. E. Selection and use of chemical compounds for vibratory finishing. Tool & Manuf. Eng. 56:26-30, March 1966.

———————— Breakthrough for plastics in fibre optics. Brit. Plastics 39:459, August 1966.

Bristol, A. C. Method for bonding a polyester resin to a resinous substrate. U. S. Patent No. 3,457,104, July 22, 1969.

Brixner, B. Automatic lens design. SMPTE Journal. 73:314-320, 1964.

Brixner, B. Automatic lens design for nonexperts. Optics, 2:1281-1286, 1963.

Brixner, B. Lens design by statistical analysis. SMPTE Journal, 76:186:188, 1967.

Brucksch, W. F. Transparent ethylene-propylene-diene terpolymer rubber vulcanizate. U.S. Patent No. 3,408,320, October 29, 1968.

Celentano, J. T., et al. *Bioastronautics Laboratory Research Tool Study.* USAF Eastern Test Range Report No. AFETR-TR-65-6, 1965.

Celentano, J. T., et al. *Field Medical Laboratory Program Final Development Report*, North American Rockwell, C7-2769/030, 1968, 201 pp.

Coates, J. B., Jr., and Beyer, J. C., Wound Ballistics, Office of the Surg. Gen. Dept. of the Army, 1962.

______________. Coating delivers premium service at bargain price. Product Eng. 38:76-79, January 2, 1967.

Combined Optical Industries Limited, Improvements in the manufacture of lenses. Belgian Patent No. 599,592, April 23, 1963.

Cooper, D. P., Jr., Mold for use in the manufacture of optical elements. U. S. Patent No. 2,406,742 September 3, 1946.

Cosgrove, K. W., Henry, J. F., and Stevenson, R. A., A study of non-occupational eye injuries, Sight Saving Review, 26:92, 1956.

Cox, R. P., et al. Bonding of plastic materials by polymerizable solvents. U. S. Patent No. 3,445,311, May 20, 1969.

Craddock, C. H., Manufacture of lenses, British Patent No. 982,528, November 11, 1963.

Craddock, C. H. Mold for the manufacture of lenses. U. S. Patent No. 3,273,204, September 20, 1966.

Crandon, H. D. Improvements in devices and methods of forming optical elements. British Patent No. 846,669, March 11, 1959.

Crandon, H. D. Mold for producing lens of any shape from a polymerizable material. U.S. Patent No. 2,890,486, June 16, 1959.

Crandon, H. D. et al. Aryl phosphate plasticized alkyd resin adhesive compositions and method of preparing. U. S. Patent No. 2,840,535, June 24, 1958.

Crooks, C. H. Improvements in or relating to the production of optical elements. British Patent No. 618,477, September 2, 1946.

Crosley, J. K. et al. An evaluation of ophthalmic plastic (CR-39) lenses in the U. S. Army Aviation environment, USAARL Report No. 69-3, U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama, February 1969.

Dahle, J. Titanate product and method of making the same. U. S. Patent No. 3,460,956, August 12, 1969.

D'Apolito, M. Molded article separator. U. S. Patent No. 3,151,813, October 6, 1964.

Davis, J. K. Corrected curve lenses and lens quality. American Journal of Optometry, 39:135-148, 1962.

Davis, J. K. Stock lenses and custom design. American Journal of Optometry, 44:776-801, 1967.

Davis, J. K. et al. An analysis of ophthalmic lens design. American J. Optom. and Arch. Am. Acad. Optom. 41(7):400-421, 1964.

Davis, J. K. et al. Instruments and methods for locating the sighting center of the eye. Am. J. Optom. and Arch. Am. Acad. Optom. 40(11):676-683, 1963.

Davis, J. K. et al. The Tillyer Masterpiece Lens--a Technical Discussion. Southbridge, Mass. Am. Optical Co., 1964.

Davis, J. K. et al. The design of a general purpose single vision lens series. Amer. J. of Optometry, 42:203-236, 1965.

De Gooreynd, P. M. J. Koch. Polymerization of a mixture of polymerizable materials. Canadian Patent No. 579,372, July 14, 1959.

Deichert, W. G. et al. Mar-resistant unsaturated polyester resins. U. S. Patent No. 3,265,763, August 9, 1966.

Deichert, W. G. et al. Mar-resistant unsaturated polyester resins. U. S. Patent No. 3,265,764, August 9, 1966.

Deichert, W. G. et al. Method of treating polymeric substrates so as to improve adhesion of mar-resistant surfaces thereto. U. S. Patent No. 3,404,996, October 8, 1968.

De Jarlis, W. J. et al. Oxazoline polyester coating resins. Am. Oil Chem. Soc. J. 44:126-128, February 1967.

De Lapp, D. F. et al. Mar-resistant products and process for making same. U. S. Patent No. 3, 387, 988, June 11, 1968.

Dettmer, R. G. Industrial eye protection program. Journal of the American Optometric Association. 38:838-842, 1967.

Deutsche Spiegelglas Atkiengesellschaft. Process for producing protective eye-glasses, screens or spectacle lenses, and protective eyewear produced by the process. British Patent No. 1, 133, 348, November 13, 1968.

_____________. Diamonds cut cost of turning plastics. Cutting Tool Eng. 17(11-12):23-24, November/December 1965.

Dickinson, T.G. Safety Lens materials. Journal of the Florida Medical Association, 48:968-971, 1962.

Dreger, D. New plastics. Machine Design. 38:144-153, January 20, 1966.

Ehlert, W. C. et al. Mold adapted to form a unitary optical device. Canadian Patent No. 530, 783, September 25, 1956.

Ehlert, W. C., et al. Mold for making integral plastic frames and lenses. U. S. Patent No. 2, 516, 373, July 25, 1950.

Emsley, H. H. and Swaine, W., Ophthalmic Lenses, London, Hatton Press, 1940.

Emsley, H. H. and Swaine, W., Ophthalmic Lenses. 6th ed. London, Hatton Press, Ltd., 1951, 339 pp.

_____________. Epoxy clings to cold parts electrostatically. Matls. Eng. 66:25, September 1967.

Ewers, R. W. Manufacture of mouldable plastic articles. U. S. Patent No. 3,240,854, March 15, 1966.

Fair, J. R. Eye armor, Am. J. Ophth. 43:258, 1957.

Fairbank, M. N. Mold for use in the manufacture of optical elements. U. S. Patent No. 2,431,926, December 2, 1947.

Fairbank, M. N. et al. Mold for use in the manufacture of optical elements. U. S. Patent No. 2, 406, 361, August 27, 1946.

Feder, D. P. Automatic lens design with a high speed computer. Journal of the Optical Society of America. 52:177-183, 1962.

Feder, D. P. Automatic optical design. Applied Optics 2:1209-1226, 1963.

Feinberg, Richard and Sherman, Reuel A., Protecting eyes from injury with safety-glass lenses, in Guide to Occupational and Other Visual Needs, by Clark Holmes and others, Los Angeles, California, copyright by Clark Holmes, 1958, p. 18.

Filderman, I. P. The spectacle lens contact lens system. British Journal of Physiological Optometry, 21:195-196, 1964.

Freeman, W. M. Method for finishing hard-plastic lenses for eyeglasses. U. S. Patent No. 3,030,745, April 24, 1962.

Frey, R. G. On the problem of vision improvement by anti-glare goggles. Weiner Klinische Wochenschrift, 73:526, 1961.

Fry, G. A. Do you wear eyeglasses? Magazine of Standards, 35:259-261, 1964.

Fry, G. A., "Lens Standards for the Optical Laboratory," Optometric Weekly, February 18, 1960.

Fry, G. A. and Hill, W. W., The center of rotation of the eye. Am. J. Optom. and Arch. Am. Acad. Optom., 39(11):581-595, 1962.

Gardner, A. R. Transparent plastics open new windows on products. Product Eng. 37:66-69, October 24, 1966.

Gaynes, N. Water soluble coatings. Ind. Finishings 42:97-99, January 1966.

Genesy, P. Die for Molding or Casting Optical Lenses. U. S. Patent No. 2,253,697, August 26, 1941.

Giles, G. H. The Principles and Practice of Refraction and Its Allied Subjects. London, Hammond, Hammond and Co., Ltd., 1965 554 pp.

Glossary of Terms Relating to Ophthalmic Lenses and Spectacle Frames. British Standard 3521:1962, British Standards Institution.

Gol'berg, S. Z. A device for checking alloys used for frames for eyeglasses. Meditsinskaia Promyshiennost SSSR (Moscow), 3:27-32, 1961.

Grandperret, Rene. Apparatus and method of producing optical and ophthalmic lenses from thermosetting resin materials. U. S. Patent No. 3,278,654, October 11, 1966.

Grandperret, R. Improvements in the manufacture of plastic ophthalmic lenses. French Patent No. 1.267.883.

Grandperret, R. Methods of producing optical and ophthalmic lenses from thermosetting resin materials. U. S. Patent 3,222,432, December 7, 1965.

Grandperret, R. Method of producing optical elements from plastic material. Canadian Patent No. 535,567, January 8, 1957.

Greef, R. Die Erfindung der Augenglaser, Berlin Alexander Ehrlich, 1921.

Greiner, H. Variations of injection molded optical components of polymethyl methacrylate. Plast u Kautschuk, 15:201-203, 1968.

Greshes, M. Casting quality plastic lenses. Plastics Technology. 11:38-39, 1965.

Grolman, B. A new single vision general purpose lens. J. Am. Optom. Assn., 37(6):553-560, 1966.

Hager, T. C. et al. Plastic fiber optics. SPEJ 23:36-42, September 1967.

Hatch, J. L., and Gunn, M. R. Radiographic characteristics of ophthalmic lenses. American Journal of Ophthalmology 51:1268-1272, 1961.

Hauck, J. E. Alloy a plastic to improve properties. Materials Eng. 66:60-63, July 1967.

Haynes, P. R. et al. The design and fabrication of haptic lenses produced from impressions of the eye. J. Amer. Optom. Assn. 39:210-222, March 1968.

Herman, W. F. et al. Means and methods for producing optical elements. Canadian Patent No. 542, 964, July 2, 1957.

Herman, W. F. et al. Means for Producing optical elements. U. S. Patent No. 2,728, 106, December 27, 1955.

Hermann, J. et al. Synthetic optics. Jena Revue (Jena), 11:178-181, 1966.

Hervey, L. R. B. Silicon containing resins and method of producing same. U. S. Patent No. 2,432,891, December 16, 1947.

Hirsch, M. J. and Morgan, M. W. The measurement and grading of refractive state by the armed forces. American Journal of Optometry and Archives of Amer. Academy of Optom. 42:707-726, 1965.

Hirsch, M. J. New horizons in ophthalmic lenses. American Journal of Optometry, 39:374-379, 1962.

Hirsch, M. J. New ophthalmic lens series and base curves. Amer. J. of Optometry. 42:370-372, 1965.

Holladay, J. C. Computer Design of Optical Lens Systems (IBM 704), Proc. 1960 Comp. Applications Symp. sponsored by Armour Research Foundation (Macmillan Co., New York, 1961).

Holmes, W. J. Prevention of eye accidents in sugar and pineapple industries of Hawaii, Indust. M. Surg. 25:73, 1956.

Hungerford, Albert O. et al. Method of producing plastic lenses. U. S. Patent No. 3,038,210, June 12, 1962.

Hyde, James Franklin. Liquid polymeric phenylalkyl-siloxanes. U. S. Patent No. 2,432,665, December 16, 1947.

Idelson, Elbert M. Method of applying mar-resistant surface coatings to thermoplastic sheets. U. S. Patent No. 3,081,182, March 12, 1963.

_______________. Improvement in the casting of optical and ophthalmic lenses with synthetic resins. International Patent No. 1,191,11B (B29d), April 6, 1959.

_______________. Instant cure for coatings. Business Week, June 11, 1966.

_______________. Intermediate for tough coating systems; DDI diisocyanate. Plastics World 23:48-49, December 1965.

Jacques, P. M. et al. Improvements in or relating to the manufacture of molded articles. British Patent No. 738,487, January 2, 1953.

Jeffree, John Henry. Grinding of lenses of dies therefor. U. S. Patent No. 2,458,384, January 4, 1949.

Jenaer Glaswerk Schott & Gen., Process for the manufacture of optical parts of plastic material, French Patent No. 1,365,803.

Jessup, J. N. Chemical and thermal resistance of thermosetting molding compounds. Modern Plastics 44:174, March 1967.

Johansson, I. Gjuthartsev--problem och anvandning. Plas/Varlden 16(5):41-42, 44-45, 50-51, May 6, 1966; pp. 36-68, June 1966.

Johnson, John. Apparatus for the manufacture of lenses. U. S. Patent No. 2,443,826, June 22, 1948.

Johnson, J. Improvements in or relating to the casting of synthetic resins. British Patent No. 847,797, December 31, 1956.

Johnson, J. Improvements in or relating to the shaping of lens preforms. British Patent No. 872,811 , April 9, 1958.

Johnson, J. Manufacture of lenses from transparent polymerizable organic plastics. British Patent No. 619,384, December 5, 1946.

Johnson, John. Method for forming coated optical elements from polymerizable materials. U. S. Patent No. 2,479,935, August 23, 1949.

Johnson, John. Method of molding lenses and like optical elements. U. S. Patent No. 2,473,588, June 21, 1949.

Johnson, John. Production of lenses from transparent plastics. Canadian Patent No. 469,344, November 14, 1950.

Johnson, John. Production of lenses from transparent plastics. U. S. Patent No. 2,640,227, June 2, 1953.

Johnson, John et al. Method and apparatus for manufacturing optical elements from moulded polymer materials. Canadian Patent No. 597,171, May 3, 1960.

Johnson, J. et al. Method and apparatus for manufacturing optical elements from moulded polymer materials. British Patent No. 858,218, March 3, 1958.

Jones, Harold A. Means for making curved optical and reflective surfaces. U. S. Patent No. 3,422,495, January 21, 1969.

Jones, R. V. and Rees, R. L. Application of polyolefin powders. SPE J. 23:80, June 1967.

Joyner, R. E. Eye protection in the chemical industry. Indust. M. Surg. 28:174, 1959.

Junker, Bernhard T. et al. Continuous polymer casting machine and process. U. S. Patent No. 3, 422, 178, January 14, 1969.

Kaelble, D. H. Spin casting of polymer films. J. Applied Polymer Science 9(4):1209-1212, April 1965.

Keeney, A. H. and Duerson, H. L., Jr. Evaluation of a new plastic spectacle lens (Teior Orma 1000). American J. Ophthal. 54:418-420, 1962.

Keeney, A. H. Lens Materials in the Prevention of Eye Injuries. Springfield, C. C. Thomas, 1957, 73 pp.

Keeney, A. H. New concepts in protective eyewear. Sight-Saving Review 35:75-79, 1965.

Keeney, A. H. Safety lens materials. Survey of Ophthalmology 5:405-412, 1960.

Kessler, Martin C., Jr. Plastic lens and guard. U. S. Patent No. 2,540,953, February 6, 1951.

Kevern, J. Glass can be machined with new techniques. Product Eng. 38:100-112, May 22, 1967.

Kingston, Arthur William. Method of making optical lenses. U. S. Patent No. 2,443,390, June 15, 1948.

Kingston, Arthur William. Production of optical lenses, prisms, and like optical elements. U. S. Patent No. 2,432,668, December 16, 1947.

Kislin, B. Recent developments in optical aids in the U. S. Air Force. Am. J. Ophthal. 44:810-817, 1967.

Klebe, J. Design of simple achromatic and apochromatic lenses. Optik 24:218-228, 1966-67.

Knill, B. New applications for hard-wearing plastics. Material Handling Eng. 23:99-102, February 1968.

Knoll, H. A. A brief history of ophthalmic lenses. J. Am. Optometric Assn. 38:946-948, 1967.

Kobrin, C. L. Coating with a charged cloud. Iron Age 200:59-60, July 13, 1967.

Koch, P. H. B. and Oertel, H., Jr. Microwave thermography. IEE Proc. 55:416-418, March 1967.

Krops, Edward L. Copolymers of allyl esters of polybasic acid with saturated monohydric alcohol esters of unsaturated polycarboxylic acid. U. S. Patent No. 2,437,962, March 16, 1948.

Kut, S. Epoxy resin surface coatings. Corrosion Technology 11(8):18-22, August 9, 1964; 16-19, September 1964.

Lamard, A. Improvements applying to cast devices for lenses of organic glass and to their processes of manufacture. French Patent No. 1,492,305.

Lamoreaux, H. F. Modified cyclotetrasiloxane polymers. U.S. Patent No. 3,438,936, April 15, 1969.

Lanman, R. K. Method and apparatus for casting thermosetting plastic lenses. U. S. Patent No. 3,211,811, October 12, 1965.

Laubman and Pank Limited. Improvements in Moulded Articles. British Patent No. 909,880, June 1, 1961.

____________. Learn from lenses. Modern Plastics, 38:90-93 and 181-182, 1961.

Lehman, C. A. Designing lenses with computer. SMPTE Journal, 76:188-196, 1967.

Le Marrec, L. Improvements in or relating to a process and apparatus for the manufacture of moulded articles mainly for optical uses. British Patent No. 743,025, July 13, 1953.

Lentilles Ophtalmiques Rationnelles Societe Anonyme. Improvements in or relating to moulds for the production of ophthalmic lenses of moulded thermosetting resin. British Patent No. 1,080,368, February 18, 1965.

Lentilles Ophtalmiques Rationnelles. Improvements in or relating to moulds for the production of optical elements. British Patent No. 967,148, March 12, 1963.

Lentilles Ophtalmiques Rationnelles-Telegic Lor-Telegic. Improvements in and relating to moulds for use in the manufacture of thermoplastic resin lenses. British Patent No. 1,109,586, January 4, 1967.

Lentilles Ophtalmiques Speciales. Improvements in and relating to the manufacture of lenses. British Patent No. 847,345, December 12, 1958.

Lentilles Opthalmiques Speciales S.A.R.L. Improvements in and relating to the manufacture of lenses. British Patent No. 790-734, April 25, 1956.

Levinson, S. B. Abrasion resistant finishes. J. Paint Technology, 38(500)458-492, September, 1966.

Levy, S. Designing optics in plastics. Plastics World, 23:44-47, 1965.

Lewis, R. B. Predicting the wear of sliding plastic surfaces. Mech. Eng. 86:32-35, October 1963.

Lippmann,O. ,M.D. Doctors need knowledge of eye safety lenses. Texas State Journal of Medicine 61 (3):163-165, March 1965.

Lissac, G. Improvements in or relating to spectacles. British Patent No. 940,089, November 29, 1961.

Lloyd, E. G. Method of and means for forming unbreakable lenses. U.S. Patent No. 2,166,215, July 18, 1939.

Lontz, H. M., et al. Identification of hot-end surface coatings. Glass Ind. 47:436-438, August 1966.

L.O.R. Lentilles Ophthalmiques Rationnelles. Improvements in the construction of molds for the manufacture of lenses of thermosetting resins. French Patent No. 1.484.653.

L.O.S. Lentilles Ophtalmiques Speciales. An improved method of producing optical elements from plastic material. British Patent No. 731,147, December 14, 1953.

Lueck, I. B. Toughened safety lenses. Rochester, N.Y., Bausch and Lomb, Inc., 1961. Sci. and Tech. Pub. No. 23.

______________. Machine for filling molds designed for the manufacture of plastic ophthalmic lenses. French Patent No. 1.334.376.

Macht, M.L. Molding of organic plastics, U.S. Patent No. 2,272,847, February 10, 1942.

Mahler, J. Hard surface treatment for plastics. U.S. Patent No. 2,925,622, February 23, 1960.

Mahler, J. Method of making an optical filter and resultant article. U.S. Patent No. 2,816,047, December 10, 1957.

Marks, A. M. et al. Electrically conductive transparent materials. U. S. Patent No. 3,357,930, December 12, 1967.

Medical Dept., U.S. Army, Surgery in World War II. Ophthalmology and Otolaryngology, Office of the Surg. Gen., Washington D.C., 1957.

Medical Service Units Theater of Operations. Department of the Army *Field Manual, FM 8-5, 1959, 155 pp.*

Megi, G.K. Optical properties and application of photochromic glass. Applied Optics 5(6):545-560, June 1966.

______________. Men of vision. Plastics World 22:56, January 1964.

Meyer, H. High-accuracy plastic-replica optics. SYMPTE Journal, 74:28-32, January 1965.

Milder, B., and Kaplan, A.H. Psychologic aspects of ophthalmologic practice: II. Psychodynamics of eyeglass acceptance; the ophthalmologist-patient relationship. Amer. J. of Ophthalmology, 52:696-702, 1961.

Miles, D.C., and Briston, J.H. Polymer Technology. New York, Chemical Publishing Co., Inc., 1965, 444 pp.

Miller, R.G. A method of measuring astigmatic optical systems and its application in a lens measuring device. Gruzlica i Choroby Pluc (Warsaw), 30:469-472, 1963.

Mock, J.A. Control glass properties with films and coatings. Matls. Eng. 66:90-93, September 1967.

Model, D.M., Medvedev, N.M., and Leshchinskii, D.A. A plastic instrument for grinding and polishing eyeglass lenses. Meditsinskaia PromyshiennostSSSR(Moscow), 9:52-57, 1962.

Modern Plastics Encyclopedia, 1967. J. Frados, ed., New York, McGraw Hill, Inc., 1966.

Modern Plastics Encyclopedia, 1968. J. Frados, ed. New York, McGraw Hill, Inc., 1967.

Modern Plastics Encyclopedia, 1969. J. Frados, ed. New York, McGraw Hill, Inc., 1968.

Modern Plastics Encyclopedia, 1970. S. Gross, ed. New York, McGraw Hill, Inc., 1969.

Morgan, M. W. The performance of ophthalmic lenses. J. Am. Optom. Assn. 32(10):797-806, 1960-61.

Murray, M. An improved detachable lens for spectacle frames and eyeglasses. British Patent No. 742,823, July 2, 1954.

Muskat, L. E. et al. Artificial glass. U. S. Patent No. 2,320,533, June 1, 1943.

Naujokas, A. A. Method of Making lenses. U.S. Patent No. 3,248,460, April 26, 1966.

Neefe, C. W. Process for molding high quality plastic lenses. U.S. Patent No. 3,380,718, April 30, 1968.

Neher, H. T. et al. Copolymers from allyl succinyl allyl, glycolate and acrylic esters. U.S Patent No. 2,521,303, September 5, 1950.

Neher, H. T. et al. Copolymers of acrylates and allyl esters. U. S. Patent No. 2,600,421, June 17, 1952.

Nervi, I., and Mosci, L. Influence of "polaroid filter" on visual acuity. Annali di Ottalmologia e Clinica Oculistica (Parma), 89:287-294, 1963.

______________. New acrylic finishes stand up to wear abuse. Matls. Eng. 69:54, February 1969.

Newell, F. W. *Ophthalmology*. St. Louis, C. V. Mosby Co., 1965, 491 pp.

____________. Newest developments in plastics technology. Mach. 74:191-193, March 1968.

____________. New molding system. Mod. Plastics 42:92-94, July 1965.

____________. New technique makes optical components of the highest quality. Bell Lab. Rec. 44:211, June 1966.

Newton, A. W. Industrial eye protection - appraisal of some current safety lens materials. Institute of Engineers (Australia), 39:163-170, 1967.

New York Naval Shipyard, Materials Laboratory. Final Report, Project 5570-4, Pt. 4, December 1957.

New York Naval Shipyard, Materials Laboratory. Final Report, Project 6216-13, March 1962.

Novak, L. J. Plastic materials comprising dextran and method of preparation. U. S. Patent No. 2,823,188, February 11, 1958.

Nyquist, A. S. et al. Method of molding thermosetting compositions in glass molds. U.S. Patent No. 2,475,194, July 5, 1949.

Ogle, K. H. *Optics.* 2nd ed. Springfield, C. C. Thomas, 1968, 264 pp.

O'Keefe, B. C. Silicone, epoxy, acrylic resin coatings. Ind. Finishing 42:98-99, October 1966.

Optical Detachments, Teams GA and GB in *Table of Organization and Equipment*, TOE 8-500. Department of the Army.

____________. Optical lens and mold for its manufacture. French Patent No. 1.347.349.

Pasini, B. et al. Means for producing optical lenses from plastic materials. U.S. Patent No. 2,823,417, February 18, 1958.

Passmore, J. W. Common eye injuries and their management. *Medical Bulletin of the U.S. Army, Europe*, 16:199-202, 1959.

Peters, H. B. The fracture resistance of industrially damaged safety glass lenses. Am. J. Optom. and Arch. Am. Acad. Optom., 39(1):33-35, 1962.

Peters, H. B. The relationship between refractive error and visual acuity at three age levels. Am. J. Optom. and Arch. Am. Acad. Optom., 38(4):194-198, 1961.

____________. Photochromics--something new under the sun. Plastics Technology 11(6):15, 125, June 1965.

____________. Phototropic glass and methods, patent. Glass Ind. 48:466, August 1966.

____________. Plastic protective coating is bonded by a special method. Product Engin. May 22, 1967.

____________. Preventive Medicine in World War II, Volume III Personal Health Measures and Immunization. E. C. Hoff, ed. Washington, D.C., Office of the Surgeon General, Department of the Army, 1955, 394 pp.

Prince, J. H. and Fry, G.A., The effect of errors of refraction on visual acuity. Am. J. Optom. and Arch. Am. Acad. Optom., 33(7):353-373, 1956.

Pristeley, J. Vision, Light and Colour. London, J. Johnson, 1772.

____________. Proceedings of the Conference on Optical Instruments and Techniques, London, 1961 (Chapman and Hall, London 1962).

Quincey, G. Glass vs. plastics. Glass Ind. 48:683-686, December 1967.

Raiford, M.B. Flexible presbyopic lenses. Journal of the Med. Assoc. of Georgia, 56:511-513, 1967.

Ramsey, W. B. et al. Mar-Resistant plastic sheet and process for producing same. U.S. Patent No. 3,421,928, January 14, 1969.

Reese, E.E. and Fry, G.A., The effect of fogging lenses on accommodation. Am. J. Optom. and Arch. Am. Acad. Optom., 18(1)9-16, 1941.

Richardson, J. H. Method of manufacturing reflecting optical elements. U.S. Patent No. 2,444,532, July 6, 1948.

Rinia, H. Optical element. U.S. Patent No. 2,332,930, October 26, 1943.

Rinia, H. Method of manufacturing optical elements. U.S. Patent No. 2,437,860, March 16, 1948.

Rose, H.W. and Stewart, G.M., Eye protection against small high-speed missiles. Tr. Am. Acad. Ophth. May-June 1957.

Rose, H.W. and Stewart, G.M. Eye protection against small high-speed missiles. Tr. Am. Acad. Ophth. & Otol., 61:404, 1957.

Rosen, E. The Invention of eyeglasses. Jr. Hist. Med. & Allied Sciences 11, 13-46, 183-218, 1956.

Roth, N. Automatic optometer for use with an undrugged human eye. The Review of Scientific Instruments, 36:1636-1641, 1965.

Rowland, W.P. Method for extruding synthetic thermoplastic sheet material. U. S. Patent 3,422,175, January 14, 1969.

Rutgerswerke Und Teerververtung Aktiengesellschaft, Process for preparing transparent synthetic organic materials. British Patent No. 1,038,694, April 17, 1963.

Sarofeen, G.M. J. Glycol carbonate addition polymers. U. S. Patent No. 2,964,501, December 13, 1960.

Sauer, H. Copolymer of diethyleneglycol-bis-allylcarbonate, triallylcyanurate and a styrene. U. S. Patent No. 3,228,915, January 11, 1966.

Schreyer, G. Plastics in optics. Kunstoffe, 51:569-576, 1961.

Schrier, I. Method of polishing plastic lenses. U.S. Patent No. 3,262,233, July 26, 1966.

Schrier, I. Mold construction for casting thermosetting plastics of accurately controlled shape. U. S. Patent No. 3,070,846, January 1, 1963.

Schroeder, J. B. et al. Ionic polishing of optical surfaces. Applied Optics 5(6):1031-1034, June 1966.

Silberstein, I.W. Eye injury experience related to total injury experience. San Francisco Naval Shipyard, from a report submitted February 1960, revised.

Silberstein, I.W. The fracture resistance of industrially damaged safety glass lenses, plano and prescription -- an expanded study. American Journal of Optometry, 41:199-221, 1964.

Sloan, L. L. Measurement of visual acuity; a critical review, A.M.A. Arch. Ophth., 45(6):704-725, 1951.

Slyk, C.M. Mold for producing lenses and lens blanks from polymerizable materials. U.S. Patent No. 3,136,000, June 9, 1964.

Smith, G.P. Chameleon in sun-photochromic glass. IEEE Spectrum 3(12):39-47, December 1966.

Smith, C.N. Method for Coloring plastic resins. U.S. Patent No. 2,260,543, October 28, 1941.

Smith, C.V. Method of molding. U.S. Patent No. 2,319,014, May 11, 1943.

Societe Francaise des Verres Igard, et al. A process for the manufacture of plastic lenses with abrasion resistant surfaces and lenses obtained by this process. French Patent No. 596,891.

SPI Plastics Engineering Handbook. 3rd ed. New York, Reinhold Publishing Corp., 1960, 565 pp.

Stewart, G.M. Eye protection against high-speed missiles. U.S. Army Chemical Research and Development Laboratories, Technical Report CRDLR 3007:1-24, 1960.

Stewart, G.M. Eye protection against small high-speed missiles. Am. J. Ophth., 51:80(Jan.), 1961.

Susi, P.V. et al. Heat resistant aminium salt infrared absorbers. U.S. Patent No. 3,341,464, September 12, 1967.

Susi, P.V. et al. Tris (p-dialkylaminophenyl) aminium hexafluoroantimonates and arsenates. U. S. Patent No. 3,440,257, April 22, 1969.

Thonemann, O.E. Manufacture of optical lenses from polymethacrylate by injection molding. Plastverarbeiter, 18:619-626, 18:707-714, and 18:819-826, 1967.

Tillett, C.W., et al. High speed photographic study of perforating ocular injury by the BB. Am. J. Ophth., 54:675 (Oct.), 1962.

Tillyer, E.D. et al. Abrading Device. U.S. Patent No. 2,224,168, December 10, 1940.

Transactions of the International Ophthalmic Optical Congress 1961. The British Optical Association. London, C. Lockwood and Sons, Ltd., 1962, 676 pp.

Trevitt, E.W. Polyesters in surface coatings. Applied Plastics 9(6):19-20, June 1966.

Tsepelev, I.A., Aizenshtat, L.I., and Bulanova, E.A. A new design for an average set of test spectacle lenses. Meditsinskaia Promyshlennost SSSR(Moscow), 18:58-61, 1964.

Umlandt, W.H., Machine for Compressing Lenses or the like. U.S. Patent No. 2,273,500, February 17, 1942.

Umlandt, W.H. Machine for making lenses or the like. U.S. Patent No. 2,327,228. August 17, 1943.

______________. Urethane coatings used in reactor facility. Materials Protection 6:63-64, June 1967.

______________. USAREUR optical laboratory. Medical Bulletin of the U.S. Army, Europe, 18:217-219, 1961.

U.S. Navy Dept., Bureau of Ships, Fed. Spec. GGG-S-00620 (Navy-Ships): Spectacles, Industrial; and Lenses, Ophthalmic, Plano and Prescription, Glare and Impact Resistant. Washington, D.C., 1959.

Val'ter, M. B., and Savenko, C. A. Experiences in increasing the durability of machines for polishing spectacle lenses. Meditsinskaia Promyshiennost SSSR (Moscow), 20:55-58, 1966.

Van Horne, W. L. et al. Copolymers of methacrylates and allyl esters. U.S. Patent No. 2,600,446, June 17, 1952.

Van Horne, W. L. et al. Copolymers of allyl esters and maleates. U.S. Patent No. 2,600,447, June 17, 1952.

Van Horne, W. L. et al. Copolymers from allyl esters and acrylic esters. U.S. Patent No. 2,600,448, June 17, 1952.

Von Rohr, M. Contributions to the History of the Spectacle Trade from the Earliest Times to Thomas Young's Appearance, Trans. Opt. Soc. 25, 1923-24.

Voronov, B. F. On protective glasses with reflective light filters. Gigiena Truda i Professional'nye Zablolevaniia (Moscow).

Weiland, G. "Orma 1000" light spectacle lens from hard plastic. Klinische Monatsblaetter fur Augenheilkunde (Stuttgart).

Weinberg, J. W. Lens mold and apparatus. U.S. Patent No. 3,056,166, October 2, 1962.

Weinberg, J. W. Process for manufacturing curved optical articles. U.S. Patent No. 3,171,869, March 2, 1965.

West, P. Clear plastic steps forward as new lightweight champ. Product Eng. 38:108, May 22, 1967.

West, P. Long-chain plastic bids for tough industrial jobs. Product Eng. 38:80-83, February 13, 1967.

White, A. Production of optical elements. British Patent No. 618,787, July 16, 1946.

Whitney, D. B. Method of making plastic lenses. U.S. Patent No. 3,109,696, November 5, 1963.

______________. Why Safety Glasses? National Society for the Prevention of Blindness, New York, 1965.

Wichterle, O. Cross-linked hydrophilic polymers and articles made therefrom. U.S. Patent No. 3,220,960, November 30, 1965.

Williams, R. L. et al. Ballistic studies in eye protection. American J. of Ophth., 58:453-464, 1964.

Williams, W. E. Making dies for plastic lenses. U.S. Patent No. 2,206,797, July 2, 1940.

Winkler, S. Embedding and preserving specimens in transparent acrylic. Dental Digest 75:188-192, May 1969.

Winter-Gesellschaft fur Optik und Augenschutz M.B.H. Improvements pertaining to protective lenses of plastic material for skiers, welders, and others. French Patent No. 1.386.827.

Wynne, C.G. and Wormell, P.M.J.H. Lens design by computer. Applied Optics, 2:1233-1238, 1963.

Young, A.W. Abrasive machining gets more muscle. Iron Age, 197:112, May 26, 1966.

Zorab, E.C. Acrylic lens tragedies. Transactions of the Ophthalmological Society of the United Kingdom, 82:705-707, 1962.

APPENDIX II

LIST OF SUPPLIERS AND MANUFACTURERS CONTACTED

AAA Plastics Equipment, Inc.
W. Berry Street
Fort Worth, Texas 76109

ABA Tool & Die Co., Inc.
Tolland Tpk.
Manchester, Conn. 06043

Asfalti Bitumi Cementi Derivati,
A. p. A.
Via Lombardia 31
Rome, Italy

ADM Chemicals
Archer Daniels Midland Co.
733 Marquette Avenue
Minneapolis, Minn. 55440

A-1 Tool Corporation
1425 Armitage Avenue
Melrose Park, Illinois 60160

A & S Corporation
10 Summit Road
Verona, New Jersey 07044

Aard Plastics, Incorporated
169-175 Linwood Avenue
Paterson, New Jersey 07502

Abbey Plastics Corporation
420 Main Street
Hudson, Massachusetts 01749

Abbott Machinery Division
Dynamics Corp. of America
888 No. Keyser Avenue
Scranton, Pennsylvania 18501

Ace Tool & Manufacturing Co.
532 Mulberry Street
Newark, New Jersey 07114

Acer Industrial Coatings, Inc.
P. O. Box 215
Cockeysville, Maryland 21031

Adamson United Company
730 Carroll Street
Akron, Ohio 44304

Adhesive Engineering Co.
1411 Industrial Road
San Carlos, California 94070

Advance Division
Carlisle Chemical Works, Inc.
500 Jersey Avenue
New Brunswick, New Jersey 08903

Airam, Incorporated
7832 Balboa Boulevard
Van Nuys, California 91406

Airco Chemical Division
Air Reduction Co., Inc.
150 E. 42nd Street
New York, New York 10018

Akromold, Incorporated
1100 Main Street
Cuyahoga Falls, Ohio 44221

Akron Presform Mold Co.
2038 Main Street
Cuyahoga Falls, Ohio 44221

Alan Plastics Corporation
35 Pequit Street
Canton, Mass. 02021

Alcolac Chemical Corporation
3440 Fairfild Road
Baltimore, Md. 21226

Alliance Mold Co., Inc.
1300 Mt. Read Blvd.
Rochester, New York 14606

Allied Chemical Corporation
61 Broadway
New York, New York 10006

Allied Chemical Corporation
General Chemical Division
P. O. Box 70
Morristown, New Jersey 07960

Allied Chemical Corporation
Plastics Division
P. O. Box 365
Morristown, New Jersey 07960

Allied Resins, Inc.
Jackson and Whitney Streets
Conneaut, Ohio 44030

Alpha Chemical & Plastic Corp.
1 Jabez Street
Newark, New Jersey

American Chemical Corporation
P. O. Box 9247P
Long Beach, California 90810

American Cyanamid Company
Organic Chemicals Division
Bound Brook, New Jersey 08805

American Cyanamid Company
Plastics & Resins Division
S. Cherry Street
Wallingford, Conn. 06492

American Durafilm Co., Inc.
2300 Washington Street
Newton Lower Falls, Mass. 02162

American Instrument Co., Inc.
8030 Georgia Avenue
Silver Springs, Md. 20910

American Optical Company
14 Mechanic Street
Southbridge, Mass. 01550

American Polymers, Inc.
144 Linwood Avenue
Paterson, New Jersey 07502

American Pyroxylin Corp.
P. O. Box 193
Arlington, New Jersey 07032

American Resin Corporation
3215 N. Sheffield Avenue
Chicago, Illinois 60657

American Rotary Tools Co., Inc.
159 Great Neck Road
Great Neck, New York 11021

Aparco Company
P. O. Box 888
Buffalo, New York 14240

Applied Plastics Co., Inc.
130 Penn Street
El Segundo, California 90246

Applied Research and Development Corp.
210 E. Columbia Street
Chippewa Falls, Wisconsin 54729

Aquitaine-Organico
16 Rue d'Artois
Paris 8, France

Arbonite Corporation
900 N. Main Street
Doylestown, Pa. 18901

Argus Chemical Corporation
633 Court Street
Brooklyn, New York 11231

Amorlite Lens Co., Inc.
272 Main Street
Burbank, California 91506

Armour Coated Products & Adhesives Co.
74 Paterson Avenue
E. Rutherford, New Jersey 07073

Armstrong Products Co., Inc.
P. O. Box 657
Warsaw, Indiana 46580

Artag Plastics Corporation
2853 W. Irving Park Road
Chicago, Illinois 60618

Artistic Engraving Co., Inc.
364 Glenwood Avenue
E. Orange, New Jersey 07017

Atlas Hydraulics, Inc.
3576 Ruth Street
Philadelphia, Pa. 19134

Atlas Minerals & Chemicals Div.
The Electric Storage Battery Co.
151 Ash Street
Mertztown, Pa. 19539

Atlas Plastics, Inc.
681 Seneca Street
Buffalo, New York 14210

Atlas Vac-Machine Division
Koehler-Dayton, Incorporated
401 Leo Street
Dayton, Ohio 45404

Atols Tool & Mold Corporation
3828 N. River Road
Schiller Park, Illinois 60176

Auburn Plastics, Incorporated
Auburn, New York 13021

Auto-Vac Company
Division of Plast-O-Craft, Inc.
391 Mulberry Street
Newark, New Jersey 07102

Avisun Corporation
21 S. Twelfth Street
Philadelphia, Pa. 19107

Axel Plastics Research
Laboratories, Incorporated
41-14 29th Street
Long Island City, New York 11101

Bacon Industries, Inc.
192 Pleasant Street
Watertown, Mass. 02172

Badische Analin & Soda Fabrik AG
67 Ludwigshafen
Rhein, Germany

Baird Dynamic Co.
Division of Searchway, Inc.
686 Bostwick Avenue
Bridgeport, Conn. 06605

Baker Brothers, Inc.
P. O. Box 101, Sta. "F"
Toledo, Ohio 43610

Baker Castor Oil Co.
40 Avenue "A"
Bayonne, New Jersey 07002

Baker, J. T., Chemical Co.
N. Broad Street
Phillipsburg, New Jersey 08865

Battenfield Corp. of America
7301 N. Monticello Avenue
Skokie, Illinois 60076

Bausch & Lomb, Incorporated
635 St. Paul Street
Rochester, New York 14602

Beacon Die-Mold, Inc.
57 Crooks Avenue
Clifton, New Jersey 07011

Bean Fiber Glass, Inc.
59 Peterboro Street
Jaffrey, New Hampshire 03452

Becker & van Heulien
Niederrheinische Maschinenfabrik
Untergath 100
Kreteld, Germany

Beckman Instruments, Inc.
2500 Harbor Boulevard
Fullerton, California 92634

Belding Chemical Industries
1407 Broadway
New York, New York 10018

Beloit Eastern Corporation
Plastic Machinery Division
Washington & Greene Streets
Downington, Pa. 19335

Benson Optical Co.
Medical Arts Building
835 Nicclliet Avenue
Minneapolis, Minn. 55402

Bermer Tool & Die, Inc.
Golt Street
Southbridge, Mass. 01550

Berton Plastics, Inc.
170 Wesley Street
S. Hackensack, N. J.

Best Quality Plastics, Inc.
4305 Oneida Street
Denver, Colorado 80216

Biggs, Carl H., Co., Inc.
1547 - 14th Street
Santa Monica, Calif. 90404

Bipel International, Inc.
22 Nutmeg Drive
Trumbull, Conn. 06611

Bishop Mfg. Corporation
10 Canfield Road
Cedar Grove, N. J. 07009

Biwax Corporation
45 E. Bradrock Drive
Des Plaines, Ill. 60016

Blane Chemical Corp.
N. Main Street
Mansfield, Mass. 02048

Bondy Engineering Co.
172 S. Portland Avenue
Brooklyn, N. Y. 11217

Bontec Corporation
750 Canal Street
Stamford, Conn. 06902

Borden Chemical Co.
Division of The Borden Co.
350 Madison Avenue
New York, New York 10017

Brand Plastics Company
130 E. Randolph Drive
Chicago, Illinois 60601

British Industrial Plastics, Ltd.
Popes Lane
Oldbury, Birmingham, England

Brown Machine Co. of
Michigan, Incorporated
110 Pearson
Beaverton, Mich. 48612

Buhler Brothers
Uzwil-SG, Switzerland

Byrd Tool & Mold Corporation
2953 W. Twelfth Street
Erie, Pa. 16505

CIBA Products Company
Division of CIBA Corporation
556 Morris Avenue
Summit, New Jersey 07901

Canadian Industries, Ltd.
630 Dorchester Boulevard
W. Montreal, Que., Canada

Cardinal Chemical Company
RFD 4, P. O. Box 779
Columbia, S. C. 45239

Carlisle Chemical Works, Inc.
West Street
Reading, Ohio 45215

Carson Tool & Mold Company
431 S. Four Lane Highway
Marietta, Georgia 30062

Carver, Fred S., Inc.
5 Chatham Road
Summit, New Jersey 07901

Catalin Corporation
Division of Ashland Oil & Refining Co.
1 Park Avenue
New York, New York 10016

Celanese Coatings Company
Resins & Chemicals Division
224 E. Broadway
Louisville, Kentucky 40201

Celanese Plastics Company
550 Broad Street
Newark, New Jersey 07102

Center-Line Machinery
14772 Collins Avenue
Orange, California 92669

Central Scientific Company
1700 Irving Park Road
Chicago, Illinois 60613

Chemical Automation Corp.
29 Burbury Lane
Great Neck, N.Y. 11023

Chemical Coatins & Engineering
Company
221 Brook Street
Media, Pennsylvania 19063

Chemical Development Corp.
Endicott Street
Danvers, Mass. 01923

Chemical Industries
75 N. Beacon Place
Pasadena, California 91107

Chemische Werke Huls AG
MarlKries
Recklinghausen, Germany

Chemore Corporation
100 E. 42nd Street
New York, New York 10017

Chemstrand Corporation
350 Fifth Avenue
New York, New York 10001

Chevron Chemical Company
200 Bush Street
San Francisco, Calif. 94120

Chicago Mold Engineering Co., Inc.
4141 Washington Boulevard
Hillside, Illinois 60162

Cincinnati Development &
Manufacturing Company
5614 Wooster Pike
Cincinnati, Ohio 45227

Clifton Hydraulic Press Co.
293 Allwood Road
Clifton, N. Jersey

Clinton Company
7701 W. 47th Street
Lyons, Illinois

Colab Resin Corporation
Main Street
Tewksbury, Mass. 01876

Collins, Caldwell & Dague, Inc.
16616 Garfield Avenue
Paramount, California 90723

Columbia Technical Corporation
24-30 Brooklyn-Queens Expressway
W. Woodside, New York 11377

Columbian Carbon Company
Plastics Division
380 Madison Avenue
New York, New York 10017

Comet Industries, Inc.
1320 N. York Road
Bensenville, Illinois 60106

Commercial Resins Division
Interplastic Corporation
2015 NE Broadway Street
Minneapolis, Minnesota 55413

Commercial Solvents Corp.
260 Madison Avenue
New York, New York 10016

Conap, Incorporated
184 E. Union Street
Allegany, New York 14706

Conneaut Rubber & Plastics Co.
U. S. Stoneware Co.
Chamberlain Boulevard
Conneaut, Ohio 44030

Consolidated Models, Inc.
P. O. Box 336
Cranbury, New Jersey 08512

Cook Paint & Varnish Co.
P. O. Box 389
Kansas City, Mo. 64141

Cosden Oil & Chemical Co.
P. O. Box 1331
Big Springs, Texas 79720

Cosmic Plastics, Inc.
12314 Gladstone Avenue
San Francisco, California

Cosmosplastics, s.r.l.
Galleria Buenos Aires 11
Milano, Italy

Covema, s.r.l.
Via Fontano 1
Milan, Italy

Coz Chemical Corp.
Providence Road
Northbridge, Mass.

Cumberland Chemical Corp.
Subsidiary of Air Reduction Co., Inc.
PVC Division
150 E. 42nd Street
New York, New York 10017

Cuming, M. A., Co.
49 Bleecker Street
New York, New York 10012

Cylke's Injection Mold Co.
Route 1, Canton Highway
Woodstock, Ga. 30188

D-M-E Corporation
6686 E. McNichols Road
Detroit, Michigan 48212

Dake Corporation
641 Robbins Road
Grand Haven, Michigan 49417

Damascus Tool Company
P. O. Box 422
Union, New Jersey 07083

Damen Tool & Engineering Co., Inc.
4621 N. Olcott Avenue
Chicago, Illinois 60656

Danley Machine Specialties, Inc.
2100 S. Laramie Avenue
Chicago, Illinois 60650

Delta Molds, Inc.
1021 Paulison Street
Clifton, New Jersey 07011

Dennis Chemical Co.
2701 Papin Street
St. Louis, Mo. 63103

Design Center, Incorporated
5-26 46th Avenue
Long Island City, New York 11101

Devcon Corporation
Endicott Street
Danvers, Massachusetts 01923

Di-Acro
Division of Houdaille Industries, Inc.
578 Eighth Avenue
Lake City, Minnesota 55041

Diamond Shamrock Company
300 Union Commerce Building
Cleveland, Ohio 44115

Diemolding Corporation
125 Basbach Street
Canastota, New York

Dolph, John C., Company
New Road
Monmouth Junction, N. J. 08852

Dow Chemical Company
Midland, Michigan 48640

Dow Corning Corporation
S. Saginaw Road
Midland, Michigan 48640

Dunning & Boschert Press Co., Inc.
329 W. Water Street
Syracuse, New York 13202

Du Pont de Nemours, E. I. & Co., Inc.
1007 Market Street
Wilmington, Delaware 19898

Durez Plastics Division
Hooker Chemical Corporation
277 Walck Road
N. Tonawanda, N. Y. 14121

Dusal Machine Division
Dusal Tool & Mold Co., Inc.
130 Finn Court
Farmingdale, N. Y. 11735

Easco-Sparcatron, Inc.
100 Morgan Road
Ann Arbor, Michigan 48104

East Coast Chemicals Co.
417 Main Street
Little Falls, New Jersey 07424

Eastman Chemical Products, Inc.
Subsidiary of Eastman Kodak Co.
Kingsport, Tenn. 37662

Efficient Industries Corporation
9314 Elizabeth Avenue
Cleveland, Ohio 44105

Electroformex Laboratories
600 Fisher Street
Franklin, Mass. 02038

Electroforms, Incorporated
239 E. Gardena Boulevard
Gardena, California

Electromold Corporation
140 Enterprise Avenue
Trenton, New Jersey 08602

Electronic Space Structures Corp.
Old Power Mill Road
E. Concord, Mass. 01781

El-Tronics, Inc.
Electronic Products Div.
11 S. Irvine Street
Warren, Pa. 16365

Emerson & Cuming, Inc.
869 Washington Street
Canton, Mass. 02021

Emery Co., Inc.
11411 Bradley Avenue
Pacoima, Calif. 91331

Enjay Chemical Company
60 W. 49th Street
New York, N. Y. 10020

Epoxy Products Co.
Division, Allied Products Corp.
119 Coit Street
Irvington, New Jersey 07111

Epoxylite Corporation
1428 N. Tyler Avenue
S El Monte, Calif. 91733

Erie Engine & Manufacturing Co.
953 E. Twelfth Street
Erie, Pa. 16512

Erie Foundry Company
1253 W. Twelvth Street
Erie, Pa. 16512

Escambia Chemical Corp.
261 Madison Avenue
New York, New York 10016

Ethyl Corp.
100 Park Avenue
New York, New York 10017

Ethyl Corporation
Polymers Division
P. O. Box 1466
Baton Rouge, La. 70821

Euclid Engineering Co.
105 E. "A" Street
Upland, California

Excel Mold, Inc.
939 E. Troy Avenue
Indianapolis, Indiana 46203

FMC Corporation
Organic Chemicals Division
633 Third Avenue
New York, New York 10017

Fabrite Metals Corp.
205 E. 42nd Street
New York, New York 10017

Farrel Corporation
25 Main Street
Ansonia, Conn. 06401

Farrell Corporation
Plastics Molding Machinery Div.
656 Blossom Road
Rochester, New York 14610

Fellows Gear Shaper Company
78 River Street
Springfield, Vt. 05156

Fenwall, Inc.
400 Main Street
Ashland, Mass. 01721

Ferracute Machine Co.
E. Commerce St.
Bridgeton, N. J. 08302

Ferro Corporation
Cordo Division
34 Smith Street
Norwalk, Conn. 06852

Ferro Corporation
Ferro Chemical Division
7050 Krick Road
Bedford, Ohio 44014

Fiberfil, Incorporated
170[illegible] N. Heidelbach Ave.
Evansville, Indiana 47717

Fiberite Corporation
513 W. Fourth Street
Winona, Minnesita 55987

Firestone Plastics Co.
Div. Firestone Tire & Rubber Co.
P. O. Box 699
Pottstown, Pa. 19464

Fjellman American, Inc.
105 Republic Avenue
Joliet, Illinois 60435

Flexible Products Company
P. O. Box 996
Marietta, Georgia 30060

Flexcraft Industries
527 Avenue "P"
Newark, N. J. 07105

Fluorocarbon Company
1754 S. Clementine Street
Anaheim, California 92802

Ford Motor Company
Paint & Chemical Products Plant
151 Lafayette Street
Mount Clemens, Michigan 48044

Foster Grant Company, Inc.
289 N. Main Street
Leominster, Mass. 01453

France Campbell & Darling, Inc.
Kenilworth, New Jersey 07033

Franklin Fibre-Lamitex Corp.
903 E. 13th Street
Wilmington, Delaware 19899

Freeman Chemical Corporation
Division, H. H. Robertson Co.
222 E. Main Street
Port Washington, Wisc. 53074

French Oil Mill Machinery Co.
1035 W. Greene Street
Piqua, Ohio 45356

Furane Plastics, Inc.
4516 Brazil Street
Los Angeles, California 90039

Fusecolor Corporation
270 Lincoln Boulevard
Middlesex, New Jersey 08846

Future Chemicals Group of Mfg. Cos.
2849 Montrose Avenue
Chicago, Illinois

G. B. F. Costruzioni Meccaniche S. p. a.
Via Vittorio Veneto 12, Bresso
Milano, Italy

GLUCO
P. O. Box 315
Monroeville, Pa. 15146

Garden State Chemical Co.
P. O. Box 97
Morris Plains, N. J. 07950

Gardner Laboratory, Inc.
5523 Landy Lane
Bethesda, Md. 20014

Garfield Manufacturing Co.
P. O. Box 59
Garfield, New Jersey 07026

Geigy Industrial Chemicals
Saw Mill River Road
Ardsley, New York 10502

General Aniline & Film Corp.
140 W. 51st Street
New York, N. Y. 10020

General Electric Company
Chemical Materials Dept.
1 Plastics Avenue
Pittsfield, Mass. 01201

General Electric Company
Insulating Materials Dept.
1 Campbell Road
Schenectady, N. Y. 12306

General Electric Company
Silicone Products Dept.
Waterford-Mechanicsville Rd.
Waterford, N. Y. 12188

General Mills, Inc.
Chemical Division
S. Kensington Road
Kankakee, Ill. 60901

General Plastics Corp.
55 La France Avenue
Bloomfield, New Jersey 07003

George, P. D., Company
5200 N. Second Street
St. Louis, Mo. 63147

Glastic Corporation
4321 Glenridge Road
Cleveland, Ohio 44121

Goodrich, B. F., Chemical Co.
3135 Euclid Avenue
Cleveland, Ohio 44115

Goodyear Tire & Rubber Co.
Chemical Division
1144 E. Market Street
Akron, Ohio 44316

Goren, H. L., Co.
1514 Van Buren Street
Chicago, Illinois 60607

Gougler, G. L., Machine Co.
705-69 Lake Street
Kent, Ohio 44240

Grat, John C., Co.
501 Central Avenue
Cheltenham, Pa. 19012

Great American Plastics Co.
650 Water Street
Fitchburg, Mass. 01420

Guardian Chemical Corporation
41-45 Crescent Street
Long Island, New York 11101

Gulf Oil Corporation
Plastics Division, Chemicals Dept.
Dwight Building
Kansas City, Mo. 64105

HPM, Division Koehring Co.
Marion Road
Mt. Gilead, Ohio 43338

Hammond Plastics, Inc.
88 Webster Street
Worchester, Mass. 01603

Hardman, H. V., Co., Inc.
575 Cortlandt Street
Belleville, New Jersey 07109

Harwick Standard Chemical Co.
60 S. Seiberling Street
Akron, Ohio 44305

Hastings Plastics, Inc.
1704 Colorado Avenue
Santa Monica, Calif. 90404

Hedrix, Frank, Mold Maker
14908 Verdura Road
Paramount, California 90723

Hercules, Inc.
910 Market Street
Wilmington, Delaware 19899

Herculite Protective Fabrics
661 Fourth Street
Newark, New Jersey 07107

High Strength Plastics Corp.
1401-17 W. Jackson Boulevard
Chicago, Illinois 60607

Hightemp Resins, Inc.
225 Greenwich Avenue
Stamford, Conn. 06902

Holland, M., Company
111 W. Lake Street
Northlake, Illinois 60164

Hoover Ball & Bearing Co.
Subsidiary of Quinn-Berry Corp.
2609 - 17 W. Twelfth St.
Erie, Pa. 48106

House of Vision
135 North Wabash
Chicago, Ill. 60602

Houston Plastic Products, Inc.
13026 Rosecrest Street
Houston, Texas 77035

Howell Industries, Inc.
494 Farnham Avenue
Lodi, New Jersey 07644

Hull Corporation
5001 Davisville Road
Hatboro, Pennsylvania 19040

Hunter Associates Laboratory, Inc.
9529 Lee Highway
Fairfax, Va. 22030

Husky Mfg. & Tool Works, Ltd.
200 Bentworth Avenue
Toronto 19, Ontario, Canada

Hysol Corporation
1100 Seneca Avenue
Olean, New York 14761

ICI - Organics, Inc.
55 Canal Street
Providence, Rhode Island 02901

Imperial Chemical & Plastics Corp.
Mill Street
Cranston, Rhode Island 02905

Improved Machinery, Inc.
150 Burke Street
Nashua, New Hampshire 03060

Incoplas Corporation
674 Pennsylvania Avenue
Elizabeth, New Jersey 07201

Industrial Coatings Company
Derry Court, RFD 5
York, Pennsylvania 17402

Industrial Engineering Service
703 Washington Street
S. Easton, Mass. 02375

Industrial Vinyls, Inc.
3310 NW 30th Street
Miami, Florida 33152

Instrument Development Laboratories
67 Mechanic Street
Attleboro, Mass. 02703

Interchemical Corp.
Finishes Division
1255 Broad Street
Clifton, New Jersey 07015

International Coatings Co.
1441 W. El Segundo Blvd.
Compton, California 90222

Ionac Chemical Co.
Div. Ritter Pfaudler Corp.
Birmingham Road
Birmingham, New Jersey 08011

Isochem Resins Co.
Cook Street
Lincoln, Rhode Island 02865

Jay, T. V., Co., Inc.
1771 Sunnyside Avenue
Chicago, Illinois 60640

Jedco Chemical Corp.
601 MacQuesten Parkway N.
Mt. Vernon, N. Y. 10552

Kard Manufacturing Co, Inc.
5312 Valley Boulevard
Los Angeles, California 90032

Karlton Machinery Corp.
200 E. Ontario St.
Chicago, Illinois 60611

Kawaguchi Iron Works, Ltd.
928 Sodeshi-cho, Shimizu
Shizuoka, Japan

Kelm, G. R., Machine Works
347 E. Railway Avenue
Paterson, N. J. 07503

Kessler Products Co., Inc.
302 McClurg Road
Youngstown, Ohio 44501

Key Polymer Corp.
275 Lowell Street
Lawrence, Mass. 01842

Klenk Epoxy Corporation
9141 E. Jefferson
Detroit, Michigan 48214

Knapp, Fred, Engraving Co., Inc.
5102 Douglas Avenue
Racine, Wisconsin 53402

Knoedler Chemical Company
651 High Street
Lancaster, Pennsylvania

Koppers Co., Inc.
Tar & Chemical Division
1350 Koppers Bldg.
Pittsburgh, Pa. 15219

Kristal Kraft, Inc.
900 Fourth Street
Palmetto, Florida 33561

Kroll Equipment Co.
1623 Milwaukee Avenue
Chicago, Ill. 60647

Kunst, John, Co.
41 Murry Street
New York, N. Y. 10007

Kureha Chemical Industry Co., Ltd.
1-8 Nihobashi Horidome-cho
Cho-ku, Tokyo, Japan

Lakeside Plastics Corp.
3325 N. Shore Drive
Oshkosh, Wisconsin 54901

Lami-Plast Products Co.
7116 N. Habana Avenue
Tampa Florida 33604

Lawton, C. A., Co.
233 N. Broadway
De Pere, Wisconsin

Leal Company
1716 S. Sixth Street
Camden, New Jersey 08104

Leepoxy Plastics, Inc.
Ferguson Road, Baer Field
Fort Wayne, Indiana 46809

Leominster Tool Co., Inc.
272 Whitney Street
Leominster, Mass. 01453

Lester Engineering Co.
2711 Church Avenue
Cleveland, Ohio 44113

Lewis Welding & Engineering Corp.
113 St. Clair Avenue NE
Cleveland, Ohio 44114

Liberty Engineering & Mfg. Co.
1417 W. Ormsby Avenue
Louisville, Kentucky

Liberty Mold & Duplicating Co.
80 Fadem Road
Springfield, New Jersey 07081

Liberty Optical Manufacturing Co., Inc
380 Verona Avenue
Newark, New Jersey 07104

Lite-Kote Plastic Corp.
4488 W. 160th St. & Puritas Ave.
Cleveland, Ohio 44135

Liquid Nitrogen Processing Corp.
415 King Street
Malvern, Pa. 19355

Logan Engineering Co.
Hydraulics Division
4901 W. Lawrence Avenue
Chicago, Ill. 60630

Lombard Industries, Inc.
300 Main Street
Ashland, Mass. 01721

Lorben Corporation
3333 Lawson Boulevard
Oceanside, New York 11572

Luther Mfg. Co., Inc.
J & H Building
Olean, New York

Luzerne Rubber Company
Subsidiary, Beisinger Industries, Ltd.
Muirhead Street
Trenton, New Jersey 08607

M & N Modern Hydraulic Press Co., Inc.
P. O. Box 504
Clifton, New Jersey 07012

M & T Chemicals, Inc.
Woodbridge Avenue
Rahway, New Jersey 07065

Maclin Company
67-6800 Stanford Avenue
Los Angeles, California 90001

Madison Plastic & Mold Co., Inc.
245 Gotzian Road
Madison College, Tenn.

Magnolia Plastics, Inc.
5547 Peachtree Industrial Blvd.
Chamblee, Georgia 30005

Mallinkrodt Chemical Works
3200 N. Second Street
St. Louis, Mo. 63160

Manco Products, Inc.
2401 Schaefer Road
Melvindale, Michigan 48122

Many, J., & Company
153 Lafayette Street
New York, New York 10013

Marblette Corp., The
37-31 30th Street
Long Island City, New York 11101

Marbon Chemical Division
Borg-Warner Corporation
P. O. Box 68
Washington, W. Va. 26101

Marco Chemical Division
W. R. Grace & Company
1711 W. Elizabeth Avenue
Linden, New Jersey

Marine Optical Manufacturing Co.
28 Mahler
Jamaica Plains, Mass. 02130

Marks Polaroid Corporation
Whitestone, Station
Flushing, New York 11357

Marland Mold Co., Inc.
Subsidiary, Greylock Plastics, Inc.
125 Pecks Road
Pittsfield, Mass.

Melamine Plastics, Inc.
Division of Fiberite Corporation
512-28 W. Fourth Street
Winona, Minnesota 55987

Merix Chemical Company
2234 E. 75th Street
Chicago, Illinois 60649

Metachem Resins Corporation
Mereco Products Corp. Div.
539 Wellington Avenue
Cranston, R. I. 02910

Metalead Products Corporation
2901 Park Boulevard
Palo Alto, California 94306

Middlesex Tool & Machine Co.
1157 Globe Avenue
Mountainside, New Jersey 07092

Midland Die & Engraving Co.
502 Factory Road
Addison, Illinois

Miles, A. L., Fiberglass &
Plastic Supply
4060 Wyne Street
Houston, Texas 77017

Miller-Stephenson Chemical Co., Inc.
16 Sugar Hollow Road
Danbury, Conn. 06813

Millmaster Onyx Corporation
99 Park Avenue
New York, New York 10016

Minnesota Mining & Mfg. Co.,
2501 Hudson Road
St. Paul, Minnesota 55119

Mitchell Rand Mfg. Corp.
Torne Valley Road
Hillburn, N. Y. 10931

Mitsubishi Rayon Co., Ltd.
8, 2-chome, Kyobashi,
Chu-ku-Tokyo, Japan

Mobay Chemical Co.
Penn Lincoln Pkwy, W.
Pittsburgh, Pa. 15205

Modern Tool & Die Co., Inc.
125 Tolman Avenue
Leominster, Mass. 01453

Mol-Rez Division
Americal Petrochemical Corp.
3134 California Street NE
Minneapolis, Minnesota 55418

Monsanto Company
800 N. Lindbergh Boulevard
St. Louis, Mo. 63166

Moore Chemical Corp.
Whitehorn Way & Kemp Road
Burlingame, California 94010

Morton Chemical Co.
110 N. Wacker Drive
Chicago, Illinois 60606

Moslo Machinery Company
20120 Detroit Road
Cleveland, Ohio 44116

Munray Products Division
Fanner Manufacturing Company
12400 Crossburn Avenue SW
Cleveland, Ohio 44135

NRM Corporation
47 W. Exchange Street
Akron, Ohio 44308

Nattone, Incorporated
425 Park Avenue
New York, New York 10022

National Coating, Inc.
P. O. Box 223
W. Hanover, Mass. 02380

National Lead Company
111 Broadway
New York, New York 10006

National Polychemicals, Inc.
Eames Street
Wilmington, Mass. 01887

National Starch & Chemical Corp.
750 Third Avenue
New York, New York 10017

National Tool & Mfg. Co.
100 N. Twelfth Street
Kenilworth, N. J. 07033

National Vacuum Platers, Inc.
2635 E. Hagert Street
Philadelphia, Pa. 19125

New Britain Machine Co.
307 South Street
New Britain, Conn. 06050

New England Butt Company
Division, Wanskuck Company
304 Pearl Street
Providence, Rhode Island

Newark Die Company
24 Scott Street
Newark, New Jersey

Newbury Industries, Inc.
10975 Kinsman Road
Newbury, Ohio 44065

Nissei Plastics Industrial Co. Ltd.
Sakaki, Hanishina
Nagano-Ken, Japan

Nonweiler, A. P., Co.
P. O. Box 1007
Oshkosh, Wisconsin 54902

Nopco Chemical Company
60 Park Place
Newark, New Jersey 07102

Nordberg Mfg. Company
Hydraulic Press Division
3073 S. Chase Avenue
Milwaukee, Wisconsin 53207

North American Machinery Corp.
60 E. 42nd Street
New York, New York 10017

Nypel Corporation
24 Union Hill Road, W.
Conshohocken, Pennsylvania

O. C. Adhesives Corporation
76 Fourth Street
Brooklyn, New York 11231

OKC Division
The Fenner Manufacturing Co.
Textron, Incorporated
900 N. Chapel Street
Louisville, Ohio

Oakley Die & Mfg. Company
4426 Brazee Street
Cincinnati, Ohio 45209

Ohio Sealer & Chemical Corp.
3060 E. River Road
Dayton, Ohio 45439

Ohnuma Seisakusho Mfg. Co., Ltd.
24-1, 5 Chome, Ohmori-nishi,
Ohta-ku, Tokyo, Japan

Omni Division
C. Tennant, Sons & Co. of New York
100 Park Avenue
New York, New York 10017

Orbit of California
211 Los Molinos
San Clemente, California 92672

Osley & Whitney, Inc.
130 Southampton Road
Wesfield, Mass. 01085

PPG Industries
Coatings & Resins Division
1 Gateway Center
Pittsburgh, Pennsylvania 15222

Pacific Resins & Chemicals, Inc.
3400 - 13th Avenue SW
Seattle, Washington 98134

Packaging Industries
Airport Road
Hyannis, Massachusetts

Pantasote Company
277 Park Avenue
New York, New York 10017

Parcloid Chemical Company
140 Greenwood Avenue
Midland Park, New Jersey 07432

Parco Chemicals, Inc.
P. O. Box 99
Morris Plains, New Jersey 07950

Parr Molding Compounds Corp.
Canal & Ludlow Streets
Stamford, Connecticut 06092

Parsons, M. W., Plymouth Div.
S. B. Penick & Company
100 Church Street
New York, New York 10008

Pasadena Hydraulics, Inc.
1433 Lidcombe Avenue
El Monte, California 91733

Patent Button Company of Tenn.
2221 Century Street
Knoxville, Tennessee 37901

Pennsalt Chemicals Corporation
3 Penn Center
Philadelphia, Pennsylvania 19102

Pennsylvania Industrial
Chemical Corporation
120 State Street
Clairton, Pennsylvania 15025

Perfect Mold Company, Inc.
1500 N. Crooks Road
Clawson, Michigan 48017

Perkin-Elmer Corporation
807 Main Avenue
Norwalk, Conn. 06852

Pfizer, Chas., & Co., Inc.
Industrial Chemicals Div.
235 E. 42nd Street
New York, New York 10017

Pfizer, Chas., & Co., Inc.
Minerals, Pigments & Metals Div.
235 E. 42nd Street
New York, New York 10017

Phelan's Resins & Plastics Div.
Phelan-Faust Paint Mfg. Co.
Oak St. & Bluff Rd.
Burlington, Iowa 52602

Phillips Petroleum Company
Chemical Dept.
Industrial Products Division
Bartlesville, Oklahoma 74003

Pittsburgh Plate Glass Co.
Coatings & Resins Division
1 Gateway Center
Pittsburgh, Pennsylvania 15222

Plamco
15518 S. Broadway
Gardena, California 90247

Plastic Electro-Finishing Corp.
1333 Flushing Avenue
Brooklyn, New York 11237

Plastic gineering & Mfg. Corp.
2800 S. lati Street
Englewood, Colorado 80110

Plastic Engineering & Sales Corp.
2628 St. Louis Street
Fort Worth, Texas 76101

Plastic Materials, Inc.
Subsidiary of Columbian Carbon Co., Inc.
New South Road
Hicksville, New York

Plastic Mold Tool & Die Co., Inc.
1 Maple Street
E. Rutherford, New Jersey 07073

Plastic Molding Powders, Inc.
487 Forest Street
Kearny, New Jersey

Plasti-Cast Mold & Products Co.
1430 Archwood Avenue
Akron, Ohio 44306

Plastics Development Corp.
145 Roswell Street
Smyrna, Georgia 30080

Plastics Engineering Company
1607 Geele Avenue
Sheboygan, Wisconsin 53081

Plastima GmbH
Postfach 586
4000 Dusseldorf-Oberkassel,
Germany

Plastimac s. r. l.
Piazzale Giulio Cesare 9
Milano, Italy

Plasti-Vac, Incorporated
526 W. Third Street
Charlotte, N. C. 28203

Plast-O-Craft, Incorporated
391 Mulberry Street
Newark, New Jersey 07102

Plastonics, Inc.
112 Prestige Park Road
E. Hartford, Conn. 06108

Plas-Tool Company
7430 N. Cronamic Road
Niles, Illinois 60648

Plating Engineering Co.
1928 S. 62nd Street
Milwaukee, Wisconsin 53219

Polaroid Corporation
549 Technology Square
Cambridge, Massachusetts 02139

Poly Resins
11655 Wicks Street
Sun Valley, California 91352

Polychrome Dispersions, Inc.
13429 S. Western Avenue
Gardena, California

Polymer Machinery Corporation
60 Woodlawn Road
Berlin, Connecticut

Polyrez Company, Inc.
S. Columbia Street
Woodbury, New Jersey 08096

Polytech Company
10423 Trenton Avenue
St. Louis, Missouri 63132

Polyvinyl Chemicals, Inc.
26 Howley Street
Peabody, Mass. 01960

Precision Products Co., Inc.
262 E. 16th Street
Paterson, New Jersey 07524

Premier Thermo Plastics Co.
3001 Middletown Road
Jeffersontown, Kentucky 40029

Primas Moldmakers, Inc.
T. C. Industrial Park
Depew, New York 14043

Princeton Chemical Research, Inc.
P. O. Box 652
Princeton, New Jersey 08540

Procter & Gamble
Industrial Soap & Chemical Products Div.
P. O. Box 599
Cincinnati, Ohio 45201

Progressive Tool & Die Company
Turnpike Road
Westboro, Massachusetts 01581

Prospect Mold & Die Company
1817 Front Street
Cuyahoga Falls, Ohio 44221

RC Division
Hooker Chemical Corporation
New South Road
Hicksville, New York 11802

Raybestos Manhattan, Inc.
123 Steigle Street
Manheim, Pennsylvania

Rector Engineering & Plastics Co.
318 Randolph Place NE
Washington, D. C. 20002

Ren Plastics, Incorporated
5656 S. Cedar Street
Lansing, Michigan 48909

Research Sales, Incorporated
P. O. Box 358
Suffern, New York 10901

Resinous Chemicals Corp.
1399 W. Blaneke Street
Linden, New Jersey 07036

Rezolin, Incorporated
1651 - 18th Street
Santa Monica, California 90404

Reichhold Chemicals, Inc.
525 N. Broadway
White Plains, New York 10602

Rheinstahl Henschel AG
Postfach 786
35 Kassel-2, Germany

Richardson Company
Insurok Division
2747 Lake Street
Melrose Park, Illinois 60160

Richardson Company
Polymers Division
345 Morgan Lane
W. Haven, Conn. 06516

Rochelle Plastic Mold Co., Inc.
35 Sebago Street
Clifton, New Jersey 07013

Rodgers Hydraulic, Inc.
Molding Press Division
7401 Walker Street
Minneapolis, Minnesota 55426

Roehlen Engraving Works
701 Jefferson Road
Rochester, New York 14623

Rogers Corporation
Rogers, Connecticut 06263

Rohm & Haas Company
Independence Mall W.
Philadelphia, Pa. 19105

Rubba, Incorporated
1015 E. 173rd Street
Bronx, New York 10460

Rudolph-Martin
Maschinen-und Formenbau
Industriestrasse 47
Velbert-Rhld, Germany

Rutgers Metals & Chemicals Co.
P. O. Box 164
New Brunswick, New Jersey

Rutland Plastics, Inc.
215 Foster Avenue
Charlotte, N. C. 28203

St. Lawrence Hydraulic Co., Inc.
2424 Beech Daly Road
Inkster, Michigan 48141

SamSon Molds, Inc.
1028 E. Edna Street
Covina, California 91722

Sarcol, Incorporated
3050 W. Taylor Street
Chicago, Illinois 60612

Sartomer Resins, Incorporated
P. O. Box 56
Essington, Pa. 19029

Saunders Engineering Corp.
4515 Alger Street
Los Angeles, California 90039

Schenectady Chemicals, Inc.
Congress & Tenth Street
Schenectady, New York 12301

7-K Color Corporation
927 N. Citrus Avenue
Hollywood, California 90038

Shamrock-Neatway Products, Inc.
1010 Lyndale Avenue N.
Minneapolis, Minnesota

Shaw, Francis, Ltd. (Canada)
1393 Grahams Lane
Burlington, Ontario, Canada

Shaw Industries, Inc.
RD 2, P. O. Box 591
Franklin, Pennsylvania 16323

Shell Chemical Company
50 W. 50th Street
New York, New York 10020

Shell Chemical Company
Industrial Chemical Division
110 W. 51st Street
New York, New York 10020

Shelmark Industries, Inc.
320 Fletcher Street
Columbus, Ohio 43215

Sherwin-Williams Company
Pigment, Color & Chemical Dept.
101 Prospect Avenue
Cleveland, Ohio 44101

Shin-Etsu Chemical Company
2, Marunouchi 1-chome
Chiyoda-ku, Tokyo, Japan

Shuron/Continental Company
40 Humboldt
Rochester, New York 14609

Silmar Chemical Corporation
Subsidiary of Standard Oil Co. of Ohio
12333 S. Van Ness Avenue
Hawthorne, California 90250

Sinclair Petrochemicals, Inc.
600 Fifth Avenue
New York, New York 10020

Smooth-On Manufacturing Co.
572 Communipaw Avenue
Jersey City, New Jersey 07304

Solar Chemical Corporation
34 Monument Square
Leominster, Massachusetts 01483

South Bend Lathe
400 W. Sample Street
South Bend, Indiana 46623

Spectrolab Division
Textron Industries
12484 Gladstone Avenue
Sylmar, California 91342

Spencer Kellogg Division
Textron, Incorporated
120 Delaware Avenue
Buffalo, New York 14240

Springfield Cast Products, Inc.
124 Switzer Avenue
Springfield, Mass. 01109

Stanchel Engineering Co.
5416 Cleon Street
North Hollywood, California

Standard Polymers, Inc.
1 Riverdale Avenue
Bronx, New York 10463

Standard Tool Company
217 Hamilton Street
Leominster, Mass. 01453

Stauffer Chemical Company
Plastics Division
299 Park Avenue
New York, New York

Steelcote Manufacturing Co.
3418 Gratiot Street
St. Louis, Missouri 63103

Steere Enterprises, Inc.
285 Commerce Street
Tallmadge, Ohio 44278

Sterling Extruder Corporation
1537 W. Elizabeth Avenue
Linden, New Jersey 07036

Sterling Varnish Company
Haysville Borough
Sewickley, Pennsylvania 15143

Stokes Equipment Division
Pennsalt Chemical Corporation
3 Penn Center
Philadelphia, Pennsylvania 19102

Stokes-Trenton, Incorporated
150 Enterprise Avenue
Trenton, New Jersey 08602

Stricker-Brunhuber Corporation
19 W. 24th Street
New York, New York 10010

Sun Chemical Corporation
Chemical Products Division
400 Old Dublin Pike
Doylestown, Pennsylvania 18901

Sun Chemical Corporation
Electro-Technical Products Div.
113 E. Centre Street
Nutley, New Jersey 07110

Sun Chemical Corporation
Specialty Chemicals Dept.
631 Central Avenue
Carlstadt, New Jersey

Swift & Company
Chemicals for Industry Dept.
115 W. Jackson Boulevard
Chicago, Illinois 60604

Symons, Ralph B., Assoc., Inc.
P. O. Box 37
Tiverton, Rhode Island 02878

Synco Resins
ADM Chemicals
Archer Daniels Midland Co.
30 Henry Street
Bethel, Connecticut 06801

Synthetic Products Company
1636 Wayside Road
Cleveland, Ohio 44112

Synvar Corporation
726 King Street
Wilmington, Delaware 19801

Tavannes Machines Company, S. A.
Rue Sandoz 2710
Tavannes, Switzerland

Tech Consolidated, Inc.
20 Dickey Street
Derry, New Hampshire 03038

Techform Laboratories, Inc.
707 W. Washington Boulevard
Venice, California 90291

Tenneco Chemicals, Inc.
Nuodex Division
1 Virginia Street
Elizabeth, New Jersey

Tenneco Chemicals, Inc.
Tenneco Plastics Division
Ryders Lane
East Brunswick, N. J. 08816

Testing Machines, Inc.
72 Jericho Turnpike
Mineola, New York 11501

Terrafluor Division
Amerco, Incorporated
343 Hindry Avenue
Inglewood, California 90301

Texas Chemical & Plastics Corp.
970 E. Maple
Birmingham, Michigan 48011

Thermoset Plastics, Inc.
5010 E. 65th Street
Indianapolis, Indiana 46220

Thermtrol Corporation
165 Holland Avenue
Bridgeport, Connecticut 06605

Thiokol Chemical Corporation
Chemical Division
780 N. Clinton Avenue
Trenton, New Jersey 08607

Thornbert, Incorporated
316 E. Seventh Street N.
Newton, Iowa 50208

Thompson Apex Company
505 Central Avenue
Pawtucket, R. I. 02862

Tilp, J. G., Inc.
80 Miltown Road
Union, New Jersey 07083

Titmus Optical Company
1015 Commerce
Petersburg, Va. 23803

Toyad Corporation
P. O. Box 30
Latrobe, Pennsylvania 15650

Tra-Con, Incorporated
25 Commercial Street
Medford, Mass. 02155

Trim Molded Products Corp.
Route 5, Box 25
Burlington, Wisconsin 53105

Triulzi, S. p. a.
Via Per Vialba 56
Novate Milanese, Italy

Tronomatic Corporation
25 Bruckner Boulevard
Bronx, New York 10454

Trueblood, Incorporated
516 N. Irwin Street
Dayton, Ohio 45403

Tylac Chemicals Division
International Latex & Chemical Corp.
Dover, Delaware 19901

Ube Industries, Ltd.
1976 Ogushi Ube-Shi
Yamaguchi-Ken, Japan

Union Carbide Corporation
Chemicals Division
270 Park Avenue
New York, New York 10017

Union Carbide Corporation
Plastics Division
270 Park Avenue
New York, New York 10017

Uniroyal, Incorporated
1230 Avenue of the Americas
New York, New York 10020

U. S. Industrial Chemical Co.
Division of National Distillers &
Chemical Corporation
99 Park Avenue
New York, New York 10016

United States Gypsum Company
101 S. Wacker Drive
Chicago, Illinois 60606

U. S. Industries, Inc.
Production Machine Division
6499 W. 65th Street
Chicago, Illinois 60638

United States Rubber Company
1230 Avenue of the Americas
New York, New York 10020

Universal Optical Company
23 Acorn
Providence, Rhode Island 02903

Universal Plastics Corporation
352 Harrison Street
Passaic, New Jersey 07056

Vacform Company
8 Lois Street
Norwalk, Connecticut 06851

Valite Division
Valentine Sugars, Inc.
726 Whitney Bldg.
New Orleans, Louisiana

Van Dorn Plastic Machinery Co.
2685 E. 79th
Cleveland, Ohio 44104

Vanderbilt, R. T., Co., Inc.
230 Park Avenue
New York, New York 10017

Vernon-Benshoff Co., Inc.
413 N. Pearl Street
Albany, New York 12201

Verson Allsteel Press Co.
1355 E. 93rd Street
Chicago, Illinois 60619

Vogt Manufacturing Corporation
100 Fernwood Avenue
Rochester,, New York 14621

Wabash Metal Products Co., Inc.
1569 Morris Street
Wabash, Indiana 46992

Ware Chemical Corporation
P. O. Box 783
Westport, Connecticut 06881

Western Coating Company
Stephenson Highway at 14-1/2
Mile Road
Royal Oak, Michigan 48073

Westwood Chemical Co., Inc.
801 Second Avenue
New York, New York 10017

Whitford Chemical Corporation
20 N. Matlack Street
W. Chester, Pennsylvania 19380

Wilco Company
4425 Bandini Boulevard
Los Angeles, California 90023

Williamson Adhesives, Inc.
8220 Kimball Avenue
Skokie, Illinois 60076

Williams-White & Co.
600 Third Avenue
Moline, Illinois 61265

Windsor, R.H., Ltd.
Leatherhead Road
Chessington, Surrey, England

Witco Chemical Company, Inc.
277 Park Avenue
New York, New York 10017

Woodmont Products, Inc.
County Line & New Road
Huntingdon Valley, Pennsylvania

Younger-Med Optics
3788 Broadway Place
Los Angeles, California 90007

Youngstown Vinyl Compounds, Inc.
4521 Lake Park Road
Youngstown, Ohio

Zack Radiant Heat Company
122 Fayette Avenue
Wayne, New Jersey 07470