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Luke K. Choi

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Abstract

LOAD DEFORMATION TEST OF METAL BRACKETS: A COMPARATIVE STUDY

by

Luke k. Choi, DDS.

The purpose of this study was to determine the effect material and design (slot torque degree and wing type) had on the force and stress to permanently deform metal brackets

Fourteen different types of metal brackets were tested and categorized into three categories. The three categories were: raw material composition, slot torque degree, and wing type. There were 5 types of raw materials (310SS, 316L, 303SE, 303S, and 17-4PH), 3 types of slot torque degree (0 degree, 7 degree, and 12 degree), and 4 types of wing design (mini twin, single, regular twin, and modified twin). All brackets were tested using arch wire torque test developed by Flores.

An analysis of variance (ANOVA) and Student's t-test showed that raw material, wing type, and slot torque degree had a significant effect on the force and stress to permanently deform metal brackets. Of the three variables, raw material had the greatest effect on the force to permanently deform metal brackets.

Results showed that 17-4PH and 303S had higher yield strengths and regular twin had higher resistance to deformation. Also, as slot torque degree increased, brackets deformed with less force.

A positive correlation between the micro hardness and the stress to deform metal brackets confirmed that brackets with the greatest stress to permanently deform were made of steels with the greatest hardness.

LOMA LINDA UNIVERSITY

Graduate School

LOAD DEFORMATION TEST OF METAL BRACKETS: A COMPARATIVE STUDY

by
Luke K. Choi, DDS.

A Thesis Submitted in Partial Fulfillment
of the Requirements of the Degree Master of Science
in Orthodontics

June 1989

Each person whose signature appears below certifies that this thesis in his opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

Joseph M. Caruso ,Chairman

Joseph M. Caruso, Assistant Professor of Orthodontics

Jack L Tomlinson

Jack L. Tomlinson, Professor of Orthodontics

Garland E Scott

Garland E. Scott, Professor of Orthodontics

toufic Jeiroudi

M. Toufic Jeiroudi, Assistant Professor of Orthodontics

Dan A Flores

Daniel A. Flores, Assistant Professor of Orthodontics

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INTRODUCTION

The orthodontic bracket is the intermediary in tooth movement. It must receive the force from an activated element, usually a wire, and transmit the force to the tooth. If the bracket fails, by breaking or deforming, the force is not transmitted and treatment is delayed. It would be useful to know which bracket characteristics are associated with resistance to deformation and breakage.

Since the introduction of pretorqued brackets to orthodontics in 1970, several types of brackets have been made with different materials, prescriptions, wing designs, slot angles, and manufacturing processes. New technology and information relating to brackets makes choosing the right bracket to meet orthodontic goals difficult and confusing at best. Many orthodontic companies claim that their brackets are superior and some information may be misleading and/or irrelevant. Therefore, orthodontists need to seek and evaluate the information available and use it to select the best bracket to move teeth more effectively.

Major advantages of pretorqued brackets are reduced chair time and decreased wire bending. However, these advantages are dependent on the ability of these brackets to deliver the necessary forces to the teeth.

In recent years, orthodontic patients have become sensitive to their appearance during orthodontic treatment as well as after treatment. In order to meet the cosmetic demands of the general public for attractive brackets, orthodontic manufacturers have introduced smaller and more comfortable metal brackets.

Since their introduction, the public's acceptance of smaller metal brackets has been positive. They have become a useful option for orthodontists in helping to satisfy patients' concerns with appearance. However, these new brackets may not withstand typical occlusal and torquing forces, which would deform the metal brackets.

The primary purpose of this study was to determine the effect of material and design (slot torque degree and wing type) on the force and stress to permanently deform metal brackets. This may lead to a better understanding of the force-deformation characteristics of metal brackets, improvements in bracket designs and raw materials, and a wiser selection of available brackets.

REVIEW OF LITERATURE

In order to evaluate brackets, the physical and mechanical properties of their materials must be understood. Considerable research has been done to evaluate the properties of chromium-cobalt, titanium-molybdenum, and nickel-titanium alloy wires.[1-5] However, little research has been done to evaluate how the properties of bracket materials influence the properties of brackets used in orthodontics. No attempt has been made to describe where the strengths or weaknesses lie within metal bracket configurations.

Flores compared the fracture strength of ceramic brackets and the force to permanently deform metal brackets and found that ceramic brackets were able to withstand a higher force than metal brackets. It was suggested that the low failure force for metal brackets may indicate they were distorting during treatment when high torquing forces were placed on them.[6] However, only one type of metal bracket was compared against four types of ceramic brackets.

Metal orthodontic brackets are now made from five different American Iron and Steel Institute types of stainless steel.[7,8] Nominal compositions of the five different types of stainless steel are listed in Table 8.

Austenitic stainless steel has been used the most in orthodontics. This alloy contains about 18% chromium and 8% nickel and is commonly known as 18-8 stainless steel. The nickel content has a stabilizing effect on austenite so that the face-centered cubic structure is stable even at room temperature. Stainless steel type 303 was the first chrome-nickel, free-machining stainless steel ever made.

Stainless steel type 303SE is a free-machining 18-8 chrome-nickel steel, which has Selenium added to it. Selenium makes it more machinable, but it also gives up some hardness and strength.

Stainless steel types 316L and 310SS are molybdenum bearing austenitic steels with increased percentages of nickel These steels have higher tensile and creep strengths at elevated temperatures.

Stainless steel type 17-4PH is a martensitic precipitation hardened stainless steel, which offers high strength and hardness and excellent corrosion resistance. It has good fabricating characteristics and can be age hardened by a single, low temperature treatment.[8,9]

A definition of terms is necessary for a better understanding of the mechanical properties measured in this study.

Hardness is described as the resistance offered by the material to indentation. Hardness of a material is dependent on its strength. Even though there is no direct constant of proportionality, the higher the strength of a material, the higher its hardness. Strength properties of the tested material can be approximated by using standard tables available for ultimate tensile strength and equivalent hardness.[10,11,12]

Tensile strength is the maximum load sustained by the material prior to fracture, divided by the original cross-sectional area of the material. It is of value in orthodontics as a metal quality indicator since it defines the maximum force the material will withstand without breaking.[11,12]

Plastic or permanent deformation is a permanent change in shape. This change in shape is brought about by a stress in excess of the yield strength of the material.[11,12]

Yield strength of a material is the point where plastic flow starts under a continuously increasing load.

Force is a mechanical action of one body on another that tends to deform the body receiving it.[13]

Force at failure for the metal brackets is considered to be the point where they permanently deformed. However, this is a gradual transformational arbitrary point where there is no clear-cut yield point on the stress-strain curve.[11]

Stress is the intensity of internal force; internal force per unit of associated area.[13]

Stress at failure for the metal brackets represent the stress placed on the brackets at the point of failure.

The main objective of this study was to determine if the effects of material and design (slot torque degree and wing type) on the force and stress to permanently deform metal brackets were significant. By evaluating the effects of material and design on the deformation of brackets, a better understanding of their interplay and its importance may be reached. The secondary objective of this study was to see if there was a direct correlation between micro hardness and stress to deform metal brackets.

METHODS AND MATERIALS

It was of primary interest to define the deformation behavior of the brackets by duplicating the lingual root torquing force applied in orthodontic treatment. An archwire torque test was used to determine the force and stress to deform brackets which involved ligating a full size rectangular archwire into the slot of a bracket bonded to a steel base, mounting the base in a holding vice, and engaging a torquing key until the bracket deformed as described by Flores.[6] This method produced consistent, repeatable, and accurate data.

Fourteen types of commercially available metal edgewise brackets were tested. A total of 140 brackets, 10 from each type, were tested for force and stress to permanently deform. In order to keep the testing variables to a minimum, only maxillary central brackets with an .018 x .025 inch slot size were used.

Three categories (raw material, slot torque, and wing type) were developed in order to see if the different materials and designs affected the force and stress to deform metal brackets. (Table 1)

There were 5 different types of raw materials (310SS, 316L, 303SE, 303S, and 17-4PH); 3 different types of slot torque degree (0 degree, 7 degree, and 12 degree lingual root torque); and 4 different types of wing designs(mini twin, single, regular twin, and modified twin).

Regular twin brackets had four wings and standard size occlusal-gingival (0.150") and mesial-distal (0.160") dimensions.

Mini twin brackets had four wings but were approximately 30 % smaller than a regular twin in the occlusal-gingival dimension. Modified twin brackets had four wings which were inter-connected mesio-distally. Single brackets had two wings, one occlusal and one gingival.

All fourteen types of brackets were compared in the raw material and wing type categories.

Four types of brackets were divided into two groups and compared in the slot torque category (Bracket ID numbers 2, 3, 8, and 9). Each group had two types of brackets having the same material and wing design with different slot angles.

A high strength, tensile strength of 340 ksi, and full size, .018 x .025, stainless steel archwire was used to minimize the distortion and play of the archwire in the slot and to transmit the force directly to the brackets.[7] This archwire was ligated to the brackets with elastic ligatures because Flores showed no significant difference between the elastic or metal ligatures as ligation methods when testing for fracture strength of ceramic brackets.[6]

A custom made torquing key with two slots was engaged to the archwire. The width between slots was reduced from .380" (Flores torquing key) to .240" in order to reduce deformation of the archwire.

An Instron, a tensile testing machine, was used to pull up on the torquing key at a crosshead speed of 10 mm/min. until the bracket failed, as described by Flores.[6] When the metal brackets deformed, the slope of the line on a graph measuring applied torsional force began to slowly decrease in steepness. The force to peramanently deform metal bracket was determined to be the point where the line's slope began to decrease.

Measurements were made from the Instron's graph paper, which plotted a slope for each bracket tested. To obtain the equivalent yield point a straight line was drawn to the linear portion of the plot and the force to deform the metal bracket was determined to be the beginning point of departure from the straight line. This is a gradual transformational arbitrary point where there is no clear-cut yield point.[11] This measurement may have introduced some experimental errors.

In this study, the Knoop hardness test was used to determine the hardness of the materials tested. This test employed a rhomboidal diamond indenting tool on which carried a half kg load. Hardness was determined from the length of the long axis of the indentation. The Knoop hardness number (KHN) is the load divided by the projected area of the surface of the indentation. Then, the Brinell hardness number (BHN) and estimated tensile strength (ETS) were determined from tables.[10]

The beam bending formula developed for Flores was used to convert force (P) to stress at failure (SF) in order to interpret the torsional forces applied to the different brackets.[6] (Figure 4) However, this equation was developed to study stress at failure for brittle materials. So, the converted stress at failure for metal materials is only an approximated value, and this may have introduced further experimental errors.

Force to deform values represent the force in lbs. exerted by the Instron at the point of bracket failure and stress to deform values in ksi represent the stress placed on the brackets at the point of failure. Stress at failure values for metal brackets are considered to be their yield strength.

Micro hardness (MH) is micro hardness number in Brinell hardness number (BHN in Kg/mm^2) and estimated tensile strength (ETS) is in ksi.

Statistical Analysis

Statistical analysis included the use of several analysis of variance (ANOVA) and Student t-tests with the force and stress to deform as the dependent variables and with raw material, slot degree, and wing type as the independent variables. A correlation regression analysis for the micro hardness (MH) and estimated tensile strength (ETS) was done with the stress to deform.

RESULTS

Raw Material

The forces to deform under the raw material category ranged from 0.233 lbs. for the 303S brackets to 0.118 lbs. for the 303SE brackets. Force values show the behavior of the material and design parameters together. Forces for 303S (0.233 lbs) and 17-4PH (0.200 lbs) brackets were significantly higher than those for the rest of the brackets: 310SS (0.140 lbs), 316L (0.129 lbs), and 303 SE (0.118 lbs). The effect of raw material, in order of force to permanently deform or fracture brackets, is shown in Table 4.

The stress values to deform under the material category ranged from 221.7 ksi for the 17-4PH brackets to 63.7 ksi for the 310SS brackets. Stress values show the behavior of the material alone under a given stress. Mean stresses for 303S (210.5 ksi) and 17-4PH (221.7 ksi) brackets were significantly higher than those for the rest of the brackets: 316L (133.9 ksi), 303SE (92.2 ksi), and 310SS (63.7 ksi). The stress values at failure for each type of bracket material was calculated and is shown in Table 5.

Wing Type

The force to deform values under the wing type category ranged from a high of 0.203 lbs. for the regular twin to a low of 0.156 lbs. for the single. The regular twin (0.203 lbs) bracket was the only one with a mean significantly higher than the other three wing types: mini twin (0.174 lbs); modified twin (0.167 lbs); and single (0.156 lbs). The effect of wing type, in order of force to permanently deform brackets, is shown in Table 6. The order of force to fail presents a sequence of wing designs which can be associated with the strongest and weakest wing design.

Slot Torque

Slot angle difference was the only variable between the two comparisons made in the slot torque category. Forces to deform were 0.102 lbs. for the 12 degree torque bracket (ID 4) and 0.134 lbs. for the 0 degree torque bracket (ID 3) in one comparison. In the other comparison, forces to deform were 0.210 lbs. for the 12 degree torque bracket (ID 8) and 0.236 lbs. for the 7 degree torque bracket (ID 9). These differences (0.033 lbs) were significantly different, as confirmed by the Student's t-test. (Table 2)

Micro Hardness

A wide range was found in micro hardness and estimated tensile strength among the five materials tested. Micro hardness ranged from a low of 177.9 (BHN) for the 310SS brackets to a high of 350.5 (BHN) for the 303S brackets. Estimated tensile strength ranged from a low of 85.5 ksi for the 310SS brackets to a high of 180 ksi for the 17-4PH brackets.

Micro hardness means of 17-4PH (339.5) and 303S (350.5) brackets were significantly higher than those of 310SS (177.9) and 316L (258.6), brackets. (Table 7)

A correlation regression analysis for the micro hardness (MH) and estimated tensile strength (ETS) was done with the stress to deform. Micro hardness and stress to deform had a correlation coefficient of .623, which indicated a positive correlation at the 0.1% level of significance between hardness and stress to deform. (Figure 4)

DISCUSSION

Raw Material

Raw material had a significant effect on the force to permanently deform metal brackets, with 17-4PH and 303S having the strongest values. The three other materials, 303SE, 310SS, and 316L stainless steels, had much lower forces to deform. There was a significant difference between these two groups of 0.088 lbs., as confirmed by the Student's t-test. (Figures 1 illustrates the values in Table 4)

Raw material study clearly showed 17-4PH to have the highest stress at failure and 310SS to have the lowest stress at failure. Table 5 shows the order of stress to fail and presents a sequence of materials which can be distinguished and asociated with the strongest and weakest materials. These stress values separate the design and material parameters and show the behavior of the material alone under a given stress.

The two strongest materials were 17-4PH and 303S stainless steels, whose stress to permanently deform averaged 216.1 ksi. The materials which failed with the lowest stress were 303SE, 310SS, and 316L stainless steels, whose stress to deform averaged 96.6 ksi. (Figure 2 illustrates the values in Table 5)

It seems clear that a major influence on force and stress to deform metal brackets is the type of alloy material used to manufacture them. For example, when comparing force and stress to deform values of two bracket types, with the same design and slot torque, but made of different raw materials, the one made from 17-4PH was much higher than the one made of 316L. This large difference in the force and stress to deform values was due to 17-4PH, which is a much stronger raw material than 316L. (Table 2)

Wing Type

When grouping force values, there were two main groups in wing type catagory also. This study clearly showed the regular twin to be the strongest wing design and the single, modified twin, and mini twin to be the weaker wing designs. There was a significant difference between these two groups (0.037 lbs). This can be explained by the fact that the regular twin brackets have larger mesial-distal and gingival-incisal dimensions. A large size bracket (mesial-distal and gingival-incisal dimensions) will allow the stresses to be dissipated throughout a greater area and minimize the deformation of bracket. Wing type had a significant effect on the force to permanently deform metal brackets with the regular twin having the strongest values. However, the effect of wing type (0.037 lbs) on the force to permanently deform brackets was not as great as raw material. (0.088 lbs) (Figure 3 illustrates the values in Table 6)

Slot Torque

Results showed a significant difference in force to deform when comparing brackets with different slot angles but having the same material and wing design. This finding showed that as the slot torque degree increased, the metal brackets deformed with less force. This can be explained by the fact that the thickness of the bracket's wing at the base of the slot was reduced as slot angle increased. This reduction in thickness may have contributed to the metal bracket deforming with less force. The magnitude of the force difference due to changes in slot angle (0.033 lbs) was less than raw material (0.088 lbs) and wing type (0.037 lbs). (Table 2)

The Effect of Three Variables on Force

All three variables had a significant effect on the force to deform values and raw material proved to have the greatest effect. This study showed that the magnitude of the force difference due to different material was greater than those due to different wing type or due to changes in slot torque. So when choosing a bracket, raw material will be the most important factor to consider.

Hardness Study on Stress

Micro hardness study showed that the brackets which require the greatest stress to permanently deform are made with the steels of greatest hardness. It is not clear whether the hardness is due to the chemistry of the alloy or the means by which the material was fabricated. The 17-4PH stainless steel is especially strong when solution treated and aged. It is not known whether all the brackets used in this study were properly solution treated and aged because brackets made of 17-4PH did not all have the same hardness and stress values. Therefore, it appears that not all 17-4PH brackets were solution treated and aged the same. So, even brackets with the same raw material but from different suppliers, may have different physical properties and orthodontists should be aware of this possibility.

Clinical Implications

Because of the limitations of the oral cavity and patients' esthetic concerns, a large bulky bracket may not be acceptable. However, if brackets are made of stronger raw materials (17-4PH or 303S), smaller, more attractive and more comfortable brackets can be made without compromising on the force to deform.

Increasing slot torque on certain brackets will allow orthodontists to achieve lingual root torque movement more efficiently, with less chair time. However, as this study indicated, this may cause metal brackets to deform with less force. Since the effect of using a stronger raw material on the force to deform brackets is greater than that of changes in slot torque degree, an implication can be made that if the brackets are made of stronger raw materials, the slot torque degree can be increased without decreasing the force to deform the metal brackets.

In the past, many orthodontists thought that one had to increase archwire size to achieve more efficient torque on the teeth. This thought is only partly true because one did not realized that brackets were deforming more and more during treatment. Thus, because the brackets deformed, larger size archwires were needed to achieve the desired torques.

SUMMARY AND CONCLUSION

A total of 140 metal brackets, 10 from each type of bracket, were tested for their force and stress to deform. In order to separate the design and material parameters, force and stress at failure were evaluated. Each type of bracket was evaluated according to the variables of material, slot torque degree, and wing type to see if they would have a significant effect on the force and stress at failure.

Results of this investigation led to the following conclusions:

1. Raw material had a significant effect on the force to permanently deform metal brackets. 17-4PH and 303S had the higher yield strengths.
2. Wing type had a significant effect on the force to permanently deform metal brackets. Regular twin had the higher resistance to deformation.
3. Slot torque had a significant effect on the force to permanently deform metal brackets. As the slot torque degree increased the metal bracket deformed with less force.
4. Of the three variables, raw material had the greatest effect on the force to permanently deform metal brackets.
5. The brackets which require the greatest stress to permanently deform are made with the steels of greatest hardness.

In the final analysis, one can conclude that the material parameter is the most important factor on the force to deform metal brackets. Based on the results at this study, brackets need a strong material, with enough bulk, and a proper design in order to prevent deformation during treatment.

It is important for the orthodontist to understand the effects different forces can impose on brackets. Due to the interplay between design and material, brackets will respond differently to applied forces. Orthodontists should be aware of the different materials and designs available and their effect on treatment efficiency.

During orthodontic treatment, an orthodontist continuously imposes forces on brackets by torquing the archwire. In order to accomplish the desired tooth movement, the amount of torque an orthodontist puts into the wire would be more effective and his treatment, therefore, more efficient if the brackets do not deform during treatment. Results from this study can help orthodontists choose the most efficient bracket for their treatment modality, when materials and designs are considered.

It is recommended that further study be done to determine the amount of deformation brackets exhibit due to prolonged static loading (the amount of creep).

APPENDIX

TABLE 1
Description of Brackets

Bracket ID Number	Number Tested	Raw Material	Slot Degree	Wing Type
1	10	316L	12	Mini Twin
2	10	17-4PH	12	Mini Twin
3	10	303SE	0	Single
4	10	303SE	12	Single
5	10	17-4PH	12	Mini Twin
6	10	310SS	12	Reg Twin
7	10	310SS	0	Single
8	10	303S	12	Reg Twin
9	10	303S	7	Reg Twin
10	10	303S	0	Single
11	10	303S	12	Mod. Twin
12	10	316L	12	Mini Twin
13	10	316L	12	Mod. Twin
14	10	17-4PH	12	Mini Twin

TABLE 2
Force & Stress at Failure for Each Type of Bracket

Bracket ID Number	Number Tested	Force		Stress	
		Mean	SD	Mean	SD
1	10	.145	.019	163.6	21.5
2	10	.127	.015	83.7	9.4
3	10	.134	.024	104.9	18.8
4	10	.102	.017	79.5	13.6
5	10	.227	.013	370.9	21.5
6	10	.163	.019	62.1	7.0
7	10	.117	.014	65.4	7.7
8	10	.210	.017	108.5	8.5
9	10	.236	.019	122.0	9.7
10	10	.270	.020	171.1	12.7
11	10	.215	.014	440.1	27.8
12	10	.122	.014	103.5	12.1
13	10	.119	.013	134.6	14.8
14	10	.247	.012	207.7	10.8

Force at failure in Lbs.
Stress at failure in ksi

TABLE 3
Hardness and Est. UTS for Each Type of Bracket

Bracket ID Number	Number tested	Hardness Mean	 SD	Est. UTS Av. Mean
1	10	346.0	57.4	168
2	10	192.8	36.6	92
3	10	261.7	20.0	124
4	10	-	-	-
5	10	529.4	150.0	304
6	10	153.4	36.2	74
7	10	202.3	45.5	97
8	10	276.2	117.0	132
9	10	-	-	-
10	10	395.0	96.0	194
11	10	380.3	87.1	188
12	10	126.9	44.2	*
13	10	302.9	109.3	148
14	10	296.4	74.6	144

MH is micro hardness number in Brinell hardness number (BHN)
ETS is estimated tensile strength in ksi
(-) Denotes no data
(*) Denotes no data due to low micro hardness

TABLE 4
Effect of Raw Material Ranked by Force

Type of Raw Material	Number Tested	Force Mean	Force SD
1. 303S	40	.233	.029
2. 17-4PH	30	.200	.055
3. 310SS	20	.140	.029
4. 316L	30	.129	.019
5. 303SE	20	.118	.026

TABLE 5
Effect of Raw Material Ranked by Stress

Type of Raw Material	Number Tested	Stress Mean	Stress SD
1. 17-4PH	30	221.7	120.4
2. 303S	40	210.5	137.3
3. 316L	30	133.9	29.6
4. 303SE	20	92.2	20.7
5. 310SS	20	63.7	7.4

Force at failure in lbs.
Stress at failure in ksi

TABLE 6

Effect of Wing Type Ranked by Force

Type of Wing	Number Tested	Force	
		Mean	SD
1. Reg Twin	30	.203	.035
2. Mini Twin	50	.174	.055
3. Mod Twin	20	.167	.051
4. Single	40	.156	.070

Force is in lbs.

TABLE 7

Hardness and Est. UTS for Each Type of Raw Material

Type of Raw Material	Number Tested	Hardness		Est. UTS	
		Mean	SD	Mean	SD
1. 17-4PH	30	339.5	172.1	180.0	91.8
2. 303S	40	350.5	111.2	171.3	28.4
3. 303SE	20	261.9	13.8	124.0	0.0
4. 316L	30	258.0	121.0	158.0	10.5
5. 310SS	20	177.9	47.2	85.5	11.8

Hardness is in Kg/mm^2

Estimated tensile strength is in ksi

TABLE 8
Chemical Composition, by Percent

Raw Material	Cr	Ni	Mn	C	P	S	Si	Mo	Se
1. 310SS	24.0 26.0	19.0 22.0	2.0	.08	.04	.03	1.5	.75	
2. 303SE	17.0 19.0	8.0 10.0	2.0	.15	.20 .17	.06	1		.15 .35
3. 316L	16.0 18.0	10.0 14.0	2.0	.03	.04	.03	1.0	2.0 3.0	
4. 303S	17.0 19.0	8.0 10.0	2.0	.15	.04	.18 .40			
5. 17-4PH	15.5 17.5	3.0 5.0	1.0	.07	.04	.03	1.0		

Note: Nominal compositions of stainless steel was generated from International Nickel Company.[8]

FIGURE 1

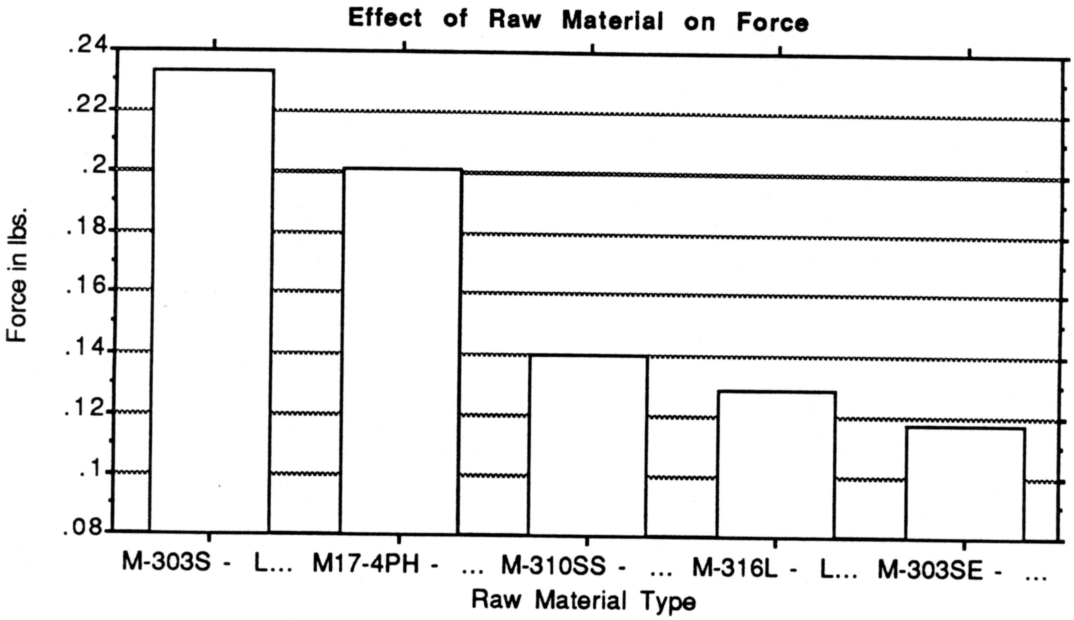


FIGURE 2

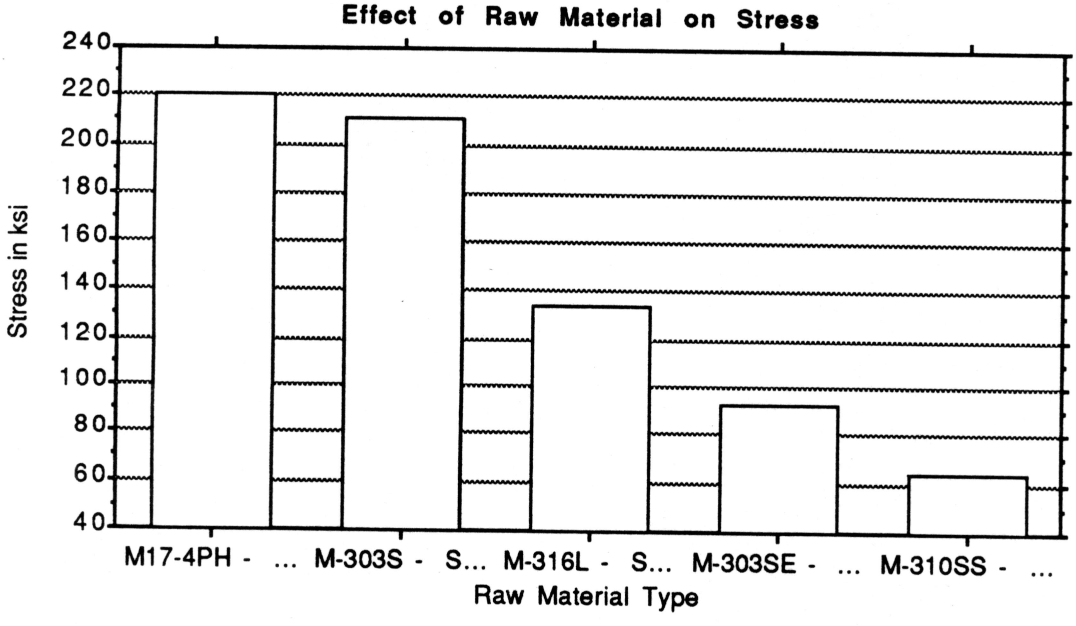


FIGURE 3

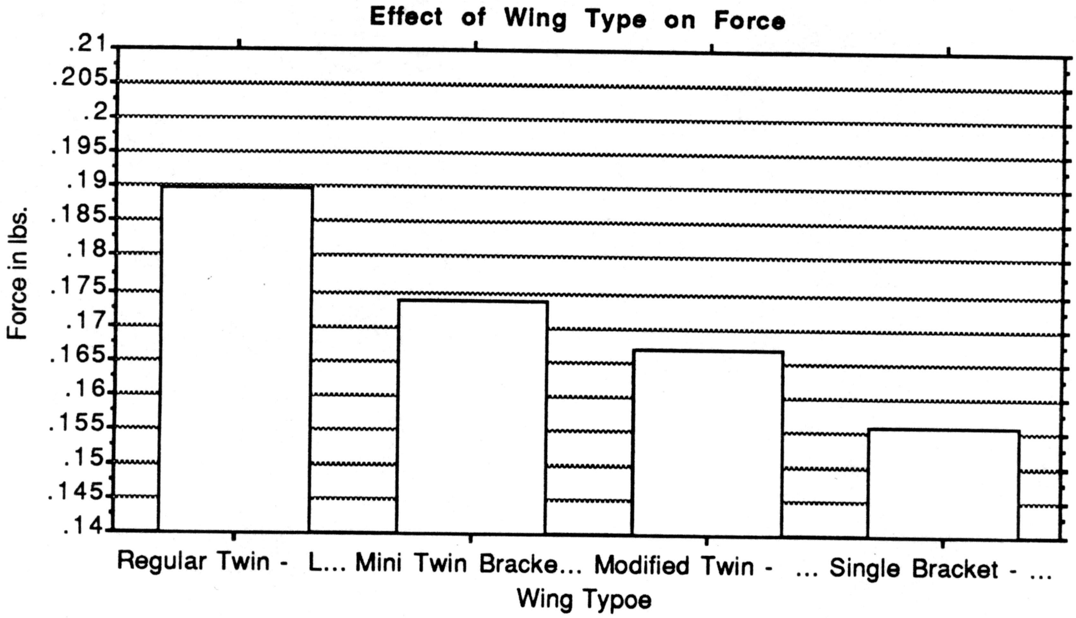
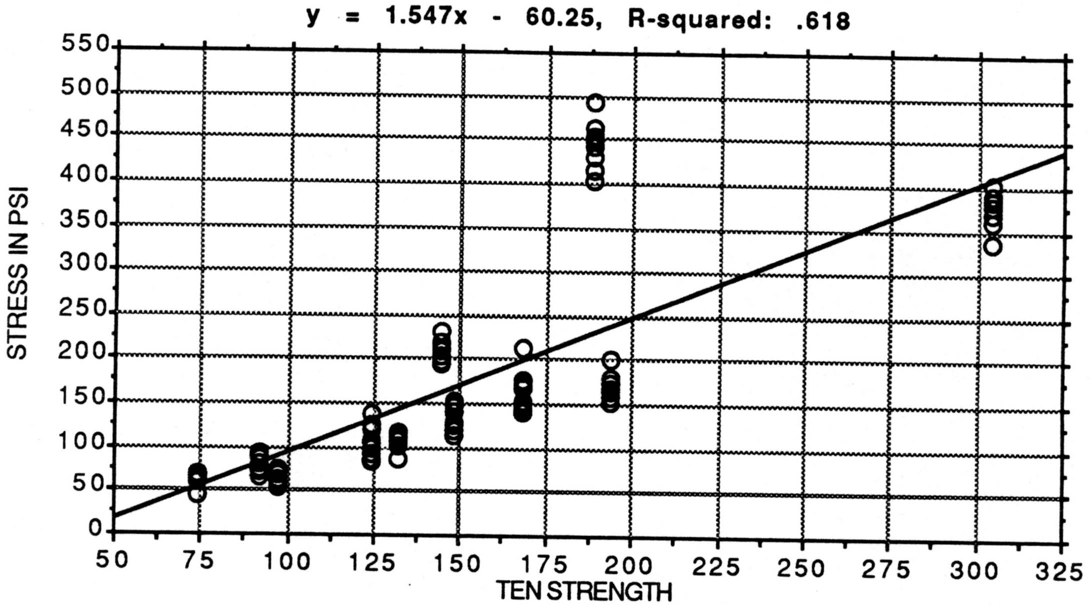

Effect of Wing Type on Force
Force in lbs.
.21
.205
.2
.195
.19
.185
.18
.175
.17
.165
.16
.155
.15
.145
.14
Regular Twin - L...
Mini Twin Bracke...
Modified Twin - ...
Single Bracket - ...
Wing Typoe

FIGURE 4

Stress to Fail vs. Hardness



Micro Hardness in Kg/mm^2

FIGURE 5
Converting Force to Stress

The beam bending formular was used to convert force (P) to stress at failure (SF) in order to interpret the torsional forces applied to the different brackets:

$$S_F = \frac{MC}{I}$$

$$M = R_B D$$

$$C = c/2$$

$$I = \frac{1}{12} a c^3$$

$$R_B = \frac{3P}{(d/2)}$$

$$S_F = \frac{\frac{LP}{(d/2)} D (c/2)}{\frac{1}{12} a c^3}$$

SF = maximum stress at the outermost fiber of the beam
M = bending moment at the section of interest
C = distance from the centroidal axis of the beam to the outermost fiber
I = moment of inertia of the cross section with respect to its centroidal axis
a = width of the bracket's wing
c = thickness of the bracket's wing at the base of the slot
d = width of the archwire being bent or the distance of the applied force of the bracket
D = distance of the applied force to the point where the fracture or bend started on the bracket
P = force to deform in lbs.
L = length of the torquing key in inches (3)

FIGURES 6

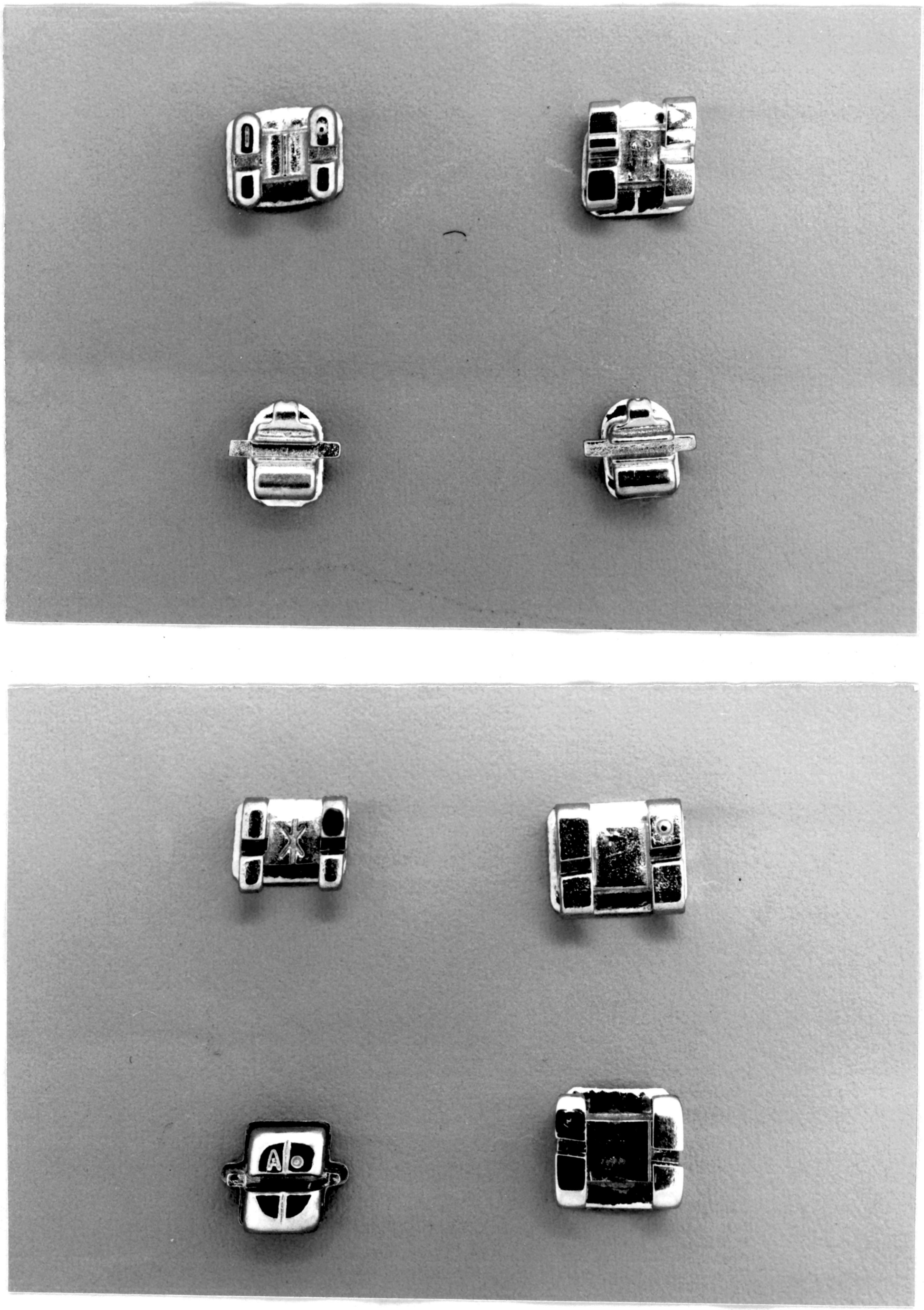


Fig. 6. An anterior view of eight of the fourteen types of brackets tested in this study. (for the other six types of brackets, see fig. 7)

FIGURES 7

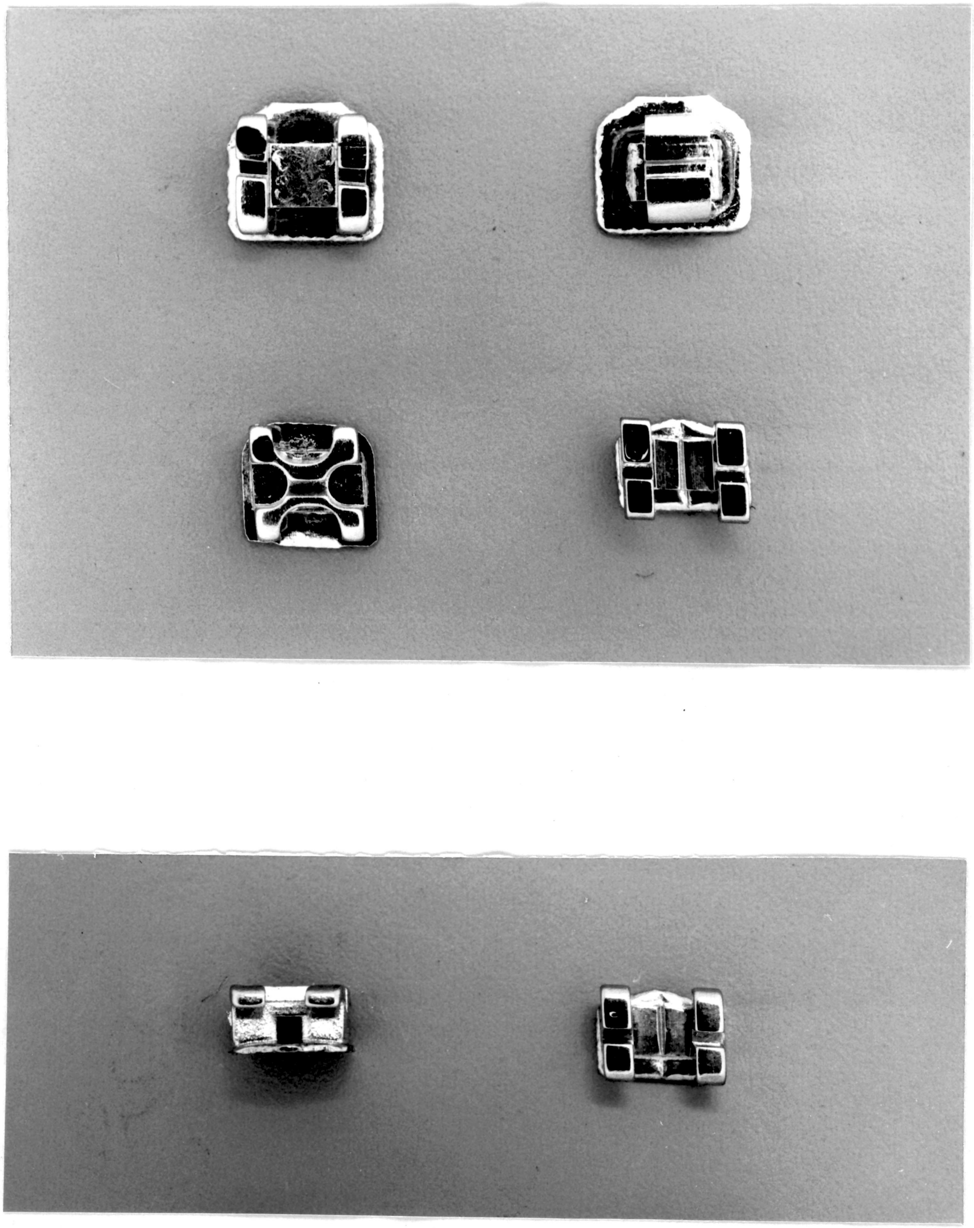


Fig. 7. An anterior view of six of the fourteen types of brackets tested in this study. (for the other eight types of brackets, see fig. 6)

FIGURES 8 & 9

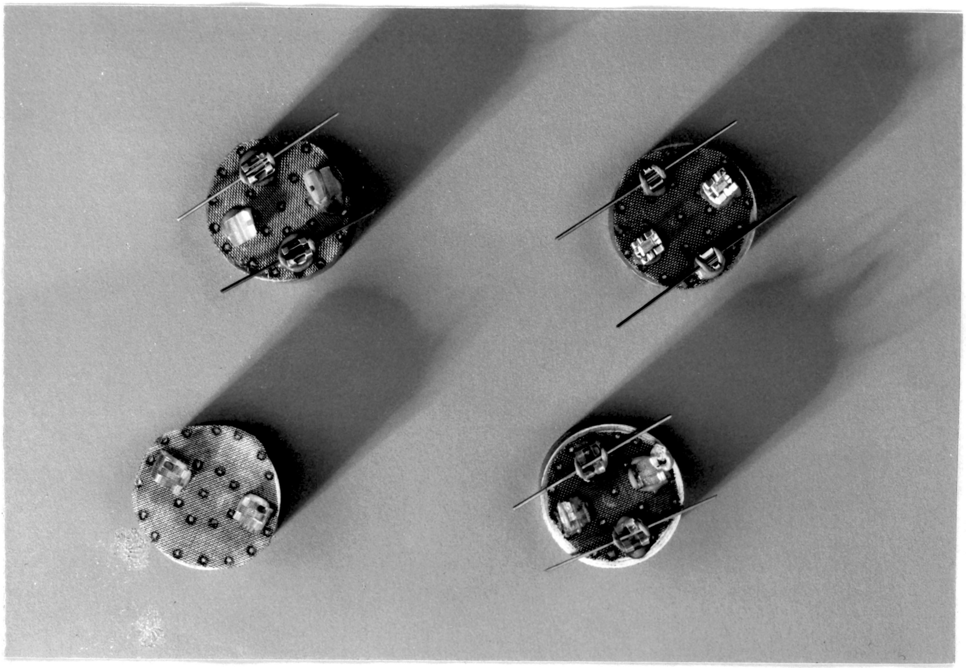


Fig. 8. A top view of the brackets mounted on the discs with the archwires ligated.

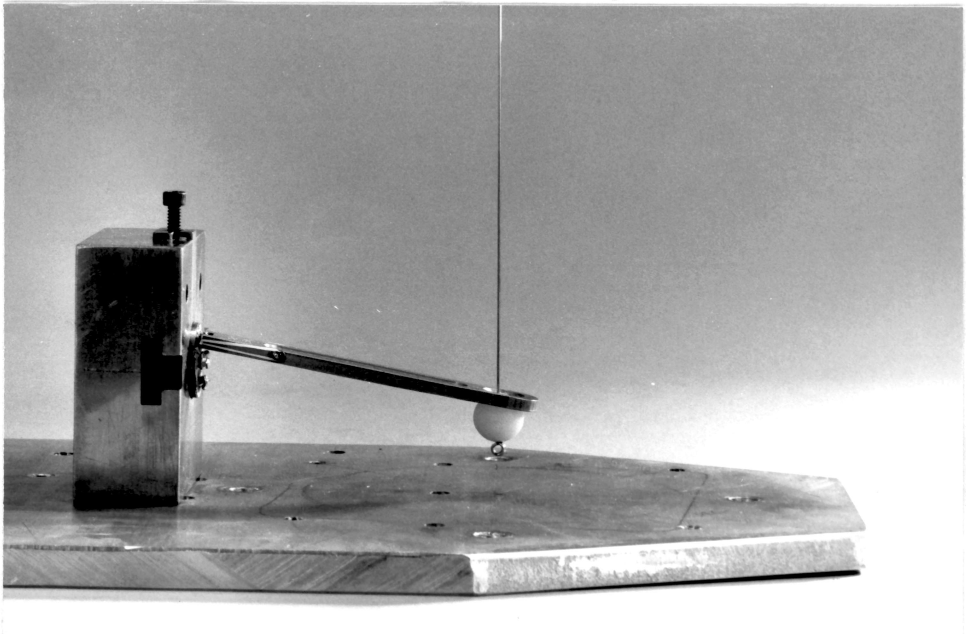


Fig. 9. A side view of the testing fixture, with the metal vice gripping a bracket mounting disc and the torquing key engaged to the archwire.

BIBLIOGRAPHY

1. Brantley, W. A., W. S. Augat, C. L. Myers, and R. V. Winders, Bending Deformation Studies of Orthodontic Wires, J. Dent Res., 57: 609-15, April 1978.

2. Caruso, J. M., An Evaluation of a Precipitation-Hardened Stainless Steel Alloy as an Alternate to Chrome Cobalt Alloys for Orthodontic Purposes, Master's Thesis, Loma Linda University, 1975.

3. Council on Dental Materials and Devices, American Dental Association: Specification No. 32 for orthodontic wires not containing precious metals, Journ. Amer. Dent. Assoc., 95: 1169-1171, 1977.

4. Fillmore, G. M., and Tomlinson, J. L., Heat Treatment of Cobalt-Chromium Alloy Wire, Angle Orthod., 46(2): 187-195, April, 1976.

5. Goldberg, A. J., C. J. Burstone, H.A. Koenig, Plastic Deformation of Orthodontic Wires, J. Dent. Res., 62(9): 1016-1020, Sep. 1983.

6. Flores, Daniel A., The Fracture Strength of Ceramic Brackets: A Comparative Study, Master's Thesis, Loma Linda University, 1975.

7. American Society for Metals Reference Book; 2nd ed, page 264; American Society for Metals, Metals Park, Ohio 44073, 1976.

8. Chromium-Nickel Stainless Steel Data, International Nickel Company, New York, 2-9,1963.

9. Carpenter Technology corporation, Technical Data, 1986.

10. Raman, A., Experiments and Problems in Metallurgy for Engineers, First Ed., A. Raman Co.,India, Jan. 1978.

11. Skinner, E. W. and R. W. Phillips, The Science of Dental Materials, Sixth Ed., Philadelphia and London, W. B. Saunders, 28-45, 1968.

12. Thurow, R. D., Edgewise Orthodontics, Third Ed., Saint Louis, The C. V. Mosby Company, 54-66, 1972.

13. Nikolai R. J., Bioengineering Analysis of Orthodontic Mechanics, Philadelphia, 1985, Lea & Febiger, pp 146-193.

14. Buchman, Dennis J. L., Effects of Recycling on Metallic Direct-Bond Orthodontic Brackets, Am. J. Orthod., 657-668, June 1980.

15. Dobrin, R. J., I. L. Kamel, and D.R. Musich, Load-Deformation Characteristics of Polycarbonate Orthodontic Brackets, Am. J. Orthod., 67: 24-33, January 1975.

16. Dooley, W. D., J. H. Hembree, Jr., F. N. Weber, Tensile and Shear Strength of Begg Plastic Brackets, J. Clin. Orthod., 694-7 Nov. 1975.

17. Harrison, K. T., The Effects of Heat Treatment on the Tensile Properties of Three Chromium-Cobalt Alloy Orthodontic Wires, Master's Thesis, Loma Linda University, 1979.

18. Jackson, E. E., Tensile Properties of Stainless Steel Orthodontic wire, Master's Thesis, Loma Linda University, 1978.

19. Kohl, R. W., Metallurgy in Orthodontics, Angle Orthod., 34:37-52, January, 1964.

20. Nations, R. L., Effects of Heat Treatment on the Mechanical Properties of Chromium-Cobalt Alloy Wire, Master's Thesis, Loma Linda University, 1978.

21. Nikolai R.J., Analytical Mechanics and Analysis of Orthodontic tooth movements, Am. J. Orthod., 82: 164-155, 1982.

22. Rains, M. D., S. J. Chaconas, A. A. Caputo, and R. Rand, Stress Analysis of Plastic Bracket Configurations, J. Clin. Orthod., 11 (2): 120-5, Feb. 1977.

23. Rocky Mountain Orthodontics, Elgiloy and Tru-chrome Orthodontic Treatment Wires, A Product Information Publication, 1977.

24. Scott, G. E., Fracture Toughness and Surface Cracks- The Key to Understanding Ceramic Brackets, The Angle Orthodontist, 58(1): 5-8, Jan. 1988.

25. Scott, G. E. and J. L. Tomlinson, Dental Materials, RSI Associates, 1984.