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THE EFFECT OF ORTHODONTIC MODEL FABRICATION PROCEDURES ON GYPSUM MATERIALS

by

Benton J. Runquist
B.S., University of California at Los Angeles, 1981
D.D.S., University of the Pacific, 1985

A Thesis
Submitted to the Faculty of the
Graduate School of the University of Louisville
in Partial Fulfillment of the Requirements
for the Degree of

Master of Science in Oral Biology

Department of Oral Biology
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ABSTRACT

This study examined four physical properties of three commercially available gypsum materials and three fabricated hybrids under five different model finishing conditions. In addition, a novel means of quantifying the time required to trim the models was presented.

The study showed that the physical properties of the different materials react in a variable fashion depending upon the model finishing conditions. Non-commercially available hybrids had superior properties over orthodontic plaster in some conditions, but not all. Model trimming times were directly related to the density of the material, but an item of interest was the time benefits that could be achieved through the use of an improved trimming wheel recently placed on the market.

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INTRODUCTION AND LITERATURE SURVEY

1.0 Introduction

Although there are presently being developed alternative means to store information obtained from orthodontic study casts,[1-3] it does not appear that they will be replaced entirely. Even concerns with cross contamination[4-6] and the problems of model storage[7-9] have had little impact. In fact, there is a growing trend among orthodontists to mount their patient models on an articulator,[10-12] and for some this means fabricating a second set of casts to do so. It follows from this that study casts are important for both the clinical assessment of cases but also for demonstration purposes with patients. Study casts are subject to repeated handling and the attendant risk of damage. There has been comparatively little attention paid in the literature, however, to the overall properties of gypsum casts or to methods of improving the strength and durability of casts.

Recent studies have looked at the effect of repeated sprayings of disinfectants on gypsum casts[4] but little work has addressed the common orthodontic model fabrication procedures. The present study accordingly was devoted to the evaluation and improvement of the properties of study casts.

Gypsum has been used in dentistry for over two and a half centuries.[13] It is a white to yellowish mineral found in nature as the dihydrate form of calcium sulfate, $2CaSo_4 \cdot 2H_20$. The first to be produced was Plaster of Paris, a name given because the usable hemihydrate form was obtained by calcining the gypsum mineral from the deposits near Paris, France. Today an increasing number of gypsum products are recognized all with different physical properties, but derived from the same chemical structure.

With the wide variety of properties which can be obtained,[9,13-42] gypsum has been found to have applications in most dental specialties, orthodontics being no exception. Since its inception as the first recognized dental specialty, orthodontics has utilized gypsum to fabricate its study models. These models, although static in nature, offer a wealth of information to the clinician, as well as acting as a time-linked record of the status of the patient's teeth and supportive tissues at a particular time. As Graber[43] noted in his orthodontic textbook, "after the clinical examination, there is no single more important diagnostic and prognostic criterion than the plaster casts that have been properly taken and prepared of the patient's teeth and investing tissues."

Compared to other fields in dentistry, the demands of gypsum casts in orthodontics are somewhat different. Unlike removable or fixed prosthodontic models, those used in orthodontics are not primarily for use in the dental

laboratory. Instead, they are painstakingly fabricated for diagnostic information and for display to the patient during the doctor's treatment planning consultation. Rather than just clearly showing clinical crowns and dental anatomy, assistants or laboratory personnel are required to follow rigid guidelines for sculpting and trimming them.[43,44] Certain anatomical landmarks must be replicated in the cast and the trimming procedures are critical if proper interpretation of the diagnostic landmarks is to be obtained[43-46]. It is not uncommon for technicians to spend several hours preparing one set of models and such services are available through several commercial orthodontic laboratories.

In addition, the bases of the models are also trimmed to specific measurements.[43,44] There are guidelines estabished by the American Board of Orthodontics[47] concerning heights, widths and the angulations to which the bases are cut. Finally, for esthetic reasons, the resulting product is brought to a polished and glossy finish. Traditionally, orthodontic study models have been bright white and most manufacturers offer an "orthodontic white" plaster and stone. No other specialty goes to such lengths to produce an esthetically appealing, diagnostic and prognostic model.

Due to the extensive demands of their casts, orthodontists desire models that are resistant to abrasion, resist fracturing, and maintain their white appearance. In

clinical practice initial and progress models are continually referred to during the patient's active treatment period, which can be in excess of 24 months. During this time models are handled repeatedly by both doctors, assistants and patients and are therefore prone to wear and damage. As Trotter[7] pointed out, once chipping has occurred, models are rendered obsolete.

Most of the research performed on gypsum materials has been for the benefit of fixed and removable prosthodontics. Although studies have looked at a multitude of means for altering gypsum's properties, relatively little has been done to examine the effect of model finishing procedures on the physical properties of the gypsum itself. Specifically, a number of orthodontists choose plaster, stone, improved stone or their own mixtures of stone and plaster to construct their models. They hybrids can give properties not available commercially and, although prosthodontists have looked into their properties,[48] they have received little research applicable to the orthodontist's demands.

In addition, many orthodontists will vary the means by which they dry their casts prior to finishing them. Bench drying, conventional ovens and microwaves all have become common methods.[17,49-51] Finally, the finishing procedures can vary from office to office. One of the most common finishing procedures is to soak the trimmed, sculpted and dried models in a soap solution.[43,44] Various solutions are

commercially available, but little research has been done to evaluate the effect of these finishing materials.[33,34]

It is the purpose of this study to review the common materials used in orthodontic model fabrication, to examine how those materials have been manipulated in the past, and to evaluate the effect of finishing procedures on the final product. Decisions can then be made as to whether certain materials or procedures should be altered or improved in order to obtain a desired end result. In addition, this may serve as a baseline for the physical properties of completed study models which could then be used in further studies concerning the effects of repeated applications of disinfectants, or other materials, on dental casts.

Presently, multiple forms of dental gypsum are available to the dentist and orthodontic specialist. The gypsum exists in a variety of altered conditions due to the manufacturers' addition of colors and modifiers to meet specific requirements. The basic physical differences, however, result from the method used to drive off the mineral's moisture, resulting in the marketed powder form. Simple heating of the mineral in the open air, called calcining, results in plaster. When the calcining is performed in an autoclave, the result is artificial stone. Improved dental stone, the most recently developed product, is produced by boiling the gypsum in an aqueous solution of calcium chloride, resulting in a finer powder and therefore a denser, harder cast.

1.1 Plaster

The powder crystals of plaster are somewhat irregular and porous in nature and are given the name alpha hemihydrate. It is a white mineral which absorbs a relatively large quanitity of gauging water when it is mixed, requiring approximately 50 grams of water per 100 grams of powder. Once the excess water evaporates, the resulting low density of the dried material results in strength values which are relatively low.

Plaster, by virtue of being the first developed, was the initial material used in dentistry and has remained the material of choice for many orthodontists. One reason plaster continues to be used is its relative softness. This feature allows for quick model sculpting and model trimming, two laboratory procedures which can require a significant amount of time and thereby incur a considerable cost to the practice. On the other hand, plaster's porous nature and resulting brittle qualities are a drawback. In the late 1920's when artificial stone was developed, many clinicians switched to this newer gypsum material to take advantage of its improved physical properties.

1.2 Artificial Stone

Also known as dental stone or Type III stone, the result of driving off gypsum's water in an autoclave is a more regular crystal with less porosity. This crystal is known as the beta hemihydrate form and requires less gauging

water for hydration. The required water-powder ratio is approximately 30 grams of water for 100 grams of powder. The amount of excess water is therefore less and the resulting product is denser and appreciably stronger than plaster, with an increased resistance to fracture.

Many clinicians desire this, for once teeth are damaged or lost, the models lose the majority of their diagnostic and informative value.[7-9,43] In addition, it is important that they have adequate transverse and tensile strength. These models are handled repeatedly throughout the patient's treatment phase and any breakage or abrading of teeth would be a loss of pretreatment information. Following treatment, models are then maintained during the patient's retention phase and indefinitely as a permanent part of their record. The trade-off however, for a harder, denser cast, was the increased laboratory time required for fabrication.

In the 1950's, an additional form of gypsum was developed which gave clinicians access to a material with even greater strength characteristics.

1.3 Improved Dental Stone

Improved dental stone or Type IV dental stone requires the least amount of water for hydration, forms a denser material and has the greatest compressive strength, transverse strength and surface hardness.[28-30,40,51-53] Compressive strength has been the most frequent measurement for strength, since cementitious materials are inherently

brittle and therefore have a greater compressive strength than tensile strength. The base line values for the three forms of gypsum are as follows:

	Compressive strength (kg/cm^2)
Plaster (Type II)	98-140
Artificial stone (Type III)	211-337
Improved stone (Type IV)	352-415

These are values taken one hour after the mix is initiated, and the values are two to three times higher once the gauging water has completely evaporated.[17,57] The method of mixing also can have an impact[25] and will be shown, there are a number of variables which can be manipulated to change the physical properties of the various gypsum materials.

As was true with the development of artificial stone, the improved surface hardness and compressive strength properties of the Type IV stone were initially most appealing to prosthodontists and general dentists. However, as more orthodontists were determined to have less wear and damage to their models, Type IV became more popular with the specialty and a "super-white" orthodontic formulation was marketed. In addition, the recent trend to mount study models on an articulator[10-12] has called for the use of this

more durable material, comparable to what is used in full mouth reconstruction cases by prosthodontists. However, the improved strength attributes detract from two requirements of traditional orthodontic models; that they trim and sculpt easily. Unfortunately, there is no gypsum product that satisfies all of these requirements. One solution has been to pour the teeth portion of the impression molds in stone, and the anatomy and bases in plaster.[43] The result is teeth less prone to damage, a relatively small surface area of stone that requires sculpting, and a base that is easily trimmed and finished. A drawback is that a dual mix procedure is more time consuming for the laboratory and a demarcation line between the two materials results. Whether the line and the added laboratory time is acceptable is a variable that weighs in the clinician's decision.

Other alternatives include altering the water-powder ratio, the method of mixing, or the addition of modifiers. Furthermore, clinicians can use a mixture of plaster and stone to produce a hybrid which has inherent compromises when compared to either of the two ingredients. In such a combination the stone adds strength, but increases the sculpting and trimming time. The plaster makes the laboratory work easier and more efficient, but tensile strength is decreased and the chance for model fracture increases. Manufacturers of gypsum materials contend that such mixing is acceptable,[54] however the resulting physical properties have not been thoroughly investigated. Presently

there are no commercially produced hybrids targeted for this demand, due primarily to too many requests for too many different mixing ratios, with the cost prohibiting multiple small volume productions.[54]

1.4 Manipulation Techniques

Due to the variety of uses and demands of dental stone in dentistry, there has been extensive research aimed at means of altering the basic characteristics. Studies have shown that the physical properties can be altered in a variety of ways, from what gypsum is mixed with[13-15], how the gypsum is mixed[19,24,26,28,38,39,58,59] and how it is handled after it is mixed.[17,51,57]

Specifically, it was established early that the strength and setting expansion can be affected to a considerable degree by such variables as the water-powder ratio, the addition of accelerators and retarders, spatulation time, water temperatures and the ambient conditions under which the material is stored or permitted to reach its final set.

In some early work, Fairhurst[57] showed how the wet strength of stone, measured one hour after mixing, is 40-50% of the dry strength. He showed that a weight increase of only 1-2%, due to water absorption, results in a significant loss in compressive strength (≈50%). It should be noted that a 1-2% weight increase due to water absorption does not result in a model that looks wet.

In 1985, Grove[55] published the following data that emphasized the importance of proper water-powder ratios:

	W/P Ratio (ml/100g)	Wet Strength (kg/cm^2)	Dry Strength (kg/cm^2)
Stone	30	337	612
	50	77	352
Improved stone	24	400	823
	30	281	633

He showed how the addition of excess water to artificial stone can reduce its strength and surface hardness to no more than that exhibited by laboratory plaster.

1.5 Mixing Techniques

Sarma et al.[25] examined the effect of mixing methods on the physical properties of dental gypsum die stones. They compared ADA hand mixing to 20-second and 30-second mechanical mixing under vacuum. The most obvious effect due to mechanical mixing was a substantial increase in compressive strength for mixes made under mechanical mixing. They also concluded that mechanical mixing increases the fluidity of the mix and reduces setting time and setting expansion.

In addition, they also commented on finding a substantial variation in the physical properties of different batches of the same stone. In some cases, this

inter-batch variation was as significant as the variation due to the mixing procedure.

1.6 Importance of Drying

Combe and Smith[15] compared the physical properties of four plasters and six stones that were commercially available. One of their conclusions stressed complete drying of the cast to obtain optimal results. In addition, Mahler[17] had demonstrated the importance of the drying environment. He was looking at gypsum materials for dental flasking procedures and his primary concern was surface hardness, not compressive strength. In general, in an average laboratory setting (23% rH and 23.3°C) excess water dissipates in about two weeks. It is at this point that he found gypsum specimens to be in optimum physical condition. He also determined that since the humidity and temperature of the atmosphere determined the rate of water loss, he could accelerate it by placing his specimens in a drying oven. After experimentation with different temperatures and times, he found 36 hours at 90°C was needed to bring his specimens to an optimum condition.

1.7 Tensile Strength and Fracture of Teeth

Earnshaw and Smith[60] were some of the first to stress the importance of tensile strength. They believed it had a more practical significance since when teeth fracture from a gypsum cast they do so by failing in tension. They found

the values to be about one-fourth to one-third the compressive strengths, indicating how brittle they are.

Combe and Smith[24] looked at methods of improving stones for the construction of models and dies. They also believed increasing the tensile strength would benefit orthodontic models by reducing the incidence of fractured teeth. By addressing the amount of water used, via an additive, they were able to reduce the water-powder ratio and produce stones of increased strength and surface hardness. A side effect was an increase in setting expansion and setting time, which they compensated for via an additional additive (potassium sulfate).

More recently, von Fraunhofer and Spiers[61] looked at a new, easier method of testing transverse strength, called the central fulcrum load test. An interesting conclusion was that the strengths of the two stones studied were insensitive to the specimen thickness. They suggested that the low tensile strength acts as the limiting factor for the transverse strength.

1.8 Additives

Sanad, Combe and Grant[26] also found they could improve the mechanical properties of gypsum products through the use of additives. By incorporating ground up gum arabic into the gypsum powder their resulting product had an increased surface hardness and resistance to abrasion. This additive, along with calcium oxide, reduced the gypsum's water

requirement, increased the modulus of rupture (strength) and reduced the setting expansion.

1.9 Compressive Strength and Surface Hardness

Schneider[28] looked at compressive strength and surface hardness of Type IV die stone when mixed with water substitutes. He looked at six different die stones and found water substitutes resulted in significantly increased surface hardness and compressive strength. One drawback was some of the hardeners produced a thin mix that they found difficult to work with. In addition, when hardeners were added they found an increase in the amount of setting expansion.

1.10 Abrasion Resistance

Numerous researchers have examined the abrasion resistance of gypsum materials,[18,21,24,30,62-66] but none have done so after model finishing procedures.

von Fraunhofer and Spiers[65] used a commercially available tester originally marketed for evaluating paint coatings. They found it worked well in evaluating gypsum materials, and they showed that some dental stones have a significant increase in abrasion resistance after 24 hours.

Lyon et al.[63] looked at the abrasion resistance of die stones and also found an effect with aging. Their testing was done at 24 hours and 7 days after mixing and in general, the values decreased with time. Interestingly, they found

that at 24 hours, a Type III laboratory stone was as resistant to abrasion as the die stones. They surmised that the Type III stone at 24 hours was lubricated by water trapped in inter-crystalline spaces. The lubrication increased the abrasion resistance but, with time, this disappeared and the resistance dropped to a level solely dependent on the strength of the stone.

Williams et al.[19] found that by adding very small amounts of finely divided silica, a significant improvement resulted. Interestingly, the amount of improvement was also shown to be dependent on the type of impression material used. They could not explain this increase, but suggested that the improvements in abrasion resistance resulted from the orientation of the surface layer of crystals.

1.11 Use of Hybrids

Finally in 1985, a group in South Africa, Hamman et al.[48] addressed the problem of creating a hybrid of plaster and stone and studied its properties. They found that an almost linear increase in compressive strength occurs when the content of the stone in a stone/plaster mixture is gradually increased. However, their field of study was related to removable prosthodontics and they only looked at compressive strengths. One of their conclusions was, "the effect of mixing on other important properties, such as surface hardness, dimensional stability and setting time has yet to be established."

At present, such mixtures of white orthodontic plaster and stone are not commercially available. There are no guidelines for the fabrication of such hybrids and the resulting properties are unknown.

During an orthodontic model fabrication course offered by the Whip Mix Corporation, an informal survey of the course participants (orthodontic laboratory and ancillary personnel) revealed that the majority of all orthodontic offices currently use such a hybrid. The plaster to stone ratio in use varied from 2:1 to 1:2. This practice may have its origin from a recommendation in Graber's text,[43] where he addressed the need for a compromise between the properties of plaster and stone by suggesting, "to mix white dental stone and plaster in equal parts and to use this mixture to pour up both anatomic and art portions at the same time." In addition, of the offices represented, all had a model finishing procedure which included dehydration of their models followed by immersion in a soap solution. The soap solutions varied in content (sulfonated fatty acids and unknowns) and concentration, as there are many on the market, and the duration of the soaking stage ranged from 15 minutes to more than one hour.

While much has been written on the physical properties of gypsum materials, and the various means of altering or improving them, little has addressed this common practice of soaping models. It is the purpose of this paper to determine the physical properties of the hybrid materials,

as well as the effect of various finishing procedures on the resulting orthodontic casts. In addition, a novel technique to quantitate the ease of trimming of various gypsum materials is presented. It is believed that such information is of value to those determining which gypsum product best suits their needs.

1.12 Statement of the Problem

Considerable work has been performed over the years on gypsum products, notably plaster, stone and improved stone as well as die stones. In contrast, little has been published on the properties of "hybrids" or mixtures of plaster and stone. Further, there is little information in the literature on the optimum finishing procedure for orthodontic study casts, that is, the drying time and soaping procedures to improve the cast appearance. Finally, abrasion resistance of casts is known to be of great importance, but there is minimal information in the literature on this characteristic. Related to this characteristic is the technically important property of trimming time. Dental laboratories devote considerable time and effort to the trimming of study casts. Accordingly, variations in the material composition, as well as the abrasion/material removal efficacy of trimming wheels, may have great significance with regard to the time devoted to laboratory procedures and the economic consequences of such procedures.

1.13 Proposed Program of Work

This study examines the effect of finishing procedures on four physical properties of three commercially available gypsum materials and three fabricated hybrids. The finishing procedures consist of air drying or oven drying the trimmed gypsum models prior to either a 15 or 30-minute soak in a finishing soap solution. Specimens which are not subjected to the finishing procedures acted as controls.

The hybrids are mixtures of plaster and stone in ratios commonly used by practicing orthodontists. The physical properties under study are compressive strength, diametral strength, transverse strength and abrasion resistance, all of which contribute to the longevity of the orthodontic study model.

In addition, a novel technique for determining the time required to trim orthodontic study models is described. This involves the use of a hand-held device, which standardizes the force delivered to a block of gypsum as it is being trimmed.

Once the experimentation has been completed and the techniques have been formalized and established, the results will be published to provide practicing orthodontists with useful information regarding the materials they use on a daily basis.

In addition, this research may not only provide the impetus for commercial production of such a hybrid material, but also encourage the manufacture of a "finishing" material more compatible with gypsum materials.

CHAPTER II

MATERIALS AND METHODS

2.0 Materials

Gypsum Materials

Three commercially available dental materials were used:

1. Whip Mix orthodontic plaster, serial number 087110500
2. Whip Mix orthodontic stone, serial number 088210600
3. Whip Mix Silky-Rock die stone, serial number 089210200

In addition, three hybrids were fabricated from the above batches of orthodontic plaster and stone. The decision on the ratios was based on common requests by orthodontists to the manufacturer. They were:

1. a 1:1 ratio of orthodontic plaster to orthodontic stone;
2. a 2:1 ratio of orthodontic plaster to orthodontic stone; and
3. a 1:2 ratio of orthodontic plaster to orthodontic stone.

These materials were chosen because they are produced by the same company and intercompany as well as interbatch variables could thereby be avoided.

Hybrids

Mixing of hybrids was performed into clean and dry gypsum containers obtained from the Whip Mix corporation. To ensure accurate ratios and weights, mixing was performed in 450 gram increments using two clean, dry flexiboles and a triple beam balance (OHAUS 2610g capacity; Florham Park, New Jersey). After each increment was added, the mixture was completely stirred by hand and then the container was rolled end over end, as recommended in the A.D.A. Specification No. 25 for gypsum products.[63]

2.1 Methods

Specimen Fabrication

The materials were all carefully weighed and measured to and mixed in accordance with the findings of Sarma et al.[25] A vacuum mechanical mixing unit (Whip Mix Vac-U-Vestor, model B power-mixer; Louisville, Kentucky) was utilized with 25 mm Hg applied for 20 seconds. After mixing, the materials were poured with vibration (Whip Mix heavy duty model) into molds designed specifically for the tests performed. The material in the molds (which are detailed later) were then covered with a glass slab to ensure parallel end faces. After 20 minutes, when an initial set was reached, the specimens were separated from the molds and allowed to air dry until the orthodontic finishing procedure. All mixing and storage of materials

and specimens was in the same lab by the same operator under the same ambient conditions.

Model Finishing Treatments

The six gypsum materials were subjected to five orthodontic finishing procedures:

1. Control - the specimens were fabricated as above for the various tests and then allowed to air dry for 21 days prior to testing.
2. Treatment 1 - the specimens were poured into their molds, separated after 20 minutes, allowed to sit for one hour, placed in a drying chamber (Drymaster x-ray film dryer, R-P corporation) at 47.8°C for 14 hours, soaked in a soap solution (TP model soap, catalog #100-881) for 15 minutes, rinsed quickly under warm running water (1-3 seconds), allowed to air dry for 21 days, and then tested.
3. Treatment 2 - was similar to Treatment 1, except the specimens were air dried for 24 hours before the 15-minute soaping procedure.
4. Treatment 3 - was similar to Treatment 1, except the soaping was twice as long, 30 minutes instead of 15.
5. Treatment 4 - was similar to Treatment 2, but the specimens were immersed for 30 minutes in the soap solution.

Compressive Strength

Specimens for compressive strength were fabricated in rubber base (Kerr Light Bodied Permlastic Impression Material; Romulus, Michigan) molds which produced cylinders 19.0 ± 0.3mm in height and 9.5 ± 0.2mm in diameter with parallel end faces. Compressive strength was determined according to A.D.A. Specification No. 25 for gypsum products.[63] The values were calculated from the load to failure P divided by the cross-sectional area.

Diametral Tensile Strength

Diametral tensile strength tests were performed on flat cylindrical specimens 10.0 ± 0.5 mm in diameter and 5.0 ± 0.1 mm thick which were poured into a rubber mold (Blak-Tufy, Perma-Flex Mold Company; Columbus, Ohio) and removed after setting. Tensile strengths were calculated using the standard relation, $Sdt = 2P/\pi dt$, where d is the diameter, t is the specimen thickness, and P is the fracture load.

Transverse Strength

Transverse strength tests were performed on flat beam specimens using a three-point loading system. The specimens were supported on parallel round bars and load was applied at their center. The span length between the end supports was 51.00 mm. The transverse strength was calculated using the standard relation, $St = 3PL/2wt^2$, where P is the

fracture load, L is the span length, w is the specimen width, and t is the specimen thickness.

A minimum of 180 specimens were fabricated for each of the four physical tests. Thirty were fabricated of each material, six of which were subjected to each of the five fabrication procedures.

Testing Apparatus

The force or load applied to the above described specimens was provided by a universal testing machine (Unite-O-Matic FM 20, United Calibration Corporation; Garden Grove, California; Figure 1). The crosshead speed for all three tests was 2.5 mm/min. and the plots produced by the internal chart recorder were digitized using a Hypad model DT-114, (Houston Instruments, Texas; Figure 2) which has an accuracy of 0.1 mm. The derived data were then used in the calculations of the properties.

Abrasion Resistance

Abrasion resistance was studied on the reciprocating arm/steel ball abrader system developed by von Fraunhofer and Spiers.[62] The gypsum materials were prepared in accordance with the manufacturer's specified water-powder ratios under vacuum spatulation (as above) and were set in a rubber mold (Blak-Tufy, Perma-Flex Mold Company; Columbus, Ohio) to produce 65 mm x 25 mm x 2 mm specimens. Specimens

of each condition were tested after a minimum drying time of three weeks.

A commercially available abrasion tester (REL abrasion tester, Research Equipment (London, Ltd.; Figure 3) was used for the study. The device consists of a reciprocating arm, mounted on the end of which is a pivoted platform, with a hardened spherical abrader (6.35 mm in diameter) mounted in a post welded to the platform. The upper surface of the platform accomodates weights for the control of the abrasive force. The arm stroke is 50.5 mm, the rate being 48 strokes per minute and a mechanical counter records the number of arm movements, each stroke giving two abrades (one each on the forward and return arm movements). The weight of the platform assembly is 126 gf, and an overweight of 300 gf was used for this study. Each specimen was subjected to 200 abrasion cycles (400 abrades). The abrasion resistance, expressed as the energy required to remove a unit volume of material, was determined by measuring the width and length of the abraded area with a traveling microscope (Griffin linear Vernier microscope, Griffin and George Ltd., London; Figure 4). The energy, E, for the loss of unit volume is given by:

$$E = 2mgNL/\Delta V \text{ erg cm}^{-3}.$$

Model Trimming

The ease of model trimming was measured on block specimens using two commercially available model trimmers

(Whemer dual trimmer model #W-108; Franklin Park, Illinois) with a standard carborundum wheel (part #2125) that had been utilized as a back-up trimmer in the Orthodontic Laboratory for approximately 3 months, and a Whip Mix model trimmer (item #09601) with a diamond cutting wheel that had been in use in the Whip Mix research and development laboratory for approximately 20 months.

Specimens were fabricated in plastic molds constructed on a Biostar vacuum former (Great Lakes model Series 1) with dimensions 51.0 mm x 51.0 mm x 25.0 mm. A minimum of 10 specimens of each of the three commercially available materials, and each of the 3 hybrids were fabricated. A line 18.0 mm from one edge was drawn cicumferentially on all specimens with a sharpened number two lead pencil. A spring-loaded, hand-held device was constructed to quantitate the amount of force that was applied to the specimen against the model trimmer (Figure 5). The force applied to the spring device was based upon the consensus of three lab personnel at the University who are engaged in model fabrication procedures in the Department of Orthodontic, Pediatric and Geriatric Dentistry. The force value, as determined on the universal testing machine, was 5.16 kg.

Two small gauge wires were soldered to the test jig and marked with a highspeed handpiece #330 bur and a black permanent ink marker to act as spring tension indicators and to ensure a consistent force was being applied. For each

reading the researcher applied the force to the model through the hand-held device while an assistant timed the removal of the material to the designated line.

Prior to the trimming of the models, the groups of dry specimens were soaked for thirty minutes in separate containers of distilled water. A Casio stopwatch (model #SDB-500W) accurate to .01 seconds was used to measure the length of time required to remove the amount of stone. To avoid any inter-batch variability, the same specimens were used on both model trimmers.

2.2 Statistics

For each of the four physical properties studied, a two-way analysis of variance was performed with the model fabrication procedure and the gypsum material used as the two study treatments. The null hypothesis was there would be no difference between the materials used or between the model finishing procedures on the resulting physical properties. When there were statistically significant differences ($p<0.05$), unifactorial analyses of variance were performed to test for statistically significant differences with *a priori alpha* set at 0.05.

For the trimming time study, a two-way ANOVA was also used with the gypsum materials and the model trimmers acting as the two variables. No model fabrication procedures were performed on the gypsum specimens used in this part of the study as models are trimmed prior to such activities.

CHAPTER III

RESULTS

3.1 Compressive Strength

The data on compressive strength are summarized in Table 1 with the statistical analyses of the data presented in Table 2 and Figures 6 and 7. Strength for the control materials increased in the order: plaster < hybrid #1 < hybrid #2 < hybrid #3 < stone < die stone and in general, for a given material, compressive strength obtained under Treatments 1-4 were lower than those obtained under the control.

The two-way Anova (Table 2) indicates that 79.5% of the variability comes from the material being used while only 7.7% comes from the model fabrication procedure.

For a more specific breakdown of compressive strength data, unifactorial analyses of variance were performed. Tables 3-7 examine the effect of gypsum material in each individual treatment condition, while Tables 8-13 show the effect of the various treatment regimens on each individual gypsum material.

From Table 3, the control, there was no significant ($p>0.05$) difference between plaster and hybrids #1 and #2, yet hybrid #3, stone and die stone were all significantly different ($p<0.05$) from these three materials and from each

other. Table 4, treatment 1 shows similar results for hybrids #1 and #2, yet hybrid #3 was not significantly different from hybrid #1 or #2 and stone was not significantly different from hybrid #3 ($p>0.05$).

Under model finishing treatment 2 (Table 5), hybrids #1 and #2 were significantly different from plaster and each other at the $p<0.05$ level. Hybrid #3 was significantly different from plaster, hybrids #1 and #2 at the $p<0.01$ level and stone and die stone were statistically different from plaster, hybrids #1-3, stone, and from each other ($p>0.05$).

Under treatment 3 (Table 6), we see somewhat similar results to the control, with hybrid #3 being significantly different from plaster and hybrid #1 at the $p<0.05$ level, stone different from plaster and hybrids #1-3 at the $p<0.01$ level and die stone being significantly different from all ($p<0.01$).

Under treatment 4 (Table 7), die stone is statistically different from all the other materials ($p<0.01$) while hybrid #3 is statistically different from plaster ($p<0.01$) and stone is significantly different from plaster ($p<0.01$) and hybrid #1 ($p<0.05$).

In general, no statistically significant difference in compressive strength ($p<.01$) was found between the hybrids and plaster until the percentage of stone reaches 66% (hybrid #3). Stone is consistently significantly different from all three of the hybrids at the $p<0.05$ level except for

treatments 1 and 4, where it is not sigificantly different from hybrid #3 and hybrids #2 and #3 respectively. Die stone, on the other hand, is consistently stronger than the other five materials.

Tables 8-13 summarize the effect of finishing procedures on each individual material. Table 8 indicates that for plaster, treatment 1 and 2 result in reduced compressive strength values ($p<0.01$) compared to the control. In addition, treatments 3 and 4 produce specimens significantly stronger ($p<0.05$) than treatment 1 and treatment 4 is significantly stronger ($p<0.05$) than treatment 2.

For hybrids #1 and #2 (Tables 9, 10), the only significant differences ($p<0.05$) are between the control and treatments 1 and 3. Table 11 for hybrid #3 indicates the control is significantly stronger ($p<0.01$) than all the other treatments, while Table 12 shows stone finished in the control condition differs significantly ($p<0.01$) only from treatment 4. Die stone (Table 13) showed a significant difference ($p<0.01$) between the control condition and treatments 3 and 4.

To summarize, these tables and Figures 6 and 7 indicate that the majority of the variance in compressive strength values arise from the choice of gypsum material. The control condition, in general, provided elevated compressive strength values that were statistically significantly different for most, but not all materials. Most of the

materials had no significant differences when treatments 1 through 4 were compared.

3.2 Diametral Tensile Strength

The data for the evaluation of diametral tensile strength is summarized in Table 14. The two-way analysis of variance is presented in Table 15 and Figures 8 and 9. The strength for the control materials increased in the order plaster < hybrid #1 ≈ hybrid #2 ≈ hybrid #3 < stone < die stone. In general, for a given material, the diametral tensile strength obtained under treatments 2 through 4 were relatively unchanged from the control. The two-way ANOVA table (Table 15) indicates that, similar to compressive strength, the majority of the variation comes from the material (69.8%) while only 4.3% comes from the model finishing procedure.

Unifactorial analyses, which examine the effect of the gypsum material under each individual finishing condition, are summarized in Tables 16-20, while Tables 21-26 show the effect of the various treatment regimens on each individual gypsum material.

In the control condition (Table 16), stone had significantly greater strength than plaster ($p<0.05$), while die stone was significantly stronger than plaster ($p<0.01$) as well as the hybrids ($p<0.05$). Under model finishing treatment 1 (Table 17), stone was significantly stonger than plaster and hybrids #1 and #2 ($p<0.05$). Die stone was

statistically significantly stonger than plaster and all three hybrids ($p<0.05$).

Under treatment 2 (Table 18), stone and die stone were statistically stronger than plaster ($p<0.01$) and die stone was stronger than hybrid #1 ($p<0.05$). Under treatment 3 (Table 19), stone and die stone were significantly stronger than plaster ($p<0.01$) and all three hybrids and die stone were significantly stronger than stone ($p<0.05$). Under treatment 4 (Table 20), there were statistically significant differences between some of the hybrids as well. Hybrid #2 was stronger than plaster ($p<0.01$), hybrid #3 was stronger than plaster ($p<0.01$) and hybrid #1 ($p<0.05$). Again, stone and die stone were significantly stronger than plaster and hybrids #1 and #2 ($p<0.05$). Die stone also differed significantly from hybrid #3 at the $p<0.01$ level and from stone at the $p<0.05$ level.

In general, the rank order of the materials did not change in the various treatments when compared to the control. Stone and die stone did have increases in strength while the only statistically significant increases between the hybrids and plaster occurred under treatment 4.

Tables 21-26 summarize the effect of model finishing treatments on each individual material. Tables 21, 22, 25 and 26 show that for plaster, hybrid #1, stone and die stone there is no significant difference in strength values across the various finishing treatments.

For hybrid #2 (Table 23), there was a significant difference ($p<0.05$) between treatment 1 and the control and between treatment 1 and 4, $p<0.05$. For hybrid #3 (Table 24), there was a significant difference between treatment 1 and 4 and between 3 and 4, both at $p<0.01$. Again, these tables indicate the finishing procedures have little effect on the diametral tensile strength values.

3.3 Transverse Strength

The data on the transverse strength testing are summarized in Table 27 with a statistical analysis of the data presented in Table 28 and Figures 10 and 11. Strength for the control materials increased in the order plaster ≈ hybrid #1 ≈ hybrid #2 ≈ hybrid #3 ≈ stone < die stone and in general, for a given material, transverse strength obtained in treatments 1-4 were lower than the control.

The two-way ANOVA (Table 28) indicates that 31.2% of the variability comes from the material being used, 16.% from the treatment procedure, 23.8% from an interaction between the material and the treatment and the remainder from error.

Specific breakdowns of transverse strength data was performed with unifactorial analyses of variance. Tables 29-33 examine the effect of each gypsum material in each individual treatment condition while Tables 34-39 present the effect of the various treatment regimens on each material.

Under the control condition (Table 29), hybrid #3 was statistically stronger than plaster and hybrid #1 ($p<0.05$). Stone was significantly stronger than hybrid #1 ($p<0.05$) but not from plaster ($p>0.05$). Die stone was significantly stronger than plaster and hybrids #1 and #2 ($p<0.01$).

Under model finishing treatment 1 (Table 30), die stone was statistically significantly different from all five of the other materials ($p<0.01$), which would make the rank order of the materials similar to the control.

Under treatment 2 (Table 31), there were no statistically significantly differences between any of the materials. In treatment 3 (Table 32), die stone again was statistically significantly stronger than all the materials ($p<0.05$) while hybrid #3 and stone were significantly stronger than hybrid #2 ($p<0.05$).

Under treatment 4 (Table 33), hybrids #2, #3, stone and die stone were all significantly different from plaster and hybrid #1 ($p<0.05$) which results in the rank order: plaster $\approx$ hybrid #1 $<$ hybrid #2 $\approx$ hybrid #3 $\approx$ stone $\approx$ die stone.

Table 34 indicates that for plaster, there is a statistically significant difference between the control and treatment 4 ($p<0.01$), as well as between treatment 3 and 4 ($p<0.05$). For hybrid #1 (Table 35), there are no statistically significant differences between any of the finishing treatments. For hybrid #2 (Table 36), treatment 3 resulted in values significantly less than the control

($p<0.05$) and values for treatment 4 were significantly greater than for treatments 2 and 3 ($p<0.05$).

Stone (Table 38) performed fairly uniformly throughout. The only statistically significant difference was between the control and treatment 3 ($p<0.01$), the control having the greater transverse strength. Die stone, on the other hand, (Table 39) was less predictable. Strength for treatment 2 was less than for the control and treatments 1 and 3 ($p<0.01$). Treatment 4 was also statistically significantly less than the control ($p<0.05$).

In summary, there was no reversal in the rank order of materials by their strength values but there were instances where statistical significance ceased to exist or increased.

3.4 Abrasion Resistance

The data for the abrasion test is summarized in Table 40 with a statistical analysis of the data presented in Table 41 and Figures 12 and 13. Resistance for the control materials increased in the order: plaster < hybrid #1 < hybrid #2 < hybrid #3 < stone < die stone and in general, for a given material, abrasion resistance values obtained after finishing treatments 1-4 were markedly greater than those obtained under the control.

The two-way ANOVA (Table 41) indicates that 19.9% of the variability comes from the material being used, 45.3% from the treatment regimen, 20% from an interaction between the two and the rest from unknown error.

The unifactorial analyses that examined the effect of each gypsum material in each individual treatment condition are presented in Tables 42-46. Tables 47-52 summarize the effect of the various finishing procedures on each individual gypsum material.

Under the control condition (Table 42), die stone had an abrasion resistance that was greater than that of all the other materials ($p<0.01$). Stone was statistically greater than hybrid #1 ($p<0.05$) and plaster ($p<0.01$) and hybrid #3 was significantly greater than plaster ($p<0.01$).

Under treatment regimen 1 (Table 43), die stone was again more resistant to abrasion than all other ($p<0.05$). Stone was significantly more resistant than plaster and hybrids #1 and #2 ($p<0.01$) and hybrid #3 was more resistant than plaster ($p<0.01$).

In treatment regimen 2 (Table 44), die stone was more resistant to abrasion than all the other materials ($p<0.01$) and no other statistically significant differences existed. Under treatment 3 (Table 45), die stone was only more resistant than plaster, hybrid #2 and hybrid #3 ($p<0.05$) and stone was more resistant than hybrid #2 ($p<0.05$).

In treatment 4 (Table 46), both stone and die stone were more resistant to abrasion than all the other materials ($p<0.05$) with the unusual finding that stone was more abrasion resistant than die stone ($p<0.01$). This was an unique case of rank order reversal, with regards to any of the four physical properties studied.

Tables 47-52 indicate that each treatment procedure produced a greater abrasion resistance when compared to the control ($p<0.01$). In addition, Table 47 shows that for plaster, treatment 3 results in greater abrasion resistance than treatment 2 ($p<0.05$). For hybrid #1 (Table 48), no statistically significant difference exists between any of the treatment regimens. For hybrid #2 (Table 49), treatments 1 and 4 resulted in greater abrasion resistance than treatment 2 ($p<0.05$). With hybrid #3 (Table 50), treatment 1 produced more abrasion resistance than treatment 4 ($p<0.05$). For stone (Table 51), treatment 4 produced more abrasion resistant specimens than all the other treatments ($p<0.01$) and treatments 1 and 3 both produced greater resistance values than treatment 2 ($p<0.01$). For die stone (Table 52), abrasion resistance for treatment 1 is greater than that for both treatments 2 and 3 ($p<0.05$).

In summary, all model finishing treatments resulted in a more abrasive resistant material as compared to the control. Die stone had the greatest resistance of all the materials except when compared to stone under treatment regimen 4.

3.5 Trimming Time

The data obtained from trimming the various gypsum specimens on the standard carborundum wheel and diamond wheel are in Tables 53 and 54 respectively. The two-way analysis of variance is presented in Table 55 and Figure 14.

Because there was a significant interaction between the type of trimming wheel and the material used, confidence intervals were used to compare the "simple effect."

Table 56 is a comparison of the time difference for each of the materials on the two different trimming wheels. From the data and graph in Figure 14, it is evident that the standard wheel takes significantly ($p<0.05$) longer than the diamond wheel. In order to put this into clinically relevant terms, one would need to determine the amount of material that required trimming and the cost comparison between the two wheels. In general, for both of the wheels, plaster trims about twice as fast as stone and the time required for the hybrids lie somewhere in between.

The major benefits of the diamond wheel seem to lie in the trimming of the denser gypsum materials (stone and die stone).

CHAPTER IV

DISCUSSION

To this date, little if any data exists in the literature concerning the effects of model finishing procedures on the physical properties of gypsum materials. Furthermore, only one article could be found that addressed the properties of hybrids fabricated from commercially available gypsum plaster and stone.[48]

The bulk of the literature has been approached from a restorative or prosthodontic standpoint and many of the conclusions and findings may not be applicable to the orthodontist's evaluation of the material. Orthodontists are concerned with many of the same physical properties, but in a different time frame. Present research evaluates the gypsum properties 1 hour and 24 hours after the mix is initiated. Orthodontics, to a large extent, is more concerned with how the materials will perform 24 days, 24 weeks or 24 months after the models are fabricated.

Furthermore, studies have shown that many, if not all the physical properties, may be subject to an aging effect. This was most notable in abrasion resistance[63,65] between 1 hour and 24 hours and again between 24 hours and 1 week. Similarly, it has been shown that compressive, diametral and transverse strengths are strongly affected by the moisture content of the material.

This study can be broken down into two parts. The first part examined four physical properties that are deemed important to the longevity of orthodontic study models. The second part described a novel technique for quantitating the time required to trim a specified volume of gypsum material.

The results of the physical property tests clearly indicate that none of the physical properties were dramatically altered by the finishing procedures except for abrasion resistance. Other authors[4,26,52,63,65] have found increases in abrasion resistance and have speculated on its cause. Lyon et al.[63] found an increase in abrasion resistance of stone over die stone at a certain time period after the specimens had been mixed. He surmised that the water content acted as a lubricant and as it evaporated with time, the abrasion resistance fell as the property was then based on the strength of the material alone. In the present study the soap solution could act as a flotation agent, allowing for a reorganization of the specimen's surface layer.

Others[26] have found that additives (i.e. silica) enhance the abrasion resistance and their explanation is similar, that the resulting intermolecular binding between the gypsum and additive create a more abrasion resistant surface.

As to why the other three physical properties didn't show comparable changes, it is believed to be due to the inability of a soap solution to alter more than the outer

most layer of the specimens. In other words, the floation effect is less marked in bulk material, i.e. abrasion resistance is the only physical property that is "surface" condition dependent. Compressive, transverse and diametral tensile strengths are proportedly determined primarily by the porosity of the material. Unlike other studies which show more dramatic changes in these properties, the present work only looked at post-fabrication alterations. No additives were made to the materials prior to mixing with water and the mixing procedures were consistent for all treatments. The model finishing procedures could only have an effect after the specimen was fabricated and thus could effect the resulting physical properties only to the degree that the solution could change the internal intermolecular arrangements.

Since no dramatic changes were noted, it could be concluded that no long term, deep reaching effects on the internal structure was accomplished. This supposition could be tested in one of two ways. The first would be to perform the same physical property tests, but on much thinner specimens. This may not be a moot point for it is actually the thin tooth projections of a model that fracture most readily and therefore the test data would be highly pertinent.

The seconds means of testing the "penetration" or internal alteration hypothesis would be to attach a die material to the soap solution to physically reveal how far

the material invaded the specimens. This may be difficult to interpret if one is not able to determine if it is actually the soap solution and not just the die material itself that is invading the gypsum material.

An important point that should be mentioned is the condition under which all specimens were fabricated and tested. In all situations steps were taken to decrease the amount of variability. This involved proper storage and mixing of materials, accurate weighing, proper water/powder ratios, mechanical spatulation under vacuum and the storage of specimens in a controlled laboratory environment. The clinician must bear this in mind when looking at the predictability of what can be expected in his office or laboratory, as variability is sure to increase without attention to detail.

In addition, not only were the specimen fabrication procedures controlled, but so were the model finishing procedures. Models were placed in a drying oven set at an acceptable temperature.[17] The temperature was controlled and the duration of drying was constant. Similar controls were set for the soaping procedures. The manufacturer's recommended times were followed and specimens were not allowed to be "forgotten" in the solution.

As for trimming time, the results clearly show an advantage in the use of the diamond trimming wheel. Again, the data depicted in Figure 10 show some interaction but clearly the diamond wheel was superior. It is unfortunate

that new wheels of both types were not available for the study. However, since the diamond wheel was in use for a significantly longer period of time and used primarily for trimming die materials (whereas only plaster or hybrids were allowed to be trimmed prior to the study on the standard wheel), it is surmised that the differences would still be present, and on an even greater scale.

Other potential areas for continued study include:

1. Comparisons of the multitude of model soaps and glossing materials on the market, not only for their effects on the physical properties of gypsum, but how they may effect the casts ability to absorb or repel bacteria. Perhaps present day model finishing techniques will need to be abandoned for a more hygienic alternative.
2. Comparisons of different brands of gypsum materials. Only one manufacturer of materials was investigated in this study and variations have been shown to exist between companies that produce similar materials.[25]
3. Evaluation of more dramatically different fabricaton procedures. The present study did not allow for any clear-cut conclusions concerning the effect of the following on a model's physical characteristics:
    a. method of drying; i.e. conventional ovens, microwave ovens, bench top or ambient lab

conditions.

b. drying temperature

c. length of time models are left in soap solutions

4. The effect of model fabrication procedures on the ability of these models to be repeatedly disinfected with spray disinfectants.

5. The effect of repeated applications of a disinfectant spray solution on the esthetics of a finished orthodontic study model.

In summary, clinicians need to base their decision on which material to use on several considerations. The first would be the material they wish to use and then the fabrication procedure they are set up for or are able to utilize. Finally, if laboratory time spent on model fabrication is a concern, the choice of material may be influenced by the type of wheel trimmer available.

CHAPTER V

SUMMARY AND CONCLUSIONS

The findings of this study permit several conclusions to be drawn:

1. The hybrids, as a group, had physical properties that fell between those of plaster and stone. However, due to the variability inherent with fabricating gypsum models, accurate predictions of the clinical performance of hybrids (i.e. how they would compare to either plaster or stone) were not consistently achieveable. This finding makes it difficult to justify the effort that is required to locally or commercially produce such formulations.
2. If compressive strength is the most important physical property, die stone fabricated in the control condition has the greatest strength. If plaster, stone or hybrids were the only alternatives, stone would be the material of choice since it exhibited the least variability with change in the model finishing procedures.
3. If diametral tensile strength is the primary concern, die stone models fabricated under any of the conditions would be the optimum choice. Stone models would rank second, with little clinical

difference between the hybrids and plaster. Again, given the amount of observed variability, no one finishing condition would be superior to another.

4. The transverse strength values varied with both the material and the finishing procedure and, consequently, selection of the optimum choice varies with both parameters.
5. Abrasion resistance was greatest for all materials with each finishing procedure compared to that of the controls. One interesting finding was that the abrasion resistance of stone exceeded that of die stone by a large margin when it was air dried followed by a thirty minute soak in the soap solution.
6. Trimming time is faster for all materials when performed on a diamond wheel, even if the latter has been in use for a significantly longer period of time.

Although this study leaves some questions unanswered, it also serves as a baseline study for any future work that deals with the physical properties of finished orthodontic study models. With increasing concerns for potential contamination vehicles in the dental office study models may need to be finished in bacteriostatic solutions. The results of this study could serve as a

starting point for research in this direction.

In addition, comparisons of different finishing solutions (of differing chemical compounds) could be tested in a similar fashion to determine their effect on the same physical properties. Certain formulations may have more penetrating capabilities or may have effects in ways not yet surmised.

Furthermore, more pronounced changes in the fabrication conditions could be examined. These could include, but not be limited to, method of specimen drying (dry heat, microwave) length of drying time, drying temperature, and the duration of soap solution immersion.

Finally, similar gypsum materials from different manufacturers could be compared. One potential problem with this is the interbatch variability that has shown to exist and the difficulty in generalizing one set of findings to a company's entire stock. As Sarma et al.[25] pointed out, in some controlled studies using only one manufacturer's product, the interbatch physical property variability was so great as to disallow comparisons between results of the same material from the same company. On a clinical level this observation probably has the most relevance since it indicates that gypsum research is full of variability. For the clinician this implies that the predictability of properties is very limited, even when dealing with only the product(s) of one company. Furthermore, it emphasizes the importance of strict laboratory procedures, with great

attention paid to each step of the model fabrication process, as any deviation or carelessness will only add to the variability and decrease the predictability of the resultant properties.

In summary, the study has provided baseline data for models fabricated and finished under four different treatment procedures and one control. It has shown that all four of the physical properties studied have extensive variability that is contributed to by both the material and finishing procedure chosen. Only one property, abrasion resistance, is clearly enhanced by all treatments as compared to the control. In addition, a novel means for measuring model trimming time was described. The value of this study is that clinicians may now base their choice of material on data that was previously undetermined. Furthermore, the efficacy of two model trimming wheels of different materials were compared and showed that there is a marked reduction in trimming time with the improved wheel, even after it has been in use for a significantly longer period of time.

APPENDIX A

TABLES

TABLE 1

Compressive Strength

(kg/sq.cm)

		Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die stone
Control	n	4	4	5	4	5	4
	m	436.46	512.74	545.62	674.54	715.62	993.73
	sd	33.88	77.36	49.06	19.61	62.55	80.56
Treat. #1	n	5	3	4	4	5	4
(oven + 15)	m	354.81	425.59	447.93	526.84	621.10	846.11
	sd	28.83	66.39	52.87	43.37	36.06	66.79
Treat. #2	n	5	6	4	4	3	6
(air + 15)	m	367.16	481.14	465.56	523.76	635.44	878.81
	sd	27.95	28.00	56.58	73.66	69.26	50.74
Treat. #3	n	6	6	4	4	5	3
(oven + 30)	m	416.18	415.60	445.72	517.58	641.21	738.31
	sd	28.56	31.40	28.34	53.60	48.21	85.04
Treat. #4	n	6	5	6	3	3	4
(air + 30)	m	418.83	439.46	490.54	514.35	536.16	734.25
	sd	25.60	29.25	35.77	30.97	51.02	97.92

TABLE 2
Two-way ANOVA
Compressive Strength

Source	DF	SS	MS	F	P	%
Material	5	2684562.7	536912.5	212.64	0.0001	79.5
Condition	4	265404.0	66351.0	26.28	0.0001	7.9
Mat•Cond	20	164552.1	8227.6	3.26	0.0001	4.9
Error	104	262593.1	2524.9			7.8

TABLE 3
Compressive Strength - Control

	Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die stone
Plaster	---	ns	ns	s	s	s*
Hyb #1		---	ns	s	s	s
Hyb #2			---	ps	s	s
Hyb #3				---	ps	s
Stone					---	s

TABLE 4
Compressive Strength - Treatment 1

	Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die stone
Plaster	---	ns	ns	s	s	s
Hyb #1		---	ns	ns	s	s
Hyb #2			---	ns	s	s
Hyb #3				---	ns	s
Stone					---	s

*ns - $p>0.05$; ps - $p<0.05$; s - $p<0.01$

TABLE 5
Compressive Strength - Treatment 2

	Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die stone
Plaster	---	ps	ps	s	s	s
Hyb #1		---	ns	ns	s	s
Hyb #2			---	ns	s	s
Hyb #3				---	ps	s
Stone					---	s

TABLE 6
Compressive Strength - Treatment 3

	Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die stone
Plaster	---	ns	ns	ps	s	s
Hyb #1		---	ns	ps	s	s
Hyb #2			---	ns	s	s
Hyb #3				---	s	s
Stone					---	ps

TABLE 7
Compressive Strength - Treatment 4

	Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die stone
Plaster	---	ns	ns	ps	s	s*
Hyb #1		---	ns	ns	ps	s
Hyb #2			---	ns	ns	s
Hyb #3				---	ns	s
Stone					---	s

*ns - $p>0.05$; ps - $p<0.05$; s - $p<0.01$

TABLE 8

Compressive Strength - Plaster

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	s	s	ns	ns
Treatment #1		---	ns	ps	ps
Treatment #2			---	ns	ps
Treatment #3				---	ns

TABLE 9

Compressive Strength - Hybrid #1

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	ps	ns	ps	ns
Treatment #1		---	ns	ns	ns
Treatment #2			---	ns	ns
Treatment #3				---	ns

*ns - $p>0.05$; ps - $p<0.05$; s - $p<0.01$

Treatment #1 - oven + 15 minutes in soap
Treatment #2 - air + 15 minutes in soap
Treatment #3 - oven + 30 minutes in soap
Treatment #4 - air + 30 minutes in soap

TABLE 10

Compressive Strength - Hybrid #2

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	ps	ns	ps	ns
Treatment #1		---	ns	ns	ns
Treatment #2			---	ns	ns
Treatment #3				---	ns

TABLE 11

Compressive Strength - Hybrid #3

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	s	s	s	s
Treatment #1		---	ns	ns	ns
Treatment #2			---	ns	ns
Treatment #3				---	ns

*ns - $p>0.05$; ps - $p<0.05$; s - $p<0.01$

TABLE 12

Compressive Strength - Stone

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	ns	ns	ns	s
Treatment #1		---	ns	ns	ns
Treatment #2			---	ns	ps
Treatment #3				---	ps

TABLE 13

Compressive Strength - Die stone

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	ns	ns	s	s*
Treatment #1		---	ns	ns	ns
Treatment #2			---	ns	ns
Treatment #3				---	ns

*ns - $p>0.05$; ps - $p<0.05$; s - $p<0.01$

TABLE 14

Diametral Tensile Strength

(kg/sq.cm)

		Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die stone
Control	n	3	3	4	3	3	3
	m	63.80	76.50	78.36	76.79	81.37	96.04
	sd	8.19	9.98	4.44	4.52	4.73	5.41
Treat. #1	n	4	3	3	4	4	3
(oven + 15)	m	61.31	69.50	64.48	72.16	85.89	91.12
	sd	1.89	6.86	10.13	5.19	4.80	11.26
Treat. #2	n	3	4	4	4	4	3
(air + 15)	m	60.92	67.58	76.08	77.26	85.25	89.78
	sd	2.15	7.57	5.48	6.03	9.14	15.35
Treat. #3	n	3	4	3	4	3	3
(oven + 30)	m	66.18	67.61	70.92	70.59	91.48	105.48
	sd	1.74	4.00	4.00	1.97	3.99	11.73
Treat. #4	n	3	4	3	4	3	3
(air + 30)	m	61.68	73.40	78.77	84.75	91.11	101.66
	sd	6.36	5.54	0.29	4.22	2.56	2.49

TABLE 15
Two-way ANOVA - Diametral Tensile Strength

Source	DF	SS	MS	F	P	%
Material	5	11557.4	2311.5	55.56	0.0001	69.8
Condition	4	708.5	177.1	4.26	0.0038	4.3
Mat•Cond	20	1296.8	64.8	1.56	0.0884	7.8
Error	72	2995.4	41.6			18.1

TABLE 16
Diametral Tensile Strength - Control

	Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die stone
Plaster	---	ns	ns	ns	ps	s
Hyb #1		---	ns	ns	ns	ps
Hyb #2			---	ns	ns	ps
Hyb #3				---	ns	ps
Stone					---	ns

TABLE 17
Diametral Tensile Strength - Treatment 1

	Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die stone
Plaster	---	ns	ns	ns	s	s
Hyb #1		---	ns	ns	ps	s
Hyb #2			---	ns	s	s
Hyb #3				---	ns	ps
Stone					---	ns

*ns - $p>0.05$; ps - $p<0.05$; s - $p<0.01$

TABLE 18
Diametral Tensile Strength - Treatment 2

	Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die stone
Plaster	---	ns	ns	ns	s	s*
Hyb #1		---	ns	ns	ns	ps
Hyb #2			---	ns	ns	ns
Hyb #3				---	ns	ns
Stone					---	ns

TABLE 19
Diametral Tensile Strength - Treatment 3

	Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die stone
Plaster	---	ns	ns	ns	s	s
Hyb #1		---	ns	ns	s	s
Hyb #2			---	ns	s	s
Hyb #3				---	s	s
Stone					---	ps

TABLE 20
Diametral Tensile Strength - Treatment 4

	Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die stone
Plaster	---	ns	s	s	s	s*
Hyb #1		---	ns	ps	s	s
Hyb #2			---	ns	ps	s
Hyb #3				---	ns	s
Stone					---	ps

*ns - $p>0.05$; ps - $p<0.05$; s - $p<0.01$

TABLE 21

Diametral Tensile Strength - Plaster

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	ns	ns	ns	ns
Treatment #1		---	ns	ns	ns
Treatment #2			---	ns	ns
Treatment #3				---	ns

TABLE 22

Diametral Tensile Strength - Hybrid #1

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	ns	ns	ns	ns
Treatment #1		---	ns	ns	ns
Treatment #2			---	ns	ns
Treatment #3				---	ns

*ns - $p>0.05$; ps - $p<0.05$; s - $p<0.01$

Treatment #1 - oven + 15 minutes in soap
Treatment #2 - air + 15 minutes in soap
Treatment #3 - oven + 30 minutes in soap
Treatment #4 - air + 30 minutes in soap

TABLE 23

Diametral Tensile Strength - Hybrid #2

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	ps	ns	ns	ns*
Treatment #1		---	ns	ns	ps
Treatment #2			---	ns	ns
Treatment #3				---	ns

TABLE 24

Diametral Tensile Strength - Hybrid #3

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	ns	ns	ns	ns
Treatment #1		---	ns	ns	s
Treatment #2			---	ns	ns
Treatment #3				---	s

*ns - $p>0.05$; ps - $p<0.05$; s - $p<0.01$

TABLE 25

Diametral Tensile Strength - Stone

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	ns	ns	ns	ns
Treatment #1		---	ns	ns	ns
Treatment #2			---	ns	ns
Treatment #3				---	ns

TABLE 26

Diametral Tensile Strength - Die stone

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	ns	ns	ns	ns
Treatment #1		---	ns	ns	ns
Treatment #2			---	ns	ns
Treatment #3				---	ns

*ns - $p>0.05$; ps - $p<0.05$; s - $p<0.01$

TABLE 27

Transverse Strength

(Kg/sq.cm)

		Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die stone
Control	n	5	6	5	5	5	3
	m	155.35	147.16	162.39	193.58	182.92	215.76
	sd	10.14	16.01	16.38	21.93	18.90	18.74
Treat. #1	n	5	5	5	3	4	4
(oven + 15)	m	140.33	150.29	148.33	138.93	157.15	200.22
	sd	10.53	7.38	19.71	10.24	8.54	13.99
Treat. #2	n	4	5	4	4	3	4
(air + 15)	m	139.79	147.96	141.97	143.38	139.05	148.46
	sd	9.90	17.77	10.03	10.75	11.61	25.98
Treat. #3	n	6	6	4	3	4	5
(oven + 30)	m	149.71	156.13	128.87	160.37	166.41	199.06
	sd	10.76	16.20	5.80	2.84	10.98	23.63
Treat. #4	n	4	6	4	3	6	5
(air + 30)	m	130.52	134.44	172.22	183.62	167.33	166.81
	sd	10.10	12.23	13.39	17.14	18.75	17.17

TABLE 28
Two-way ANOVA - Transverse Strength

Source	DF	SS	MS	F	P	%
Material	5	26559.0	5311.8	23.03	0.0001	31.2
Condition	4	14117.1	3529.3	15.30	0.0001	16.6
Mat•Cond	20	20241.8	1012.1	4.39	0.0001	23.8
Error	134	24220.1	230.7			28.4

TABLE 29
Transverse Strength - Control

	Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die stone
Plaster	---	ns	ns	ps	ns	s
Hyb #1		---	ns	s	ps	s
Hyb #2			---	ns	ns	s
Hyb #3				---	ns	ns
Stone					---	ps

TABLE 30
Transverse Strength - Treatment 1

	Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die stone
Plaster	---	ns	ns	ns	ns	s
Hyb #1		---	ns	ns	ns	s
Hyb #2			---	ns	ns	s
Hyb #3				---	ns	s
Stone					---	s

*ns - $p>0.05$; ps - $p<0.05$; s - $p<0.01$

TABLE 31

Transverse Strength - Treatment 2

	Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die stone
Plaster	---	ns	ns	ns	ns	ns*
Hyb #1		---	ns	ns	ns	ns
Hyb #2			---	ns	ns	ns
Hyb #3				---	ns	ns
Stone					---	ns

TABLE 32

Transverse Strength - Treatment 3

	Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die-stone
Plaster	---	ns	ns	ns	ns	s
Hyb #1		---	ns	ns	ns	s
Hyb #2			---	ps	s	s
Hyb #3				---	ns	s
Stone					---	ps

*ns - $p>0.05$; ps - $p<0.05$; s - $p<0.01$

TABLE 33

Transverse Strength - Treatment 4

	Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die stone
Plaster	---	ns	s	s	s	s*
Hyb #1		---	s	s	ps	ps
Hyb #2			---	ns	ns	ns
Hyb #3				---	ns	ns
Stone					---	ns

TABLE 34

Transverse Strength - Plaster

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	ns	ns	ns	s
Treatment #1		---	ns	ns	ns
Treatment #2			---	ns	ns
Treatment #3				---	ps

*ns - $p>0.05$; ps - $p<0.05$; s - $p<0.01$

TABLE 35

Transverse Strength - Hybrid #1

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	ns	ns	ns	ns
Treatment #1		---	ns	ns	ns
Treatment #2			---	ns	ns
Treatment #3				---	ns

TABLE 36

Transverse Strength - Hybrid #2

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	ns	ns	ps	ns*
Treatment #1		---	ns	ns	ns
Treatment #2			---	ns	ps
Treatment #3				---	s

*ns - $p>0.05$; ps - $p<0.05$; s - $p<0.01$

Treatment #1 - oven + 15 minutes in soap
Treatment #2 - air + 15 minutes in soap
Treatment #3 - oven + 30 minutes in soap
Treatment #4 - air + 30 minutes in soap

TABLE 37

Transverse Strength - Hybrid #3

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	s	s	ps	ns
Treatment #1		---	ns	ns	s
Treatment #2			---	ns	s
Treatment #3				---	ns

TABLE 38

Transverse Strength - Stone

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	ns	s	ns	ns
Treatment #1		---	ns	ns	ns
Treatment #2			---	ns	ns
Treatment #3				---	ns

*ns - $p>0.05$; ps - $p<0.05$; s - $p<0.01$

TABLE 39

Transverse Strength - Die stone

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	ns	s	ns	ps*
Treatment #1		---	s	ns	ns
Treatment #2			---	s	ns
Treatment #3				---	ns

*ns - $p>0.05$; ps - $p<0.05$; s - $p<0.01$

TABLE 40

Abrasion Resistance

(x 10^{-11} erg. cm^{-3})

		Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die stone
Control	n	6	6	6	6	6	6
	m	1.170	1.498	1.624	2.054	2.189	3.023
	sd	.1716	.1386	.3107	.5537	.3786	.6011
Treat. #1	n	6	6	6	6	6	6
(oven + 15)	m	15.23	18.90	20.05	28.09	33.59	45.09
	sd	4.131	1.529	3.295	8.760	3.420	9.541
Treat. #3	n	6	6	6	6	6	6
(air + 15)	m	13.86	19.07	13.30	20.83	14.954	32.36
	sd	1.268	6.072	3.715	5.422	5.330	4.501
Treat. #4	n	6	6	6	6	6	
(oven + 30)	m	19.64	24.28	16.20	19.12	26.93	29.67
	sd	3.472	10.13	3.508	4.204	4.229	6.072
Treat. #5	n	6	6	6	6	6	6
(air + 30)	m	18.68	23.81	18.94	16.42	60.70	39.34
	sd	4.810	15.03	4.358	6.504	8.49	11.26

TABLE 41

Two-way ANOVA - Abrasion Resistance

Source	DF	SS	MS	F	P	%
Material	5	6991.9	1398.4	39.06	0.0001	19.9
Condition	4	15871.5	3967.9	110.84	0.0001	45.3
Mat•Cond	20	7010.6	350.5	9.79	0.0001	20.0
Error	145	5190.6	35.8			14/8

TABLE 42

Abrasion Resistance - Control

	Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die stone
Plaster	---	ns	ns	s	s	s
Hyb #1		---	ns	ns	ps	s
Hyb #2			---	ns	ns	s
Hyb #3				---	ns	s
Stone					---	s

TABLE 43

Abrasion Resistance - Treatment 1

	Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die stone
Plaster	---	ns	ns	s	s	s
Hyb #1		---	ns	ns	s	s
Hyb #2			---	ns	s	s
Hyb #3				---	ns	s
Stone					---	ps

*ns - $p>0.05$; ps - $p<0.05$; s - $p<0.01$

TABLE 44

Abrasion Resistance - Treatment 2

	Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die stone
Plaster	---	ns	ns	ns	ns	s*
Hyb #1		---	ns	ns	ns	s
Hyb #2			---	ns	ns	s
Hyb #3				---	ns	s
Stone					---	s

TABLE 45

Abrasion Resistance - Treatment 3

	Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die stone
Plaster	---	ns	ns	ns	ns	ps
Hyb #1		---	ns	ns	ns	ns
Hyb #2			---	ns	ps	s
Hyb #3				---	ns	ps
Stone					---	ns

*ns - $p>0.05$; ps - $p<0.05$; s - $p<0.01$

TABLE 46

Abrasion Resistance - Treatment 4

	Plaster	Hyb #1	Hyb #2	Hyb #3	Stone	Die stone
Plaster	---	ns	ns	ns	s	s*
Hyb #1		---	ns	ns	s	ps
Hyb #2			---	ns	s	s
Hyb #3				---	s	s
Stone					---	s

TABLE 47

Abrasion Resistance - Plaster

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	s	s	s	s
Treatment #1		---	ns	ns	ns
Treatment #2			---	ps	ns
Treatment #3				---	ns

*ns - $p>0.05$; ps - $p<0.05$; s - $p<0.01$

Treatment #1 - oven + 15 minutes in soap
Treatment #2 - air + 15 minutes in soap
Treatment #3 - oven + 30 minutes in soap
Treatment #4 - air + 30 minutes in soap

TABLE 48

Abrasion Resistance - Hybrid #1

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	s	s	s	s
Treatment #1		---	ns	ns	ns
Treatment #2			---	ns	ns
Treatment #3				---	ns

TABLE 49

Abrasion Resistance - Hybrid #2

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	s	s	s	s*
Treatment #1		---	ps	ns	ns
Treatment #2			---	ns	ps
Treatment #3				---	ns

*ns - $p>0.05$; ps - $p<0.05$; s - $p<0.01$

TABLE 50
Abrasion Resistance - Hybrid #3

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	s	s	s	s
Treatment #1		---	ns	ns	s
Treatment #2			---	ns	ns
Treatment #3				---	ns

TABLE 51
Abrasion Resistance - Stone

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	s	s	s	s
Treatment #1		---	s	ns	s
Treatment #2			---	s	s
Treatment #3				---	s

TABLE 52
Abrasion Resistance - Die stone

	Control	Treatment #1	Treatment #2	Treatment #3	Treatment #4
Control	---	s	s	s	s*
Treatment #1		---	ps	s	ns
Treatment #2			---	ns	ns
Treatment #3				---	ns

*ns - $p>0.05$; ps - $p<0.05$; s - $p<0.01$

TABLE 53

Trimming Time - Carborundum Wheel

#	Plaster	Hybrid #1	Hybrid #2	Hybrid #3	Stone	Die stone
1	15.74	19.47	22.98	26.03	36.25	68.12
2	14.31	20.17	22.40	26.67	34.03	62.43
3	14.53	18.90	22.19	26.47	33.04	63.83
4	14.49	18.89	20.53	25.56	32.27	65.88
5	14.88	19.73	21.25	24.71	32.96	62.20
6	15.54	20.74	24.16	26.02	36.08	60.96
7	15.52	19.42	21.67	26.33	34.92	62.51
8	14.93	20.05	21.40	25.50	34.75	61.27
9	16.22	19.31	21.40	26.28	33.16	66.10
10	14.24	19.48	22.44	25.27	33.46	64.12
mean	15.04	19.62	22.03	25.88	34.09	63.74
sd	0.68	0.58	1.04	0.61	1.36	2.33

TABLE 54

Trimming Time - Diamond Wheel

#	Plaster	Hybrid #1	Hybrid #2	Hybrid #3	Stone	Die stone
1	10.03	13.66	18.16	19.91	24.28	45.41
2	11.48	12.80	17.16	20.16	23.09	42.16
3	10.03	13.85	17.28	18.97	23.66	48.97
4	9.48	12.66	17.60	18.91	23.41	47.03
5	11.91	13.72	16.47	21.47	28.35	43.53
6	11.78	13.60	17.91	18.22	27.84	51.03
7	10.53	14.72	19.59	21.22	27.66	45.60
8	10.72	13.47	19.72	20.04	25.91	46.41
9	10.97	14.53	17.59	21.22	24.54	45.53
10	10.03	14.97	17.16	20.85	28.16	44.84
mean	10.70	13.90	17.86	20.10	25.69	46.05
sd	0.83	0.76	1.05	1.12	2.14	2.54

TABLE 55

Analysis of Cutting Time Data

Two-way analysis of variance on cutting time to compare the standard cutting wheel against the diamond cutting wheel over six gypsum materials.

Variable	DF	SS	MS	F	P	%
Wheel	1	1779.47	1779.47	882.6	0.0001	19.9
Material	5	23087.17	4617.43	2290.2	0.0001	45.3
Whl•Mat	5	656.26	131.25	65.1	0.0001	20.0
Error	108	217.74	2.02			14.8

Because of the significant interaction, the following confidence intervals compare the "simple effect."

TABLE 56

Carborundum Wheel - Diamond Wheel Trimming Times

Material	Lower	Upper
Plaster	2.66	6.01**
Hybrid #1	4.14	7.49**
Hybrid #2	2.49	5.84**
Hybrid #3	4.10	7.45**
Stone	6.72	10.07**
Die stone	16.01	19.36**

From the above table, it can be seen that the standard cutting wheel takes longer than the diamond wheel for each of the six gypsum materials.

TABLE 57

Comparisons of Materials

Materials	Standard Wheel		Diamond Wheel	
6-5	27.78	31.51**	18.49	22.22**
6-4	35.99	39.72**	24.08	27.81**
6-3	39.84	43.57**	26.32	30.05**
6-2	42.24	45.98**	30.38	34.11**
6-1	46.83	50.56**	33.48	37.21**
5-4	6.34	10.07**	3.72	7.45**
5-3	10.19	13.92**	5.96	9.69**
5-2	12.60	16.33**	10.02	13.75**
5-1	17.18	20.91**	13.12	16.85**
4-3	1.98	5.70**	0.37	4.10**
4-2	4.39	8.12**	4.43	8.16**
4-1	8.97	12.70**	7.53	11.26**
3-2	0.54	4.27**	2.19	5.92**
3-1	5.12	8.85**	5.29	9.02**
2-1	2.17	6.44**	1.23	4.96**

Legend:

Material 1 = Plaster
2 = Hybrid #1
3 = Hybrid #2
4 = Hybrid #3
5 = Stone
6 = Die stone

APPENDIX B

FIGURES

FIGURE 1

FM-20 Unite-O-Matic Testing Machine

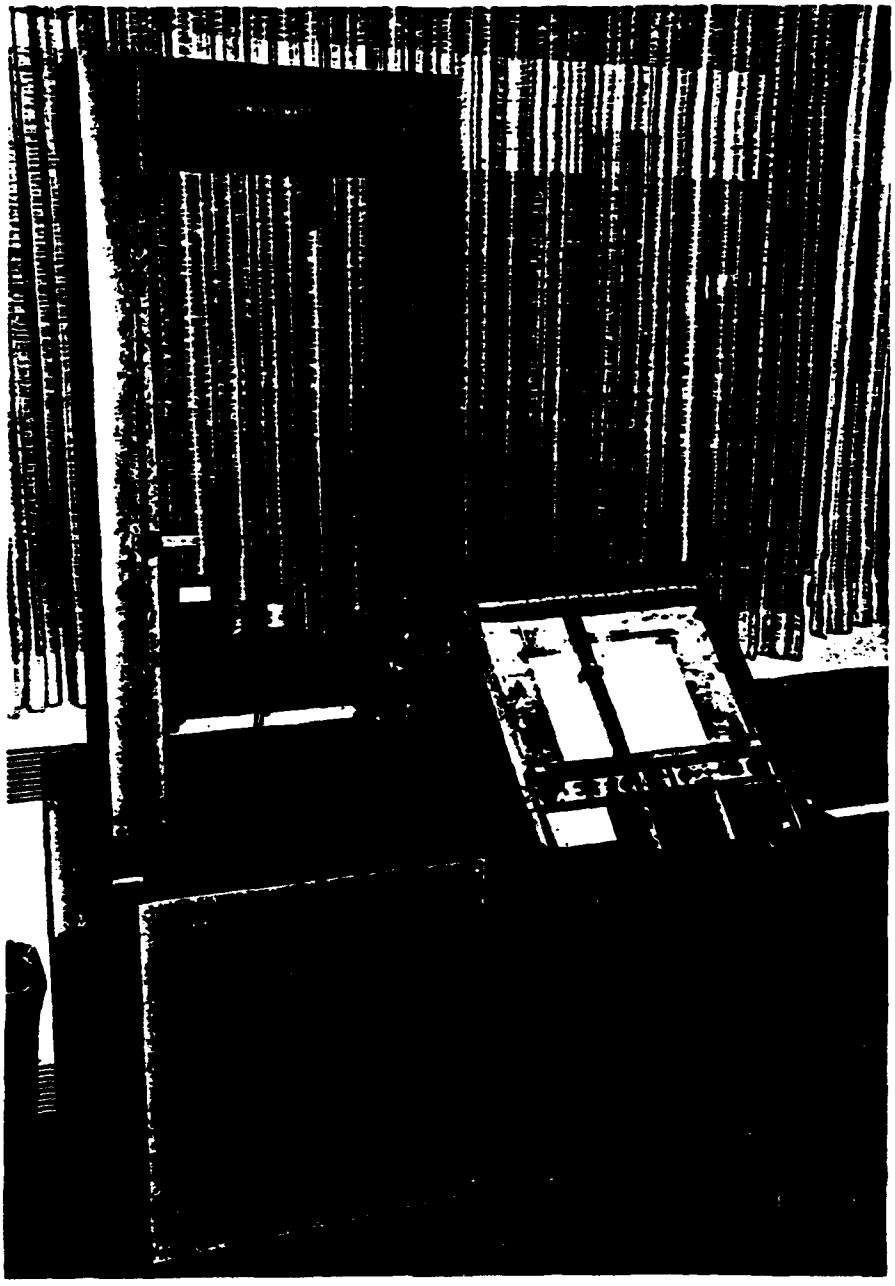


FIGURE 2

Houston Instruments X-Y Plotter

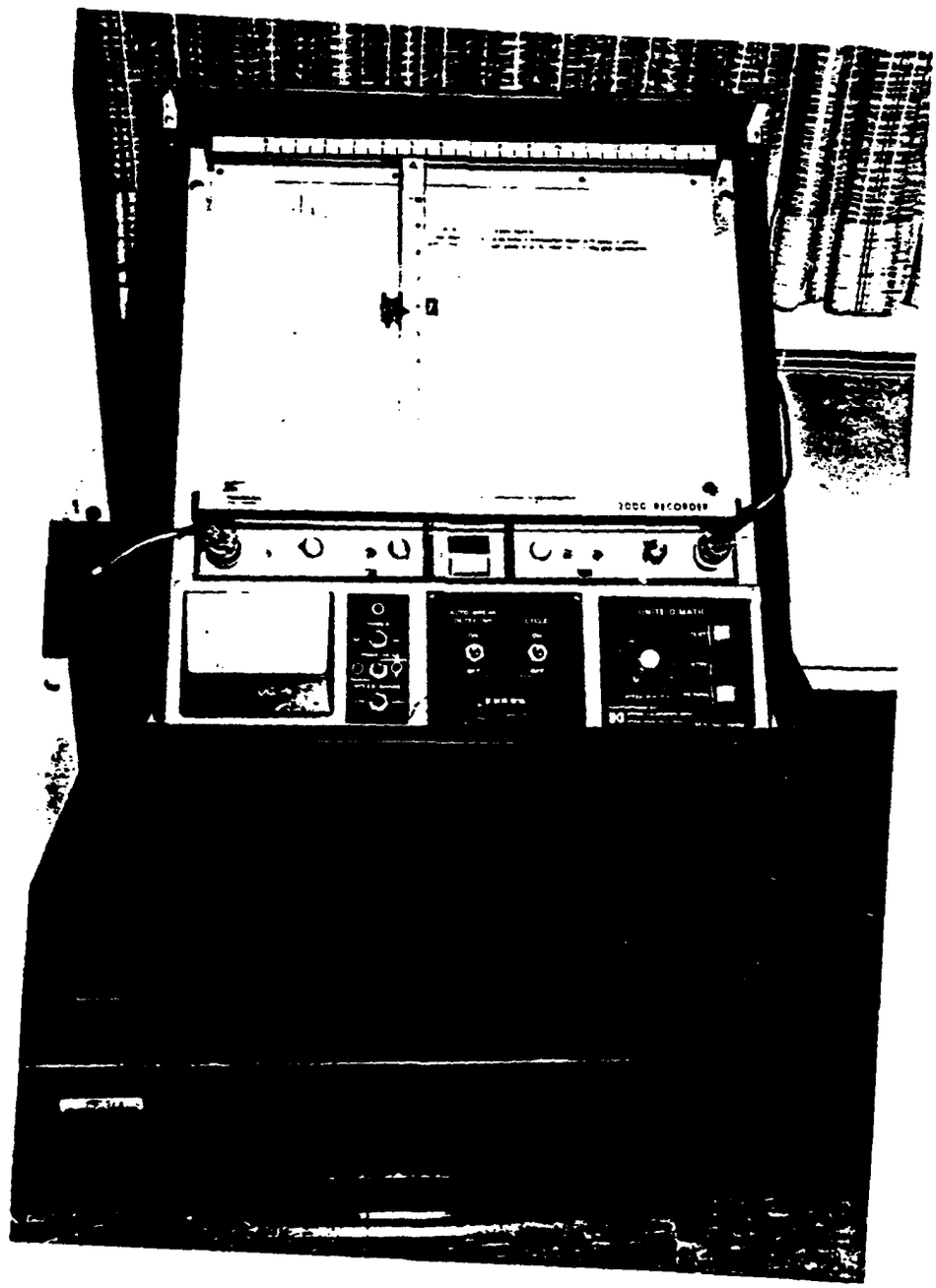


FIGURE 3

REL Abrasion Resistance Device

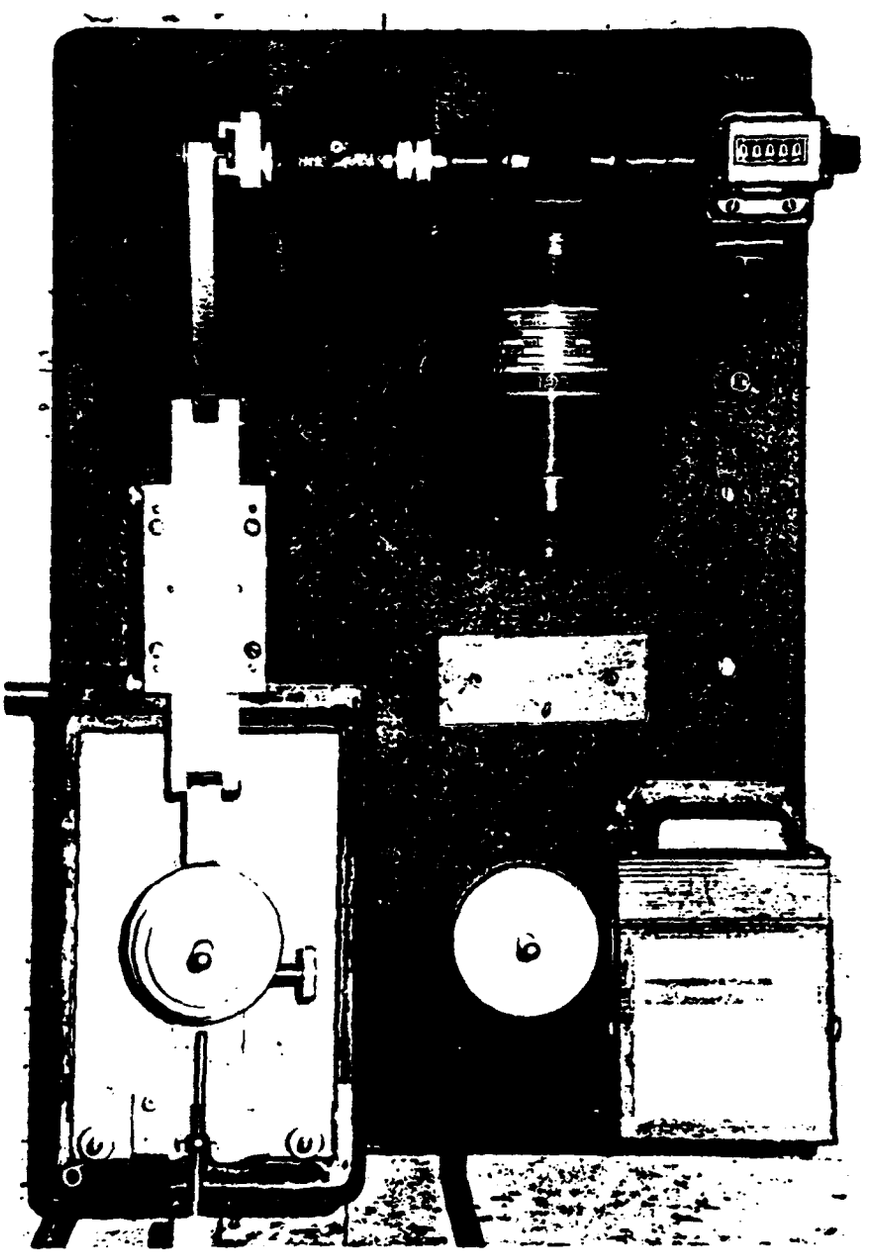


FIGURE 4

Linear Vernier Microscope

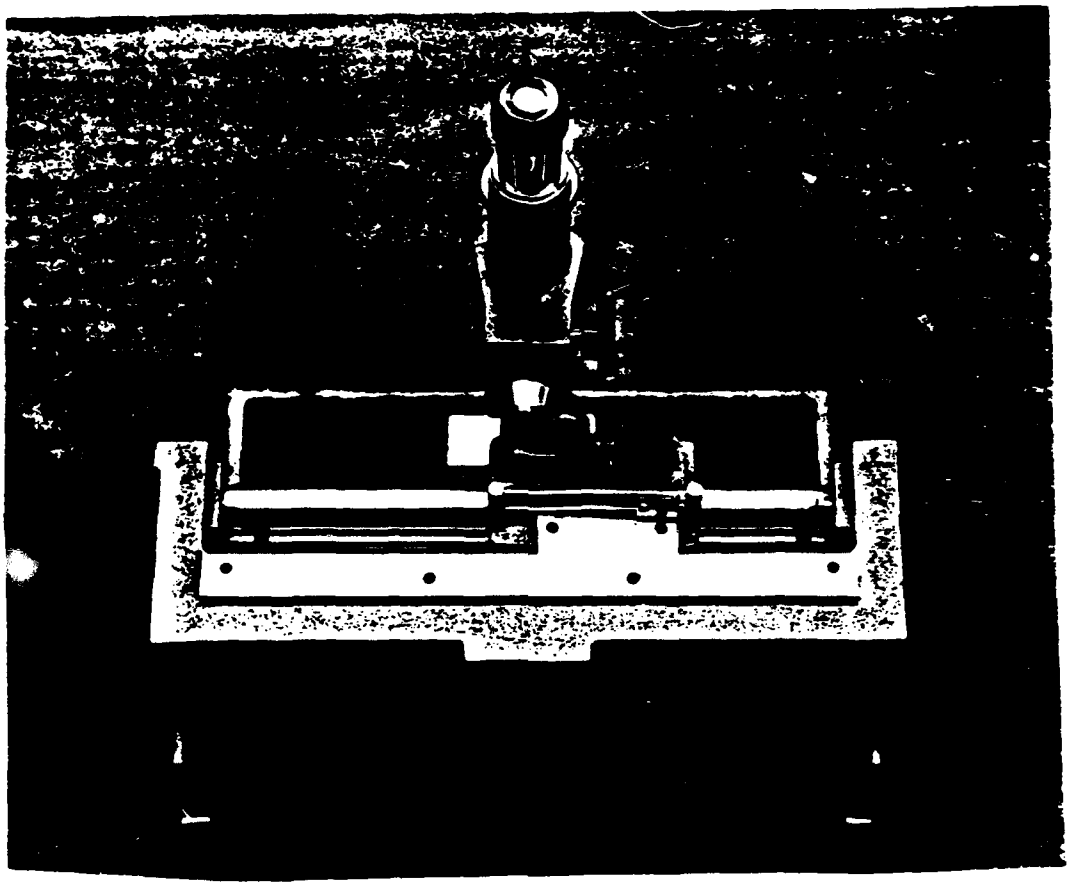


FIGURE 5

Model Trimming Device in Use

FIGURE 6

Compressive Strength - Effect of Material

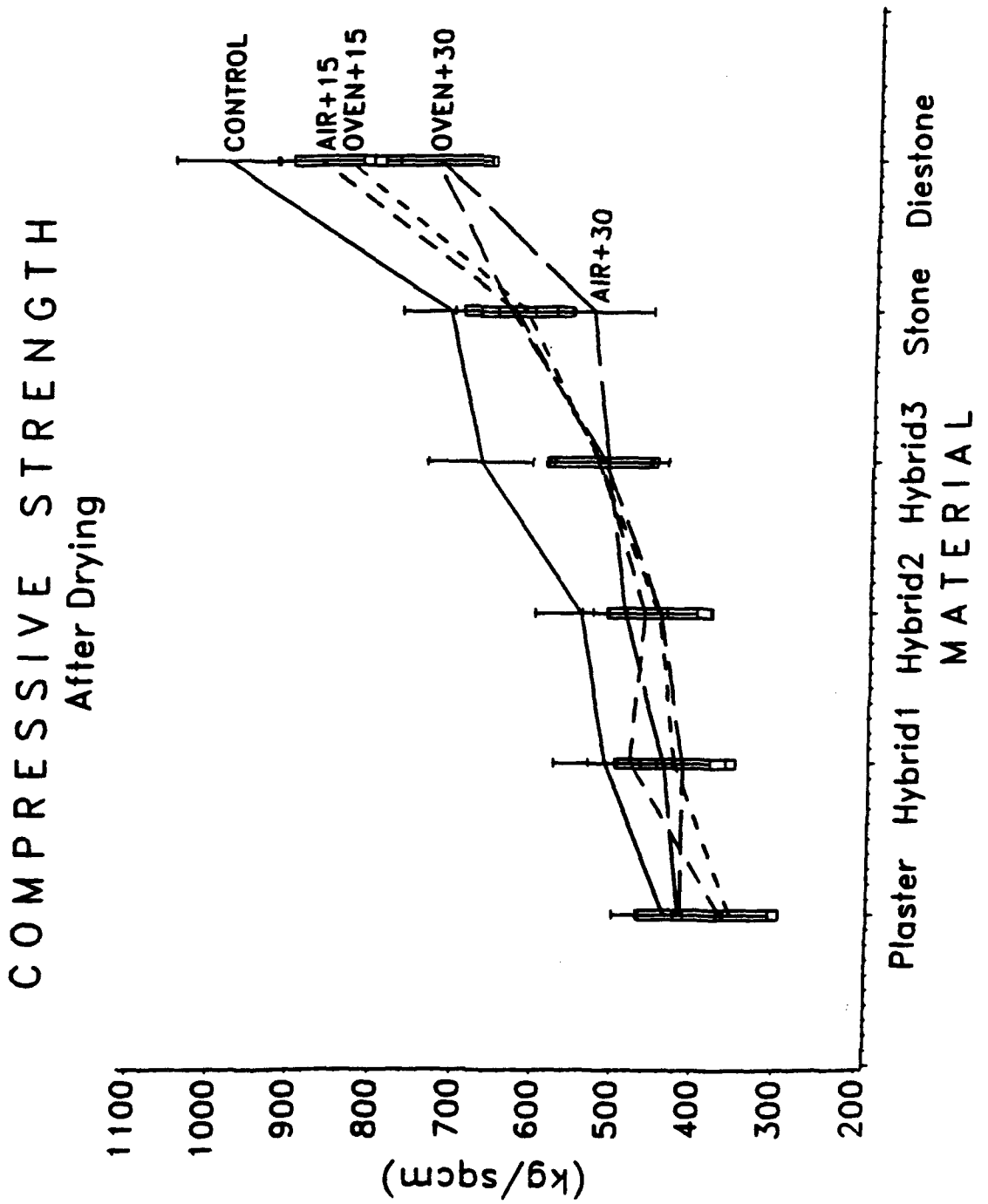


FIGURE 7

Compressive Strength - Effect of Treatment

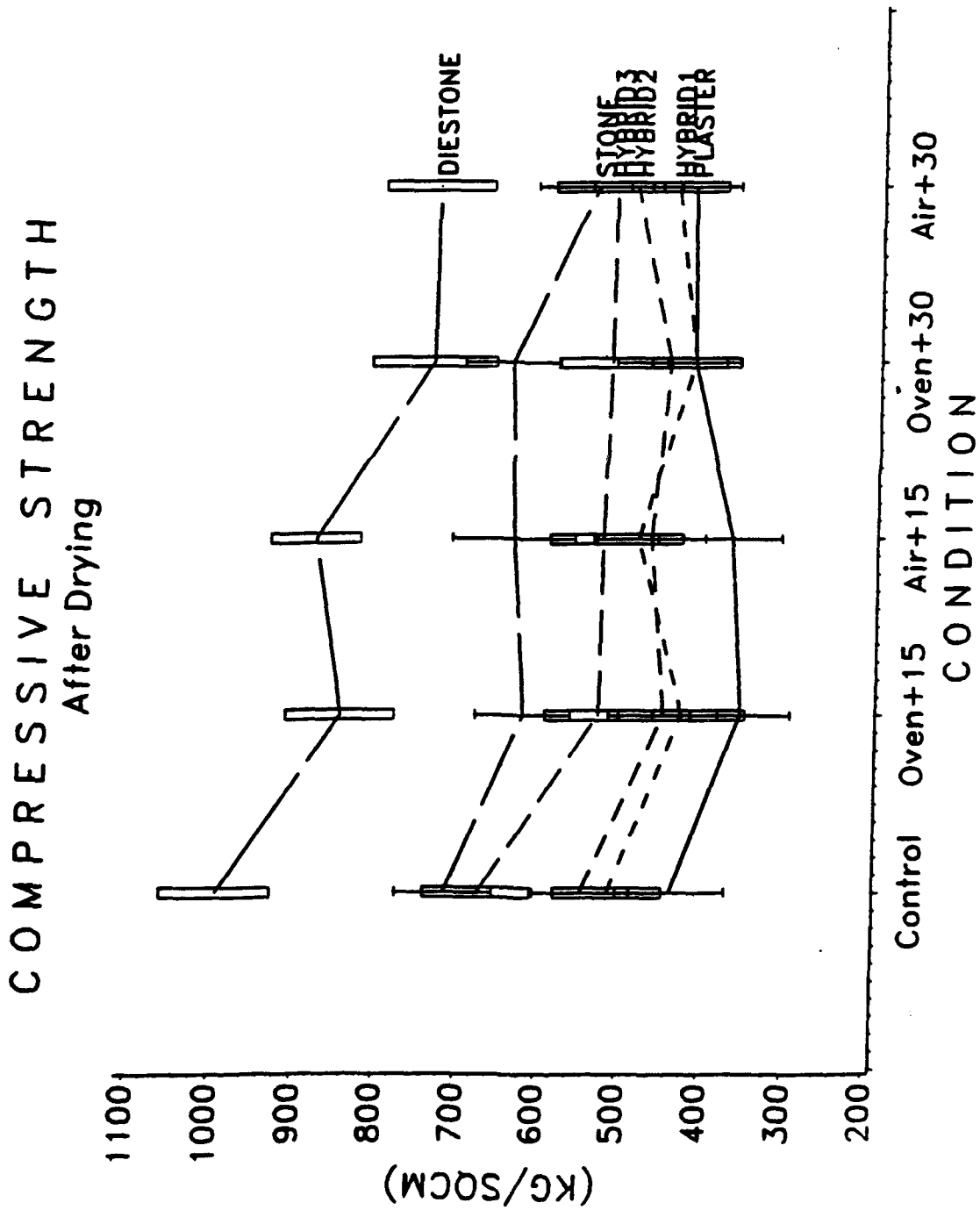


FIGURE 8

Diametral Strength - Effect of Material

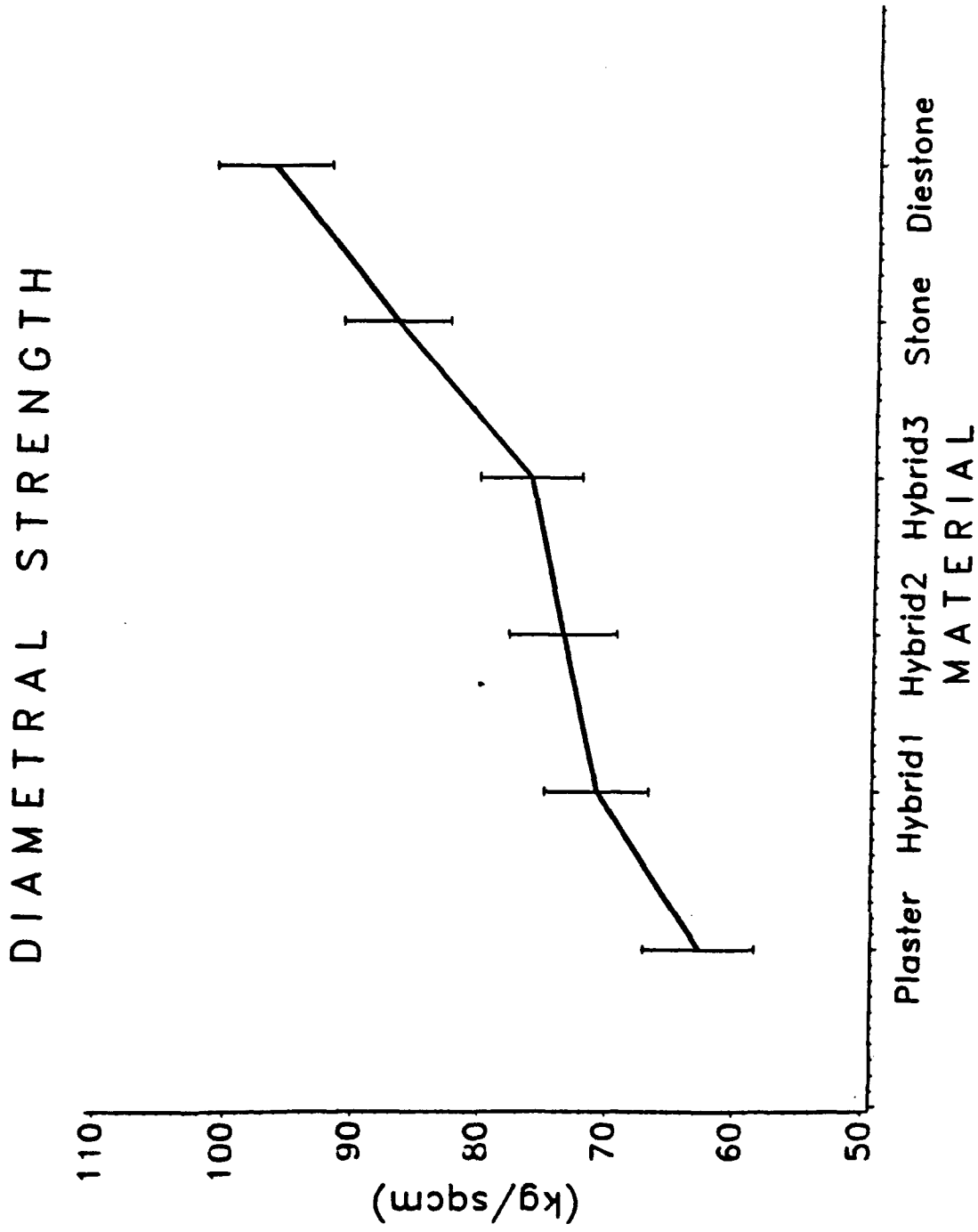


FIGURE 9

Diametral Strength - Effect of Treatment

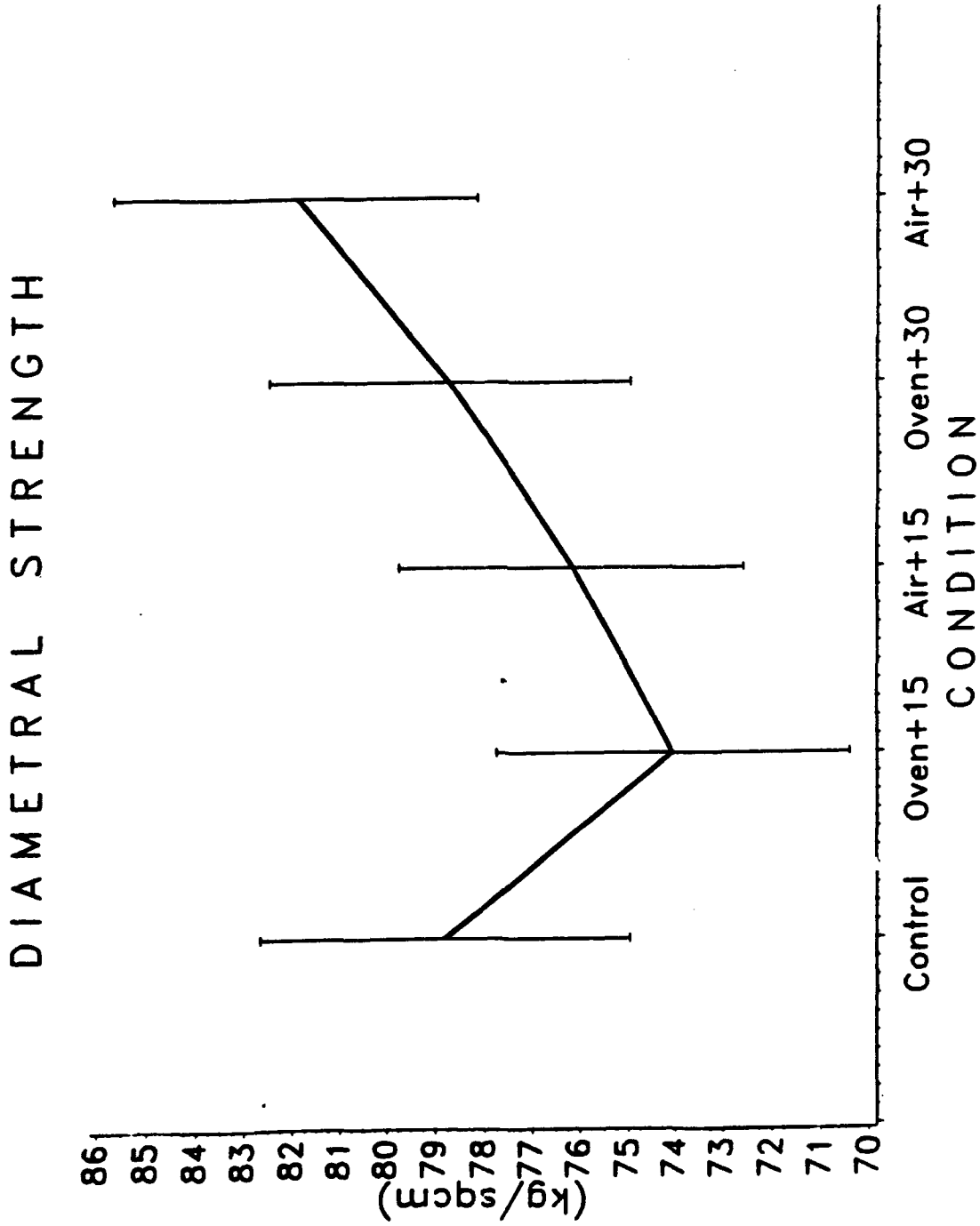


FIGURE 10

Transverse Strength - Effect of Material

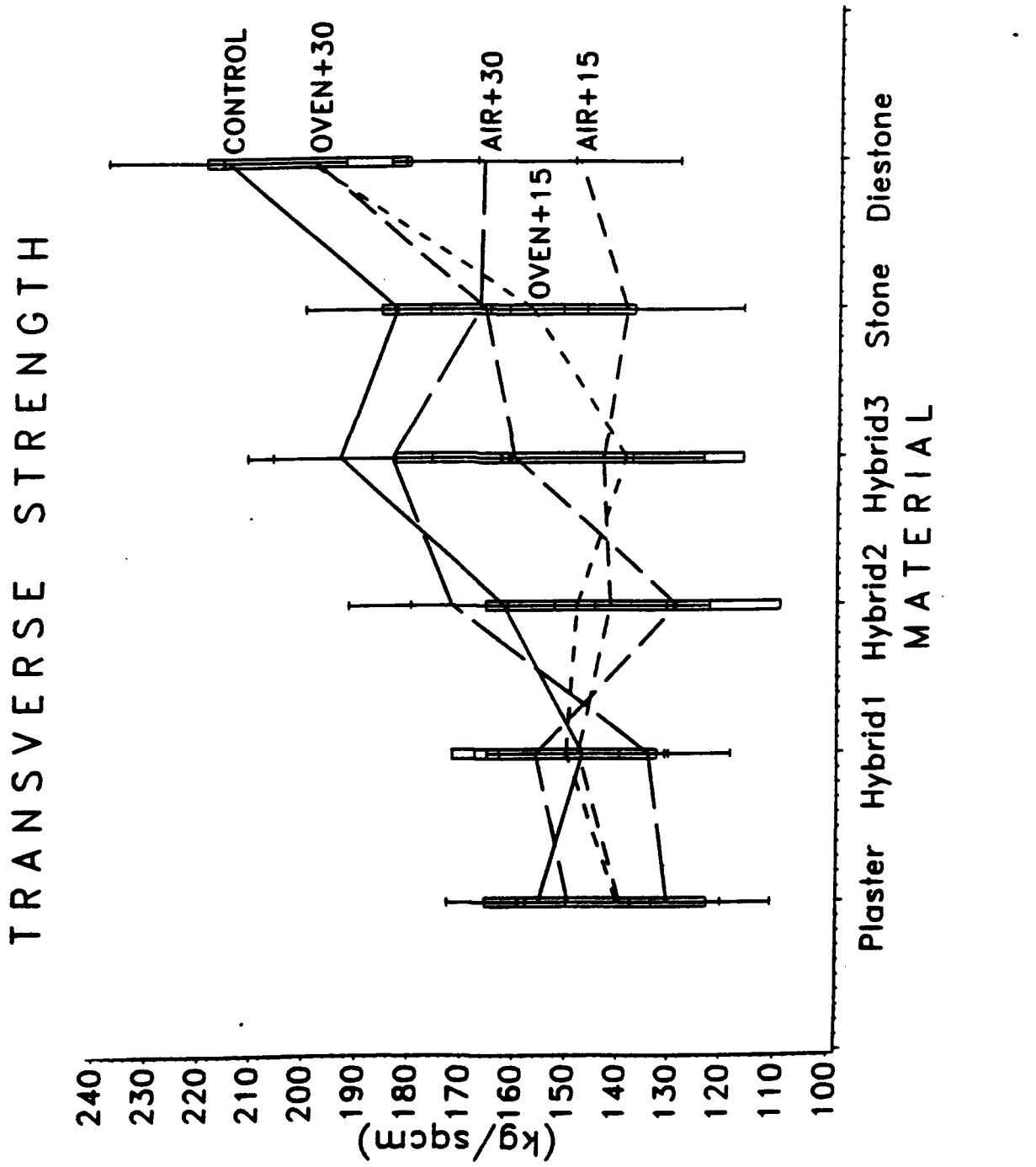


FIGURE 11

Transverse Strength - Effect of Treatment

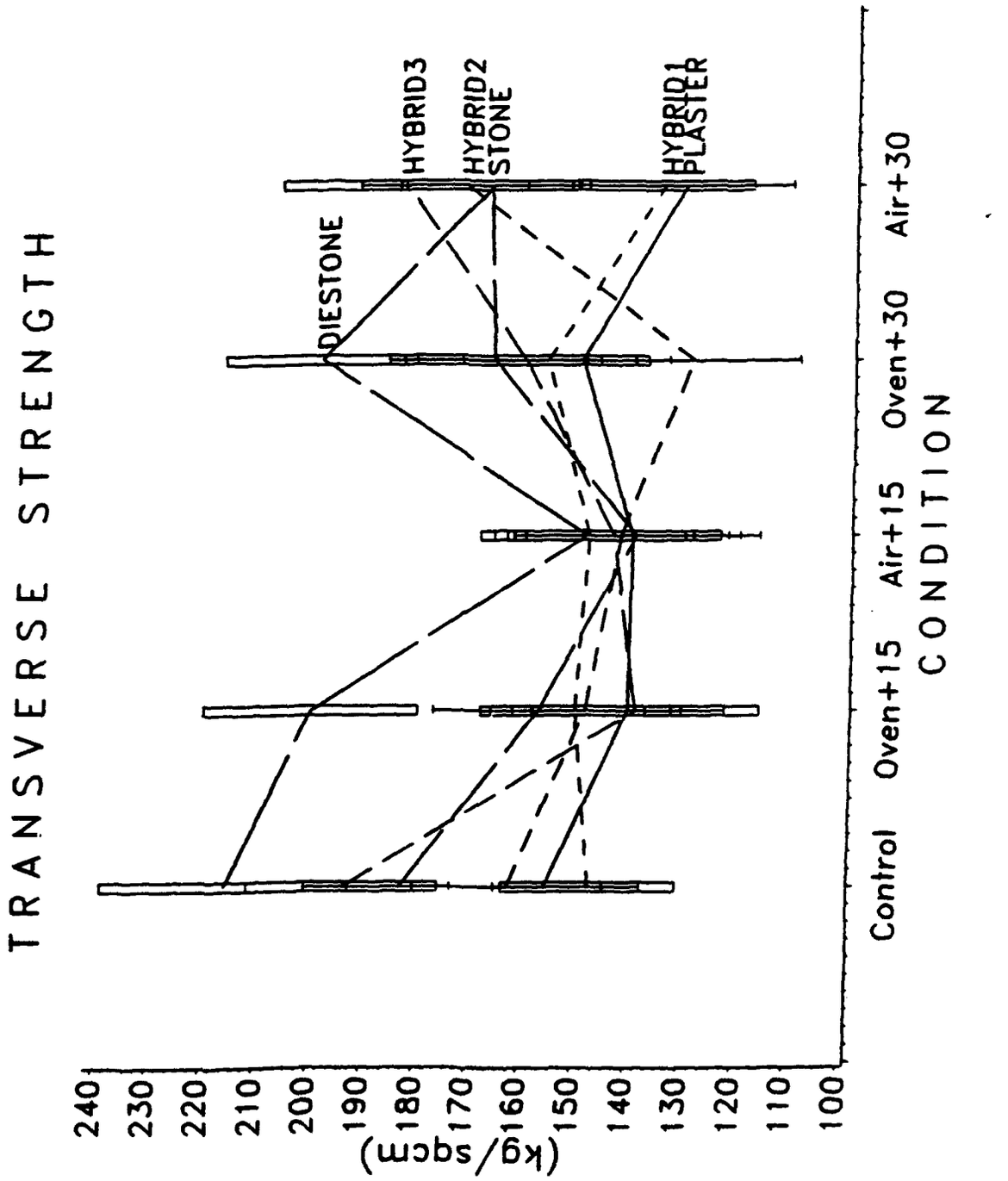


FIGURE 12

Abrasion Resistance - Effect of Material

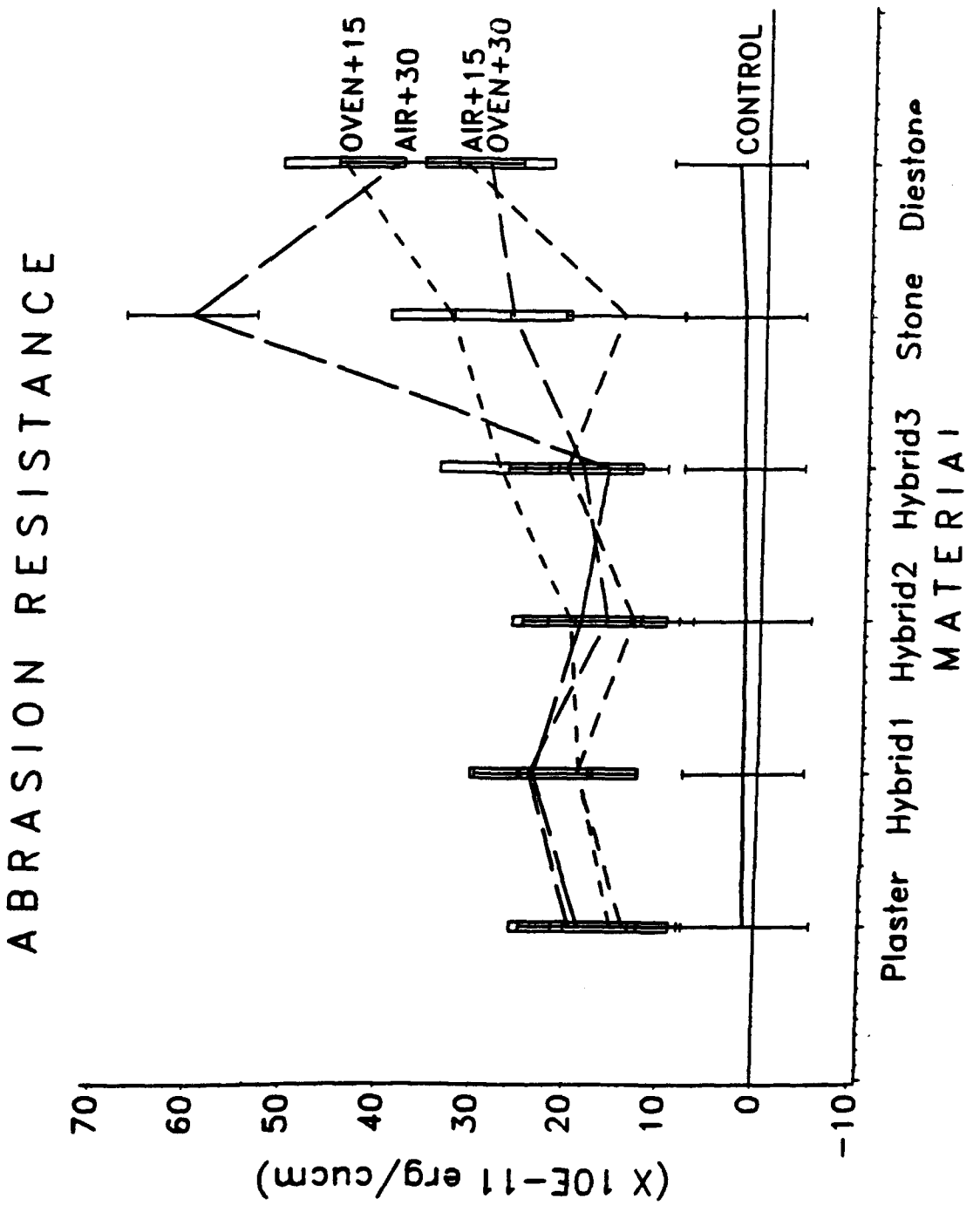


FIGURE 13

Abrasion Resistance - Effect of Treatment

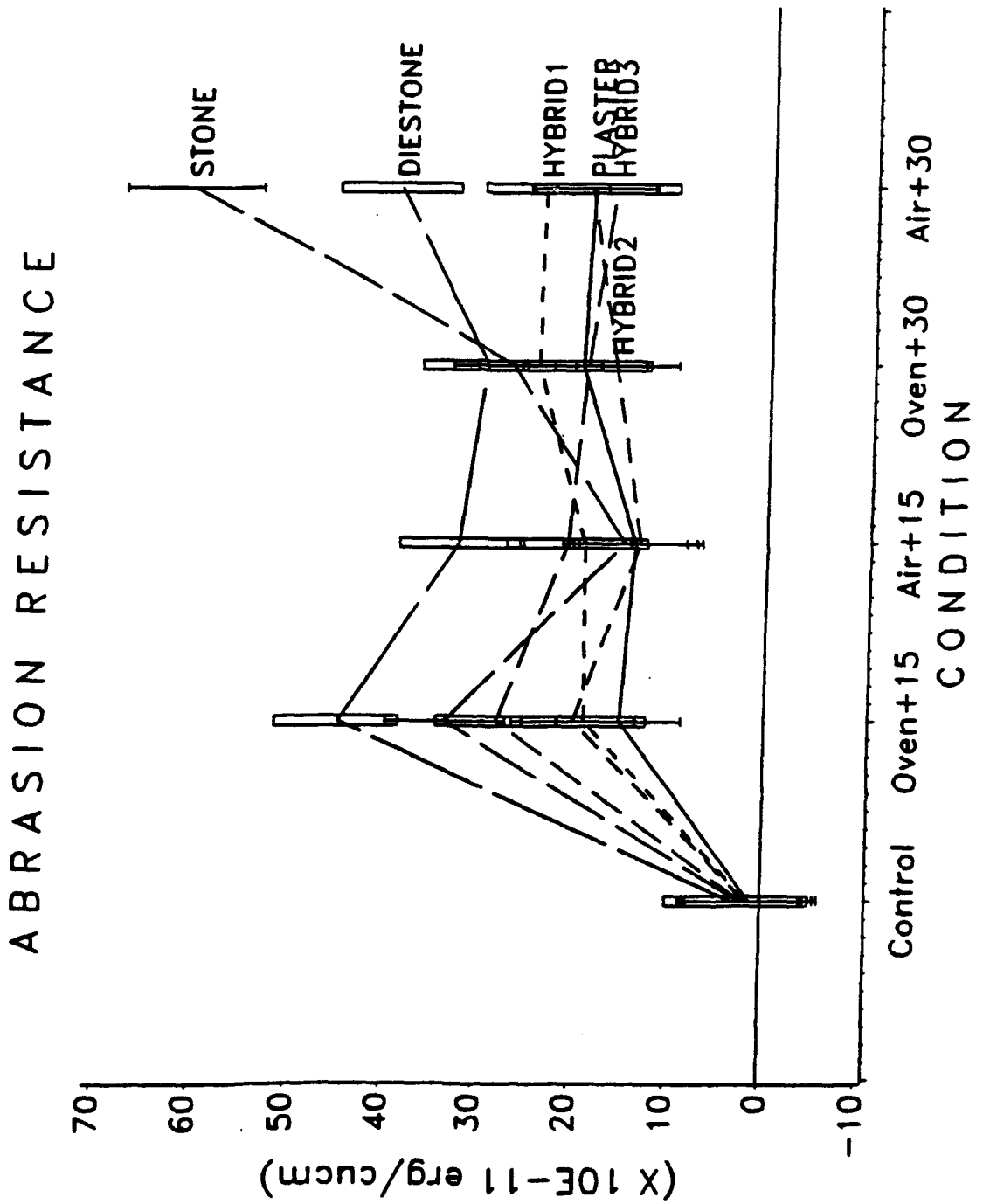
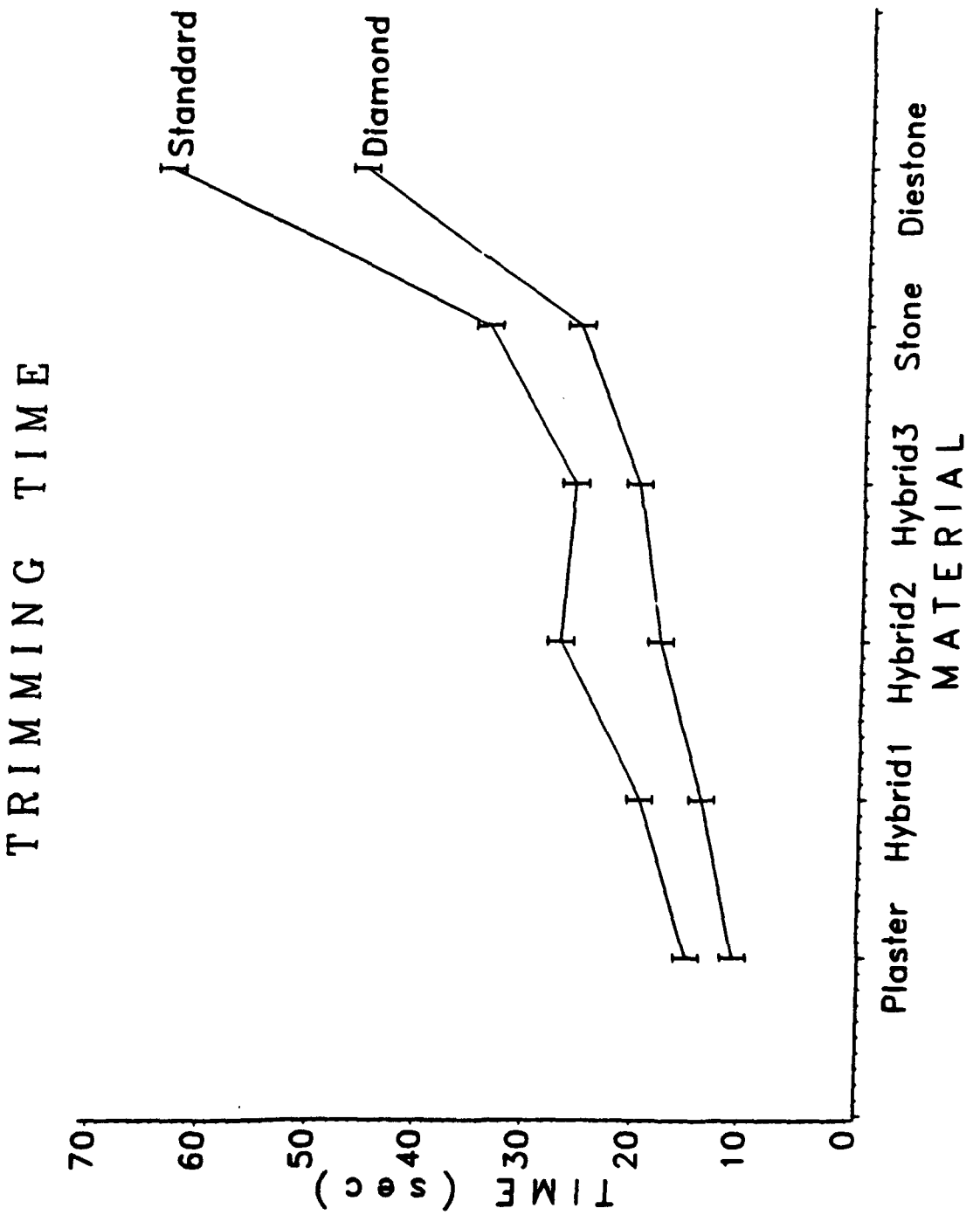


FIGURE 14

Trimming Times - Standard vs. Diamond Wheel



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VITA

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In June 1985, he entered the U.S. Air Force as a Dental Corps Officer and in July 1986, completed a one-year Advanced Education Program in General Dentistry. In July 1990, he entered the University of Louisville School of Dentistry, Graduate Program in Orthodontics, Louisville, Kentucky, where he received specialty training and will be granted a Certificate in Orthodontics in June 1992.