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MANUFACTURING METHODS AND TECHNOLOGY (MM&T) PROJECT TO ESTABLIS--ETC(U)
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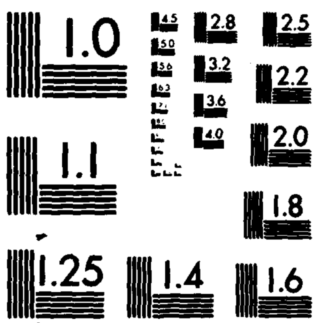

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SI ER-915

COMBINED EIGHTH AND NINTH
QUARTERLY REPORT

LEVEL III

(12)

MANUFACTURING METHODS AND TECHNOLOGY PROJECT TO ESTABLISH PRODUCTION TECHNIQUES TO MANUFACTURE RIGID ARMOR FOR RADAR ANTENNA HARDENING

A064395

REPORT PERIOD

1 OCTOBER 1979 TO 31 MARCH 1980

TECHNICAL SUPPORT DIRECTORATE
UNITED STATES ARMY ELECTRONICS
RESEARCH AND DEVELOPMENT COMMAND
FORT MONMOUTH, NEW JERSEY

PREPARED UNDER CONTRACT NO. DAAB07-77-C-0476

Approved for public release; distribution unlimited.

PREPARED BY

SWEDLOW, INC.

12122 Western Avenue, Garden Grove, California 92645

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(14) SI-ER-915-8/9

REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A091863
3. RECIPIENT'S CATALOG NUMBER	(9)
4. TITLE (and Subtitle)	(6) MANUFACTURING METHODS AND TECHNOLOGY (MM&T) PROJECT TO ESTABLISH PRODUCTION TECHNIQUES TO MANUFACTURE RIGID ARMOR FOR RADAR ANTENNA HARDENING
5. TYPE OF REPORT & PERIOD COVERED	[redacted] Quarterly Report no. 8/9, 1 Oct [redacted]79- [redacted] 31 Mar[redacted]80
6. PERFORMING ORG. REPORT NUMBER	
7. AUTHOR(s)	(10) G. Cook
8. CONTRACT OR GRANT NUMBER(s)	(15) Contract No. DAAB07-77-C-0476
9. PERFORMING ORGANIZATION NAME AND ADDRESS	SWEDLOW, INC. 12122 Western Avenue Garden Grove, Ca 92645
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	(11)
11. CONTROLLING OFFICE NAME AND ADDRESS	TECHNICAL SUPPORT DIRECTORATE U.S. ARMY ELECTRONICS RESEARCH & DEVELOPMENT CMD FORT MONMOUTH, NEW JERSEY
12. REPORT DATE	Mar[redacted]80
13. NUMBER OF PAGES	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	(12) 22
15. SECURITY CLASS. (of this report)	UNCLASSIFIED
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Armor
Panel
Polymeric
Radar Antenna Hardening

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

(See reverse side)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

402550

Block No. 20

ABSTRACT

Modification of contract was received September 1979 after a six month limited activity period due to depletion of the majority of the original funding. Limited activity period involved preparation of the seventh quarterly report and optimizing molding procedures and molding panels during the production demonstration for AMMRC.

Project continuation is based on a reduced effort to supply a limited number of Engineering and Confirmatory Samples and provide a Production Capability Demonstration. Pilot run has been eliminated.

The fabrication procedures will conform to the method of production demonstrated at Swedlow, Inc. to AMMRC personnel in May 1979.

This period included fabrication of Engineering Samples within the guideline established during the demonstration run in May, 1979.

Run data sheets were analyzed to determine process revisions required to assure replication of final thickness from panel to panel.

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CONTENTS

1.0 PURPOSE

The purpose of this program is to establish production techniques and production capabilities for the manufacture of armor panels. The armor panels are intended for use with flat radar antennae to provide protection from munitions fragments.

The armor panels will be flat molded sheets of various sizes and edge finishes. The sheets will be molded from cross-plied assemblies of unidirectionally oriented, blown film made from a dielectric grade polypropylene. A protective over-lay will be molded into the panel surfaces and camouflage will be incorporated in or onto a portion of the panels.

The program is divided into four tasks as described below:

Step 1 Engineering Samples

Two sets of two each panels will be produced in order to demonstrate the ballistic capabilities of the selected materials and processes.

Step 2 Confirmatory Samples

Ten sets of two each panels of various sizes, thicknesses, and camouflaging methods will be produced in order to demonstrate the total capabilities of the panels in regards to environmental stability, electronic transmission, and ballistic characteristics. In addition, camouflaging techniques and panel trim and edge fusing will be demonstrated.

Step 3 Pilot Run

Thirty-two sets of two each panels will be produced in order to demonstrate the capacity of each production step and verify the capability of the line to fabricate at an acceptable rate.

Step 4 Production Capability Demonstration

An in-plant demonstration will be held in order to show the production capabilities of the pilot production line to invited representatives of industry and government.

The first quarterly report described in detail the program objectives, tasks, and schedule.

2.0 INTRODUCTION

The following is a combined report for two quarterly periods from 31, September 1979 to 31, March 1980 and includes update during limited activity period.

Technical activity was limited due to program reactivation after extended downtime.

Engineering samples were fabricated and shipped this period. Panels were fabricated per the AMMRC demonstration procedure.

Bond tensile strength versus mid-point fusion temperature were studied.

Factors affecting final panel thickness were studied this period. Run sheet data from all previous moldings for this program and NRL panel production were tabulated in an effort to establish molding cycles which will assure replication of thickness from panel to panel.

Dimensional Stability Tests per 4.2.5 of PD-105 were run on finished panels of each thickness.

3.0 AMMRC PRODUCTION DEMONSTRATION

3.1 Preparation

A step by step fabrication procedure was prepared and reviewed by AMMRC personnel during the Production Demonstration runs (Table 1). A Run Control Document was also designed to include all material identification, assembly weight, and layup configuration. (Table 2). A Molding Record data sheet was also included to record all time, temperature, and pressure data for each run (Table 3).

These procedures were designed to incorporate maximum control at all critical process points and provide accurate documentation of cycle history.

Rapid cool-down from 350°F to 300°F was determined to be desirable to retain the amorphous structure of the polypropylene fraction which had melted to form the fusion bonding media.

After 300° platen temperature was attained during cool-down, the controlling factors would then be the temperature differential from panel face to face (maximum Δt_f of 5°F) and from panel faces to mid-point (maximum Δt_m of 10°F). The purpose for establishing these modest temperature differentials during cool-down was to reduce the thermal gradient and minimize the build-up of interply shear stresses which could cause panel delamination after removal from the press.

The mid-panel target temperature of 348° - 350°F was established to be the determining factor in total press cycle. To obtain this mid-point target temperature the platen temperature limits were established at 355°F. This temperature can cause excessive XP material flow (as determined by Prifti, etal, in the AMMRC study) however, it was found necessary in order to obtain the desired mid-panel temperatures.

3.2 Demonstration Run

The Demonstration Run consisted of a total of four molding cycles of one inch nominal thickness panels. Two cycles were under the direct supervision of Alesi and Prifti of AMMRC, with the two additional cycles used to verify the reliability of the established molding conditions.

The results of the Demonstration Run were very good. Replication of panel quality was consistant within the established conditions. During the trials however, it was determined that the best cool-down temperature differentials which could be achieved were 20°F for face to face and 90°F for face to mid-point. This extreme variation from from the desired ($\Delta t_f \leq 5°F$, $\Delta t_m \leq 10°F$) temperature differentials did not appear to effect panel quality. The only problems which persist are thickness control. Panel to panel thickness and variations within each panel are excessive. These problems are discussed in detail in the Problem Areas Section of this report.

4.0 CONTRACT REVISION

4.1 Rescheduling

The program objectives were not achieved within the originally scheduled time period due to the problems encountered in obtaining suitable oriented polypropylene. A major program rescheduling was approved on 12 September 1979.

4.2 Revised Scope of Work

The redefined program is covered in detail in the formal Modification of Contract. The basic changes are a reduction of the quantity of panels to be fabricated as Confirmatory Samples and deletion of the Pilot Run. The scope of the program regarding the technical effort has not been changed. The revised program includes, in brief, the following tasks:

Task #1 Engineering Samples

Mold three full sized panels of each thickness and submit the best two of each conduct required environmental testing.

Task #2 Confirmatory Samples

Mold six full sized panels of each thickness and submit the best four of each. Conduct all required environmental and electrical testing.

Task #3 Production Demonstration

Hold Production Capability Demonstration at Swedlow, Inc. facility in accordance with 1.2.13, 1.2.14 and 3.1.13 of ECIPPR #15, revised August, 1976.

5.0 N.R.L. PRODUCTION RUN

Five full sized panels were produced for N.R.L. this period. The panels were fabricated per the procedures established during the AMMRC supervised Demonstration Run. Minor adjustments were made in charge weight, cycle time, and temperature in an attempt to achieve replication of panel to panel thickness. This work was done under a different contract but is mentioned here and later as pertinent to selecting an optimum molding cycle.

6.0 ENGINEERING PANEL FABRICATION

Full size panels were molded in 1.160 inch and .375 inch thickness this period, with two of each submitted to AMMRC for ballistic testing.

One of each of the remaining panels in each thickness was tested for dimensional stability per 4.2.5 of PD 105.

7.0 PROBLEM AREAS

7.1 Thickness Control

Thickness control has been the most serious problem encountered during the lamination of the X-P armor panels. Variations within each panel have been up to .060 inches from high to low reading. Panel to panel average thickness has also been unpredictable.

7.1.1 Basic Molding Concept

In order to attempt to solve the thickness control problem, a review of the process theory and study of the data obtained from panel production is in order. The technique for fabricating uniaxially oriented polypropylene film plies into fragment resistant P-F transparent panels can best be described as a fusion process. Fusion bonding in this case requires the application of heat and pressure to melt a small fraction of each oriented film ply until an amorphorous matrix media is formed, then cooling under pressure to achieve a chemical and mechanical bond. Optimum fusion conditions will be when melt fraction is limited to sufficient material to produce a panel with a density equal to that of the base polymer. The processing technology which was developed by AMMRC and the processing refinements introduced during the course of this program, provide fusion conditions which result in slight variations in melt fraction levels. These variations in turn result in unpredictable replication of panel thickness from molding to molding.

7.1.2 Striation Pattern

The striation pattern observed at AMMRC and Swedlow, Inc. is discussed in the Seventh Quarterly Report. This theory explained why the central panel area of each X-P panel was thicker than the edges. Verification of this theory was obtained by pressing two half size panels on the same mold (SN052379) and measuring panel thickness variations. The central portion in each panel was thicker with variations of as much as .050 inch observed.

7.1.3 Check X-P Film For Purity

Differential Scanning Colorimeter melting point and Infra-red spectra studies were run on four samples of the production film plies to determine if the material was a polypropylene-polyethylene copolymer. Per Swedlow Evaluation Report EVR No. 95-79-014A (October 22, 1979) which was run on four separate film pads, the material was determined to be a polypropylene homopolymer. Five more samples were tested on December 17, 1979 with the same results. In both cases the unrestrained melting point of the oriented polypropylene film was determined to be from 325°F to 331°F (163°C to 166°C). This melting point range confirmed that the polypropylene film is isotactic with a high degree of crystallinity. It should be noted that the 325°F melting point of the unrestrained film is considerably below the 355°F maximum processing temperature used to fuse the armor panels. To understand why the required fusion temperature is so much higher than the melting point of the base polymer, a review of the morphology and order in crystalline polymers is discussed.

7.1.4 Crystalline Polymers and Physical Properties Relationship

In order to produce polypropylene with maximum physical properties, the configuration or molecular structure of the polymer must be highly ordered. The arrangement of the constituents of a molecule in space is called stereochemistry, and when the spatial relations of a polymer follow a predetermined pattern, it is called a stereospecific polymer. Generally, polymer chains can be grouped into either amorphous or crystal structures. The amorphous polymers are of a random sequence said to have an atactic configuration, whereas the crystalline polymers are spatially ordered with the configuration called syndiotactic or isotactic depending on the position of the substituent groups on the main chain. These ordered polymers are identified as stereospecific chains. Stereospecific polypropylene polymers range from syndiotactic to isotactic configurations with respective melting points of from 280°F (138°C) to 367°F (186°C). The higher melting point is for the isotactic polymer at its highest degree of crystallinity. From the melting points observed for the AMMRC supplied uniaxially oriented polypropylene, we can conclude it is a polymer with a moderate to high degree of crystallinity. It also follows from the above, that the higher the degree of crystallinity the higher the melting point of polypropylene.

7.1.4.1 Orientation of Polymers

Orientation of polypropylene is accomplished by stretching the film rapidly at a temperature below its melting point but above the glass transition temperature. This causes an alignment of the polymer chains in the direction of the applied stress, and can increase the degree of crystallinity. As noted above, the increased crystallinity can impart a higher melting point in the polypropylene. This higher melting point will be apparent as long as the polymer orientation is maintained. As indicated previously, the DSC melting point of the uniaxially oriented polypropylene was run on unrestrained film. In this case the material was heated until relaxation occurred, cooled to room temperature, then heated to observe melting point of the unoriented polymer.

7.1.4.2 Orientation Release Stress

Orientation release stress is determined by measuring the maximum load exerted by a restrained specimen during a heating cycle. The minimum average temperature of maximum release stress for the oriented polypropylene being used for this program is 345°F. It follows that a material which meets this requirement cannot melt below this temperature while being restrained. The amorphous fraction of the polymer can melt below this temperature, however, and it is this portion which melts and supplies the matrix media for the fusion operation.

7.1.5 Fusion Process-Melting Point Relationship

It appears from the above discussion that the melting point of the oriented polypropylene film, when restrained by pressing at sufficient pressure, is somewhat above 345°F. The melting point of this same material drops to around 325°F when heated un-restrained. Experience at AMMRC and Swedlow, Inc. indicate the maximum critical temperature cannot exceed 355°F to maintain the required r-f transmission and ballistic efficiencies. At the maximum platen temperature of 355°F and a target mid-point temperature of 350°F, panel to panel thickness control was the only problem with the established fusion process. During the AMMRC Demonstration Run, the AMMRC Engineering Sample Run, and the N.R.L. panel production effort, variations were made in the platen and mid-point temperatures in an attempt to achieve predictable flow during the fusion process. A maximum surface temperature of as low as 348°F was tried with a minimum mid-point temperature of 340°F. Interlaminar Bond Strength and Dimensional Stability tests showed no deleterious effect at the lower mid-point temperature. Separate studies on four inch thick panels for N.R.L. indicate bonding can occur at 335°F, however the soak time at this temperature range is considerably longer.

7.1.6 Time-Temperature Versus Flow Rate

In an attempt to establish a time-temperature relationship with respect to material flow, the thickness reduction of molded X-P panels was plotted versus the time the surface temperature was at 335°F or above. (Figure 1). The material flow was based on the theoretical thickness calculated from the Specific Gravity of polypropylene copolymer (.91) versus the material change weight and area. Actual thickness was the average of twelve readings across the molded panel. The run data used includes variations in maximum platen temperatures and heat-up rates which were introduced in order to optimize the fusion process. These variations resulted in considerable scattering of the data points.

The slope approximation developed from the plotted average flow of each panel shows a flow rate of 4.0 mil/minute for the 1.160 inch thick panels versus a rate of 1.5 mil/minute for the .375 inch thick panels. These flow rates represent the thickness reduction rate for each thickness at or near thermal equilibrium. This indicates, for example, that a five minute variation of cycle on a one inch thick panel can result in a 20 mil thickness reduction.

7.1.7 Process Cycle Optimization

The above discussion provides a basic overview of the complexities of the fusion process as it relates to X-P armor fabrication. It is apparent that the melting point and resultant material flow of the oriented polypropylene can be significantly influenced by minor changes in any of the processing variables. Previous cycle control was based on attainment of a 348°F to 350°F mid-point temperature. This resulted in unacceptable variations in cycle times with the present mold design and heating system employed. In order to eliminate these variables and achieve improved replication of panel thickness, the Confirmatory Sample Runs shall be made with all the above processing variables maintained at predetermined levels. The selected cycle shall be based on data from the previous run sheets, with cycle time started when the platen surfaces reach 335°F. The cycle times will be 90 minutes for the 1.160 inch thick panels and 25 minutes for the .375 inch thick panels. Platen temperatures shall be at 350°F to 352°F with molding pressure maintained at 2000 psi. These cycle times will assure a minimum mid-point temperature of 340°F or more. This will be sufficient to provide the required interply fusion of the oriented polypropylene film plies to meet the necessary structural and ballistic requirements.

8.0 PROGRAM FOR NEXT PERIOD

8.1 Confirmatory Sample Production

Confirmatory Sample Production shall begin as soon as approval is received from AMMRC for the Engineering Samples. Processing conditions established for production of the Engineering Samples shall be maintained throughout Confirmatory Sample Fabrication.

8.2 Confirmatory Sample Testing

8.2.1 Mechanical Testing

Four panels of each size shall be inspected for conformance to PD-105 paragraph 4.1.2 except for ballistic and S-band frequency testing.

8.2.2 Electrical Testing

Two panels of each size shall be tested for S-band frequency characteristics to PD-105 paragraph 3.2.1.2 by an outside test laboratory.

8.3 Production Capability Demonstration

8.3.1 Production Capability Demonstration Plan Outline shall be prepared and submitted per paragraph 1.2.13 of ECIPPR NO. 15.

8.3.2 Production Capability Demonstration shall be conducted in accordance with paragraph 1.2.14 and 3.1.13 of ECIPPR No. 15 at Swedlow, Inc. facility.

8.4 Final report shall be prepared in accordance with paragraph 3.5 and 3.5.2 of ECIPPR No. 15.

TABLE 1

FABRICATION PROCEDURE 1.160 AND .375 PANELS

AMMRC DEMONSTRATION RUN

WEEK OF MAY 14, 1977

1. Cut six (6) 24 x 34 film stacks.
2. Wrap panel in kraft paper and transport to clean room.
3. Strip off polyethylene and 3 - 5 plies and cover with protective film (Film to be pre-washed with methanol).
4. Turn stack over onto a pre-weighed caul plate.
5. Strip the other pad and add to stack making:

   a) Two (2) total for 3/8 panel.
   b) Five (5) total for 1" panel.

6. Place on 30K gm balance and strip down to the following amount (including top protective film).

   a) 4,778 gms. for 3/8" panel
   b) 14,913 gms. for 1" panel

7. Check thickness four places - should be:

   a) ≈ 0.405" for 3/8" panel
   b) ≈ 1.253" for 1" panel

8. Position on pre-cleaned caul plates.
9. Position seal around stack.
10. Insert Scott foam spacers.
11. Insert two (2) mid-panel T.C.s
12. Cover with top caul plate.
13. Evacuate and check vacuum (Should be 29 in. Hg min. after 10 minutes valved off) - Record actual.
14. Condition at 170°F for 15 hours.
15. Valve-off and transport to press - Load and setup T.C.s.
16. Final check vacuum - Record actual.

TABLE 1 (CONT'D)

17. Close press to 850 PSIG line (2200 PSI).

18. Start press heat up -

    Bleed steam lines - close by-pass.
    Adjust steam pressure 110 PSIG.

19. Raise temp to -

Caul plates		350 - 355°F
Mid panel	a)	350 - 352°F for 3/8" panel
	b)	348 - 350°F for 1" panel

20. Start cool-down as soon as mid-panel temperature reaches -

    a) 350°F for 3/8" panel
    b) 348°F for 1" panel

21. Force water cool-down while attempting to hold temperature variation as follows:

$$\Delta t_{faces} \leq 5°F$$

$$\Delta t_{mid} \leq 10°F$$

22. Cool to room temperature before removal.

TABLE 2

RUN CONTROL DOCUMENT

PANEL SERIAL NO. ______________ DATE ____________________

PANEL SIZE ______________

CROSS PLIED FILM - RECEIVED ______________ VENDOR ______________

ASSEMBLY NO./PAD NO. #1 ___________ #2 _________ #3_________

#4 ___________ #5 _________ #6_________

PROCTECTIVE FILM - VENDOR ___________ TYPE ___________ RUN ________

ASSEMBLY CONFIGURATION -

SKETCH LAYUP, THERMOCOUPLE PLACEMENT AND,

BLEEDER FOAM LOCATION AND QUANTITY.

ASSEMBLY WEIGHT ____________

ASSEMBLY THICKNESS __________ __________ __________ __________

INITIAL VACUUM _____ AVERAGE AFTER 15 HRS AT 170°F_______________

INITIAL VACUUM CHECK ________ IN Hg AFTER 10 MINUTES.

FINAL VACUUM CHECK (AT PRESS) _________ AFTER 10 MINUTES.

TABLE 3

MOLDING RECORD DATE: ____________ SERIAL NO. ____________

Time (Clock)	Time Cum (Min)	#1 Mid T C (°F)	#2 Mid T C (°F)	#3 Top Caul (°F)	#4 Bottom Caul (°F)	Steam Press Top (psig)	Steam Press Bottom (psig)	Line Press (psig)	Vacuum (In Hg)	Page 1 of ____ Comments	

REMARKS: ____________

FIGURE 1

X-P PANELS - FLOW VS TIME
(DATA BASE - TABLE 4)

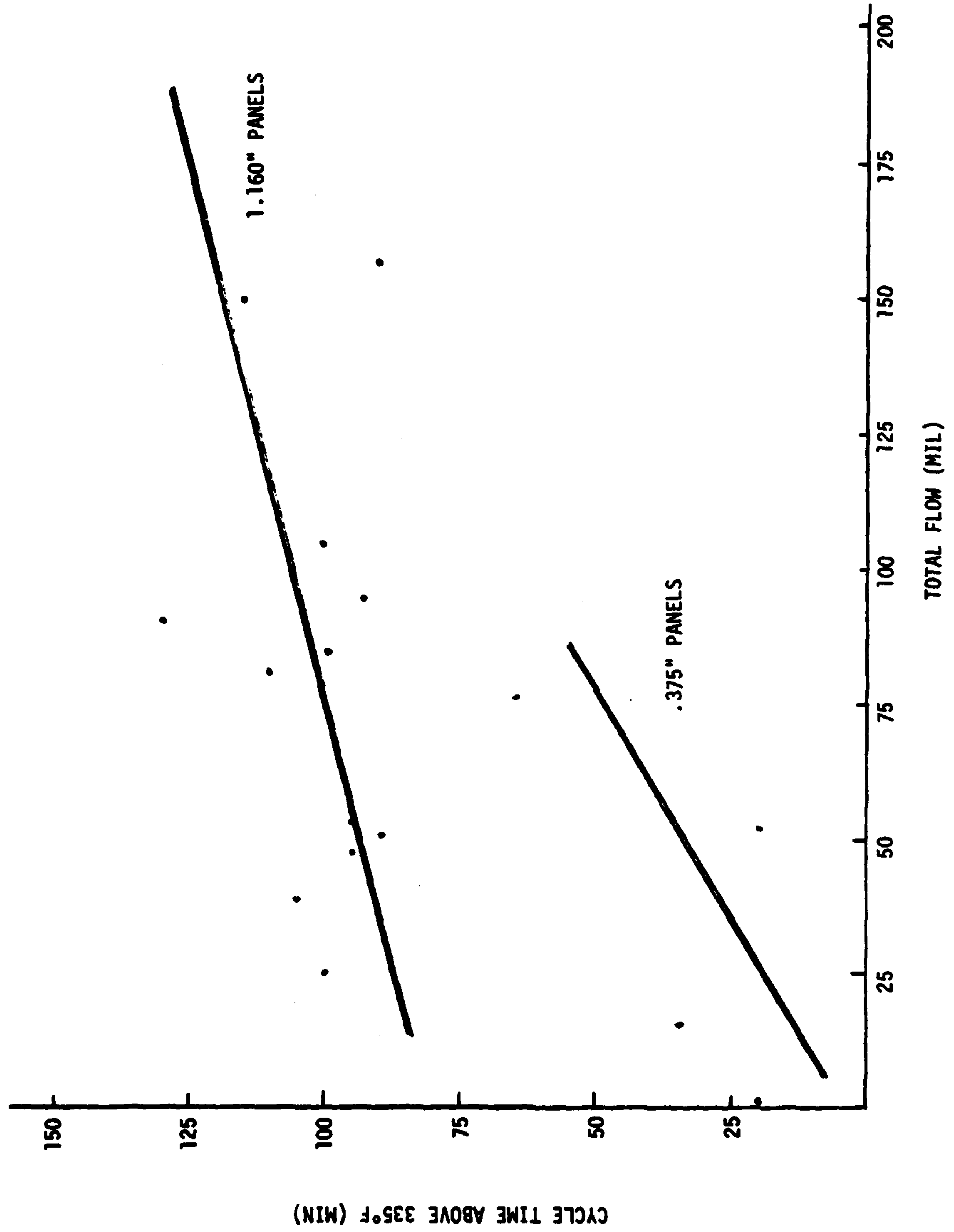

TABLE 4

X-P PANEL MOLDING RECORD RECAP

Serial Number	Cycle Time(1)	Charge Weight	Theor Thick.(2)	Actual Thick.	Thickness Reduction
	Minutes	Grams	Inch	Inch	Inch
SN 051579	110	13115	1.249	1.161	.082
SN 051779	100	15295	1.255	1.170	.085
SN 052179	95	5922	1.067	1.020	.047
SN 052379	93	6046	1.067	.972	.095
SN 053079		6355	1.1031	N.A.	N.A.
SN 090779	170	13028	1.027	.820	.207
SN 0901179	115	13475	1.068	.917	.151
SN 091379	85	13660	1.077	.920	.157
SN 091779	90	14154	1.116	1.065	.051
SN 101679	35	5450	.432	.416	.016
SN 101779	20	5050	.400	.401	-0-
SN 102579	20	5450	.432	.380	.052
SN 112879	65	5450	.432	.356	.076
SN 120479	95	14450	1.146	1.093	.053
SN 120679	130	15550	1.233	1.143	.090
SN 121179	105	15850	1.257	1.219	.038
SN 121379	100	15550	1.233	1.128	.105
SN 121879	70	15550	1.233	1.191	.042
SN 013080	85	15600	1.241	1.183	.058
SN 013180	85	15450	1.225	1.157	.068

(1) Cycle time is based on time after platens reach 335°F.

(2) Theoretical Thickness is calculated based on Sp. Gr. of .91 for Polypropylene Homopolymer and panel area.

LME