A FORCE COMPARISON STUDY OF ROUND ORTHODONTIC WIRES

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TABLE OF CONTENTS

INTRODUCTION

One of the fundamental factors involved in orthodontic tooth movement with fixed appliances is the magnitude of force delivered by the arch wire to the teeth. Many authors have described forces necessary for various types of tooth movement.[1,2,3] Although light forces have been generally advocated, whether or not they are actually delivered by the various appliances has been questionable.

Because of appliance design, one would expect a great deal of variation in the magnitude of forces actually produced. The nature of the appliance construction primarily determines whether the force system produces movement of a tipping or bodily nature. In edgewise orthodontics there has been a trend to simplify the mechanical phase of orthodontic treatment primarily by the use of level arch wires, eliminating the bends and various loop configurations previously used in the initial stages of treatment.

Level light round wires and multistrand wires have been utilized for the early leveling and aligning phases instead of larger dimension wires. Recent investigations of level multistranded wires tested in an in vitro simulated clinical situation, indicated that the magnitude of the forces produced by these wires were considerably higher than what was generally considered to be optimal for any type of orthodontic tooth movement. Forces in the range of 254 to 917 grams were measured by deflecting the wires 1 mm. After allowing them to return 0.5 mm., there remained a force range of 56 to 280 grams in the various wires tested.[4] In view of these results, the question arose as to what the actual forces were that solid round wires would deliver in the same testing situation. Therefore it was the purpose of this study to examine the manner in which forces vary within a group of solid round orthodontic wires when they are subject to various deflections.

The method of testing the wires was similar to that of the previous study of Lohse utilizing a testing apparatus capable of producing forces that result in the extrusion or intrusion of a canine tooth.[4]

Force-deflection curves were obtained and the two parameters examined were:

1) The force necessary to produce the various deflections of the wires.

2) The residual forces produced at a subsequent unloading deflection.

REVIEW OF THE LITERATURE

Orthodontic wires have been investigated by various methods of testing. Difference in wires have been analysed using criteria such as flexural rigidity, stress, strain, modulus of elasticity, proportional limit and force values.

Conley, et al.[5] theoretically compared wires by a mathematical formula, and established a basis that he applied to a slide rule calculation for making comparisons of the relative flexural rigidities. It was derived from: the modulus of rigidity, amount of flexure of the wire between two brackets, and the amount of loading. By knowing the relative flexural rigidity of various wires, relative stiffness can be compared. This makes it possible to select a progression of orthodontic wires based on their relative amount of stiffness rather than by the diameter of the wire. As an example, if a wire with two times the flexural rigidity was wanted and a .010 round wire was being used, by going to his calculations it would indicate that a .012 wire of the same composition would give the needed stiffness.

Stephens and Waters[6] devised a method for evaluating orthodontic wires by calculating the amount of energy a wire can store before permanent deformation occurs. The wires were compared by being wrapped around a minimum radius mandrel. This minimum radius was necessary to create permanent deformation in the wire. Then by mounting a straight wire of the same type and diameter, as a cantilever, and applying various forces, values for the relative flexural rigidities were obtained. By combining this with the minimum radius value, the maximum stored energy was calculated. This was his "Elastic Recovery Test." Later Waters[7] described another method of comparison of wires shaped in the form of an arch. In this way wires in coils along with straight lengths could be compared under conditions which cover the range for deformation normally imposed in arch fabrication. The wire is wound around a mandrel of known diameter and when released, the maximum and recovery stain values can be determined. The amount of bending was measured by a Vernier microscope. This method differentiated between the standard and high resilience wires. This was called the "Mandrel Test."

In 1975, Waters, Stephens and Houston[8] used these two methods to compare 12 different types of .016-inch wires and multistrand wires. They found that certain wires were superior on the criteria of the amount of stored energy and recoverable elastic strain. There was a range of 23% in flexural rigidity between the stiffest and the most flexible type of .016-inch wire. They noted little difference between the different makes of similar wires but the heat-treated forms of the same makes seemed to have more stored energy than their standard counterpart. Unitek* .016 and TP** .016 Special Plus had similar recoverable elastic strain values, but because of the rigidity of the TP .016 was 17% higher than the Unitek .016-inch as it had more stored energy per unit length in this test. When standard and heat-treated forms of the same brand of wire were compared, the heat-treated forms had 8% higher rigidity and stored energy 50% higher than its standard counterpart.

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*Unitek Corporation, Monrovia, California 91016

**TP Laboratories, Inc., LaPort, Indiana 46350

Williams and Von Fraunhofer[9] believed failure of orthodontic wires is partly due to inconsistancies in the manufacturing process. They mentioned high variations in the metallic phases effect the physical properties and consequently the clinical success. In a continuing study of wires, by electro chemical milling process, the microstructure and metallic phases of wires can be identified and correlated with their physical properties. Burstone[10] mentioned that the clinical success of a wire is mainly determined by the way it is manipulated during arch wire formation, i.e., the size and type of loop design rather than any inherent flaws in the wire itself. Others have commented on considerable variation in the diameters of batches of the same wires. Keys[11] mentioned a tolerance of ± .00004 inches for .014, .016, and .018-inch wires measured at 20 random points along a 100 cm. length of wire. Waters[7] noted differences from .390 to .412 mm. for .016 wires and a difference of .010 mm. for standard and high-tension (HT) wires from the same manufacturer. Slight variations in the diameters of wires can significantly affect load deflection rates since the rates vary as the fourth power of the diameter of round wire.

In 1953, Halderson, Jones and Moyers[12] tabulated force values for solid round wires with diameters from .006 inches to .020 inches. The wires were deflected the same amount .020 inches to the maxillary lateral tooth with all the other teeth ligated to edgewise brackets. The force was measured with a strain gauge. He found forces for .014-inch wire in the range of 200 grams, .016-inch wire 390 grams, .018-inch wire 440 grams, and .020-inch wire 675 grams. He mentioned these forces decreased after being ligated to the arch wire.

More recently Keys[11] compared forces generated by regular 18-8 stainless steel wire of .014, .016, and .018-inch diameters. The wires were bent in the shape of an arch with the ends of the wires fixed in a clamp. The wires were then bent at 30, 45, and 60-degree angles at a point 1.5 cm. in front of the clamp. Weight was added to the midpoint of the arch until it was bent to a predetermined point. He tested 54 wires, six pieces of each diameter, with each piece replicated two times. By an analysis of variance, as would be expected, he found statistically significant differences between the three diameters of wire, the three angles the wires were bent at, and the six pieces of wire. By Duncan's new multiple range test, he found no significant difference between the forces produced by arch wires of .014-inch diameter bent at 45 degrees and .016-inch bent at 30 degrees; nor .016 bent at 45 degrees and .018 bent at 30 degrees; or .016-inch bent at 60 degrees and .018 bent at 30 degrees; thus indicating a relationship between force and deflection of an arch wire. He concluded that there was significant variation between the samples of the same diameter wire bent at the same angle due to work hardening in the area of the bend.

Considering the fact that orthodontics has existed for some 75 years, relatively little research exists with regard to in vitro force comparisons. Since stainless steel wires are the primary source of force in orthodontics, more knowledge of the actual forces delivered by arch wires in edgewise appliance would be worthwhile.

MATERIALS AND METHODS

The material consisted of clinically used round wires of sizes .014, .016, .018, .020, .022-inch diameters. Three types of 18-8 stainless steel wires were tested: United Standard, Unitek Hi T, and TP Australian Orange Special Plus. No test was made for Australian .022 since it was not commercially available. Each size and type of wire was deflected .1, .25, .5, .75, 1, 1.5, 2.0 mm. with ten replications for each deflection. Thus a total of 980 trials were performed. The individual lengths of Unitek wires were randomly selected from tubes of wire as supplied by the manufacturers. The TP wire was taken from coiled spools. All wires were selected from the clinical supply of the Department of Orthodontics, University of Oregon School of Dentistry.

The method utilized a model previously described[4] for testing multistrand wires. The model consisted of a series of level .022-inch edgewise brackets aligned in the shape of an ideal arch and supported by a model shaped as a dental arch (Fig. 1). The bracket in the position of the right canine tooth was connected to the end of a movable testing pin. The model was then clamped in a supporting jig through which the testing pin could move, thus applying a force to the arch wire (Fig. 2). The wires were all ligated to the brackets by A-1 Ālastik modules.*

The portion of the wire to be tested spanned a gap of 12 mm. from the mesial of the first bicuspid bracket to the distal of the lateral bracket. The jig, model, and wire were then placed in an Instron testing instrument that produced and recorded the force and deflection to which the wires were subjected. The resulting force-deflection curves were obtained and the two parameters derived from it. It was necessary for the curve to be extrapolated since the exact amount of deflection would not be achieved with consistency. The curve shown in Fig. 3 is an example of an extrapolated curve. Point "A" established 0 pounds of force and 0 mm. of deflection. Point "B" is a measure of the amount of force necessary to deflect the wire the

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*Unitek Corporation, Monrovia, California 91016 desired amount (Parameter 1). The plateau at the top of the curve is the result of a decrease in force. Point C is the force value at the particular amount of unloading deflection (Parameter 2). The amounts of unloading deflection tested were: .05 mm. for .1 mm. of initial deflection, .125 mm. for .25 initial deflection, .25 mm. for .5 mm. deflection, and .5 mm. for .75, 1, 1.5, and 2.0 mm., initial deflection.

Fourteen-inch lengths of Unitek wires and 36-inch lengths of Australian wires were used. This enabled a deflection to be made at the canine bracket and then the wire was pulled through the brackets to a new section for a subsequent test. This was done to expedite the testing procedure. It was necessary to test whether this faster method was significantly different from a method utilizing single pieces of wire which would be the case clinically. Student "t" tests were performed (Table I) to test for difference between Method A: wires pulled through the brackets; and Method B: for one test per wire, i.e., single wires tested once for each wire. Ten deflections were made for .014-inch Australian wires deflected 1 mm. No significant differences were obtained at the 95% level of confidence for the two parameters tested. Therefore, it was concluded that more than one test could be made on portions of the same wire after being pulled through the brackets.

The standard error of the measure = SEMeas. established the ability to construct the same points on the graph paper with consistency during extrapolation from the curve produced by the Instron. Twenty-eight deflection curves were selected for replicate measurement to establish confidence levels for measuring the force values for Parameters 1 and 2. The first measurement was made on acetate tracing paper so as not to mark the graph paper and bias the next measurement. The second measurement was made directly on the graph paper two weeks later. The SEMeas. was calculated using the formula:

$$\text{SEMeasure} = \sqrt{\frac{\Sigma\ (X - Y)}{2N}}$$

Due to the various load scales used, the standard error of the meaaure is different for the different wires at different deflections (Table II). Thus, for all load-deflection curves the standard error of the measure for replicate measurements of Parameter 1 ranged between 1.39 grams for a .014 wire deflected .1 mm. and 69.4 grams for a .022 wire deflected 2 mm.

The data was analyzed by a two-way analysis of variance to test for significant differences between the Variable A, deflection, and the Variable B, a combination of 14 wire sizes and types. Only differences in the means at/or above the 95 percentile will be considered significant.

A Scheffé test was then performed on the results to determine contrasts so significant differences could be detected within the various groups.

The force-deflection data was analyzed next by linear regression. The slopes of the 14-wire size-type combinations were compared in relation to the force produced at the various deflections, versus the amount of deflection. This was performed for both Parameters. The regression formulas and standard error of the slopes were calculated for the 14 wires (Table III) and plotted with the mean ± 1 standard error of the slope (Figs. 4-10).

Regression formulas and one standard error of the slope were also plotted for four Wild Cat[*] wires tested in the previous study[4] and compared with the slopes of the solid round wires for Parameter 1 (Figs. 4 & 5).

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[*] TP Laboratories, Inc., LaPort, Indiana 46350

FINDINGS

PARAMETER 1: FORCE PRODUCED AT THE INITIAL DEFLECTION

The forces produced by the various wires were generally high even at the smaller amounts of deflection (Tables IV, V, VI, VII, & VIII). There was a large variation around the means of the ten replicate tests indicating the difficulty in standardizing the applied force using this type of appliance and testing procedure.

Analysis of Variance: Comparison of the 14 different wires (type and size combined) at all the various deflections by a two-way analysis of variance (Table IX) gave a significant "F" ratio. A Scheffe′test was utilized to see which of the 14 wires were significantly different at which particular deflection. The contrast for Variable B (wire size and type) was .0198339 which implies that a significant difference at the 95% level of confidence exists between any two means that are equal to or greater than the contrast. The results in applying the contrast showed no significant difference between .014-inch Hi T and .014-inch Australian wires; all three

.016-inch wires; all three .018-inch wires; and the .020-inch standard and Australian wires (refer to Table IX). By comparing the means of Variable A (deflection) for all the wires, the Scheffe´test indicated significant differences between all deflections at the 95% level of confidence.

Linear Regression Analysis: The best fitting lines and one standard error of the slopes were plotted by linear regression analysis (Figs. 4 & 5) thereby allowing comparison of the variables: force versus initial deflection for the 14 wires. Generally, as wires increased in size the slopes became steeper, indicating higher forces were produced at a similar deflection for larger diameter wires.

The order of the three types of wires varied as to which produced more force. Of the three types of wires, the standard wires always produced a more flat slope indicating less force. The Australian and Hi T wires varied as to which produced more force. There was considerable overlap of the slopes of best fitting line at the smaller deflections. Often the standard wires produced more force than the comparable Hi T or Australian wires. Only one wire, the .020-inch Hi T, produced significantly more force than its Australian counterpart at all deflections.

The analysis of variance (Table IX) gave a significant "F" ratio for Variable AB (all wires at all deflections). Table X shows groups of wires at various deflections that produce no significantly different forces at the 95% level of confidence. Utilizing the Scheffé test, the means of all 98 wire-deflection combinations that were not equal to or greater than the contrast number .1230690 were grouped together. The group of wires that produced the lightest forces ranged from 68.9 grams to 88.4 grams. This range is shown to be produced by any .014-inch wire at .1 mm. of deflection, or .016-inch Hi T wire at .1 mm. deflection. The highest force of 6937.8 grams was produced by a .022-inch Hi T wire at 2 mm. of deflection.

This table can be used as an estimate of the type or size of wire that would produce a certain force at a certain deflection. By knowing the force range wanted and the amount of deflection necessary for the wire to reach the bracket, the size or type of wire may be selected.

Figs. 4 & 5 compare the slopes of the .014-inch wires and the four multistrand wires tested in the previous study. The .0215-inch Wild Cat wire was the only wire that compared significantly within one standard error of the slope with any solid wire. It delivered more force than the .014-inch standard wire above .75 mm. of deflection. Above deflections of .25 mm., it compared favorably with the .014-inch Hi T wire besides having a steeper slope of its regression line.

The slopes of the 14 wires were compared by a one-way analysis of variance (Table XI). The Scheffe´test indicated that no significant difference was found between the slopes of any of the three types of wire of one particular size. Generally no significant difference was found between wires with sizes close together, i.e., .014-inch and .016-inch wires.

PARAMETER 2: FORCE PRODUCED AT UNLOADING

The amount of unloading varied with the wire size used. As expected, the forces produced were less than that for Parameter 1. They ranged from 25.62 grams for the lightest wire (.014-inch) to 1704.6 grams for the heaviest wire (.020-inch) (Tables IV-VIII).

Analysis of Variance: The contrast for Variable A, deflection, was .0470465. Again the means for Variable A were all found to be significantly different, as in Parameter 1.

Variable B: the forces produced by the various wires had a contrast of .0248751. All progressively larger wires produced significantly higher forces than the size before it. No difference was found between .014-inch Hi T and .014-inch Australian wires, both producing more force than the .014-inch standard. No difference was found between the following: 1) any .016-inch wire, 2) the 0.18-inch Australian, .018-inch Hi T, or .020-inch standard wires. The .020-inch standard wire produced more force but not significantly so. No difference was found between .020-inch Australian, .020-inch Hi T or .022-inch standard wires either.

The contrast for comparing differences between the means of variables AB was .2919211. Table XIII grouped the various wire sizes-types combinations at the various deflections that gave no significant differences. By using this table and knowing the force wanted by a wire after a known amount of initial deflection and a certain amount of tooth movement, the type and size of wire can be selected.

Linear Regression Analysis: The slopes of the best fitting lines are graphically compared in Graphs VII-V. A one-way analysis of variance was run comparing the slopes of the 14 wires. A Scheffé test indicated that the only differences existed between the slopes of 1) .014-inch standard wire and the following wires: .018 Australian, .018-inch Hi T, and the .020-inch Hi T; 2) .020-inch Australian and the following: all three .014-inch wires and the .016-inch standard wire.

The relative order of the slopes of the wires differed from the order in Parameter 1. Above the 1.0 mm. of total deflection (Graph VII), the wire that produced the most force was .020-inch Australian instead of the .022-inch Hi T wire as in Parameter 1. The forces produced by the smaller diameter wires of .014-inch and .016-inch diameter, remained the lightest as in Parameter 1. The forces produced by the .020-inch and .022-inch standard wire at the higher deflections were superseded by forces produced by the smaller diameter .018-inch Australian and Hi T wires.

DISCUSSION

Lohse[4] mentioned certain possible sources of error capable of affecting this testing situation:

1) The Instron testing machine is capable of measuring ± .25% of the full load scale.[13] The present study used load scales from 1 to 50 pounds. This would establish a range of accuracy from ± 1.1 grams for tests run at one-pound load scales to ± 56.7 grams for the 50-pound load scales. These amounts are relatively small compared to the forces produced, except for the fact that they could become additive when combined with other possible sources of error.

2) Operator error, inherent in manipulation of the test, may influence variation in the results. The fact that the same operator performed all the tests would indicate that any error should be the same for all tests.

3) The standard error of the measure for replication of measurements is given in Table II. A great deal of diagramatic construction was

involved in measuring the various parameters. This also included the ability to read numbers from the graphs with consistancy. For Parameter 1 at the 99% level of confidence, the mean of a .014-inch wire deflected .1 mm. may fall within a range of ± 3.9 grams. At the high end of the scales the force produced by a .022-inch wire deflected 2 mm. which is 6937.81 grams would fall within a range of ± 208.2 grams 99% of the time.

The variation from the ten replications of each deflection was higher than what was thought to exist in our testing situation, thus, adding to the uncertainty of the true value of the mean. For example, a .016-inch Australian wire deflected 1.5 mm. produced a force at initial deflection with a mean of 2060.25 grams with a standard deviation of 110.23 grams. This variation can be a measure of inherent differences between the wires themselves, or be caused by friction or slippage of the wires in the brackets, or be affected by the force that the A-1 AlastiK ligatures exert as they hold the arch wire to the bracket; all of these potentially adding to the differences in the force values observed in this study.

Two primary questions to be answered from this study are: 1) what are the actual forces produced by arch wires in a testing situation such as this, and 2) how do the various types and sizes of wire differ?

There is no doubt that the forces produced especially at the initial deflections are extremely high by any tooth movement standards.[1,2,3] This force seems even more excessive when considering it is of an extrusive or intrusive nature. Reitan[14] mentioned that extrusive forces should not exceed 25-30 grams in a human tooth movement clinical situation. Along with the extrusive and intrusive movements, a tipping component of force also exists in the adjacent teeth. As the canine tooth undergoes these verticle movements, the adjacent teeth must tip in a mesial or distal direction besides undergoing vertical movements. Thus, three teeth are primarily involved in the distribution of forces here. With this premise it could be argued that only a percentage of the force described in this paper would be actually delivered to the canine tooth with the rest distributed to the adjacent teeth. In discussing other reasons why high forces exist, a mention must also be made of the inability of the brackets to compensate by movement on the test model. This factor would appear to increase the force that a similar situation in the mouth would produce. Exactly how much this would affect the force was beyond the scope of this paper.

In looking at the relatively high forces in another manner, the ones produced at the initial deflection of the wire rapidly dissipated upon unloading of the wire. The forces at unloading ranged from 7-42% of the force produced at the initial deflection. It has been recognized[15] that an initial amount of tooth movement occurs upon immediate loading of a tooth by bending of the bone and encroachment on the periodontal membrane space by the tooth. Therefore, the high forces seen in parameter[1] may be considered to be decreased rather quickly in the mouth due to some initial movement of the tooth and the inability of a straight piece of wire to produce the same force over a long range of deflection.

Comparison of the standard and high tensile wires used in the study indicate that at the initial deflection the only standard wires that produced significantly less force than the comparable high tensile wires are diameter: .014 and .022 inches. All the other standard wires were not different from at least one of the high tensile wires of the same size in this parameter. At the unloading deflection, all standard wires were significantly different from the high tensile wires except the .016-inch size which was different in parameter 1.The Hi T and Australian wires changed positions with respect to which produced the most force, but no significant difference existed between any of these two types of wire except in the .020-inch size in Parameter 1 (the Hi T wire producing more force than the Australian), and these wires at the unloading deflection in Parameter 2 showed no difference. Therefore, it may be concluded that there is no difference between Australian and Hi T wires in regard to force produced because of a lack of consistancy in being significantly different in both parameters.

When analyzing the slopes of the regression lines by analysis of variance, the lack of significant difference is seen between not only Australian and Hi T but standard wires as well. Mahler and Goodwin[16] found that Unitek standard and Hi T wires compared favorably with Australian wires when testing elastic force-deformation ratios and elastic force limits. The results in this study comparing the differences in slopes of regression lines suggest the same thing. The only differences between the slopes of the 14 wires occurred between sizes of wires, never between any of the three types of the same size.

Waters[8] indicated that standard and high tensile wires had different modulii of elasticity, elastic strain, and ability to store energy. These properties were then supposed to influence the clinical usefulness of the wires, with the high tensile wires exhibiting more resistance to deformation than the standard wires and thus producing more force. The results of this study indicate that these differences found between standard and high tensile wires are generally valid, as shown by the two-way analysis of variance, with the high tensile wires producing significantly more force, and the standard wires producing less. Since the variation in the testing procedure was rather high, it is impossible to generalize differences except between wire sizes, the various deflections and the standard and Hi T type of wires.

SUMMARY AND CONCLUSIONS

In this investigation, the production of force from various types of orthodontic wires was determined for an in vitro clinical situation. The force was directed at the canine tooth and determined for seven different deflections of each type of wire. Three types of 18-8 stainless steel wire in five sizes were tested to determine if any significant differences existed between forces they produced. In view of the results of this study, the following conclusions seem appropriate:

1) The most commonly used level round orthodontic wires are capable of producing forces well in excess of that which is necessary to produce tooth movement.

2) Forces produced by deflecting arch wires in a vertical direction between two fixed points is not only affected by wire size and amount of deflection but also by the physical properties of the wire itself.

3) Significant differences in the amount of force produced existed between the various deflections of the arch wires (Variable A).

4) Significant differences in forces produced did exist between the standard and high tensile wires more often than not, expecially after some unloading of the initial deflection was allowed to occur.

5) Rarely did significant differences exist between either the Australian or Unitek Hi T wire. They both compared similarly so that no conclusion could be made as to which type would be superior in its ability to produce various wire dimensions.

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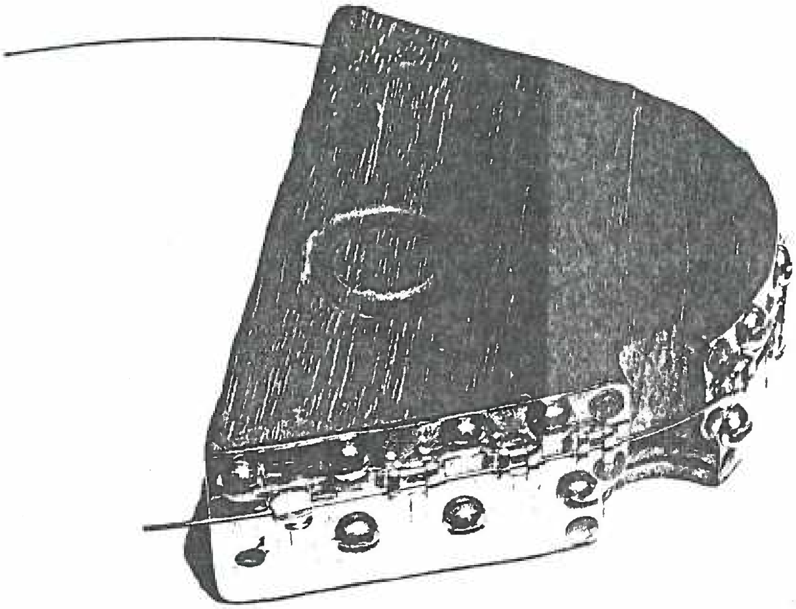


Fig. 1 Testing model shaped as a dental arch.

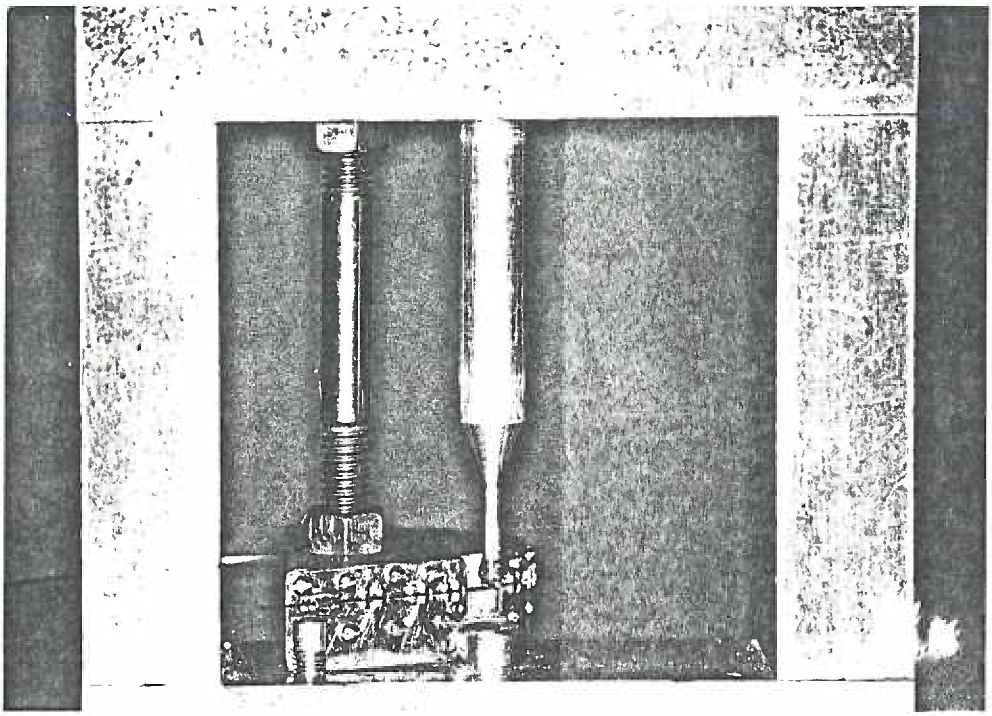
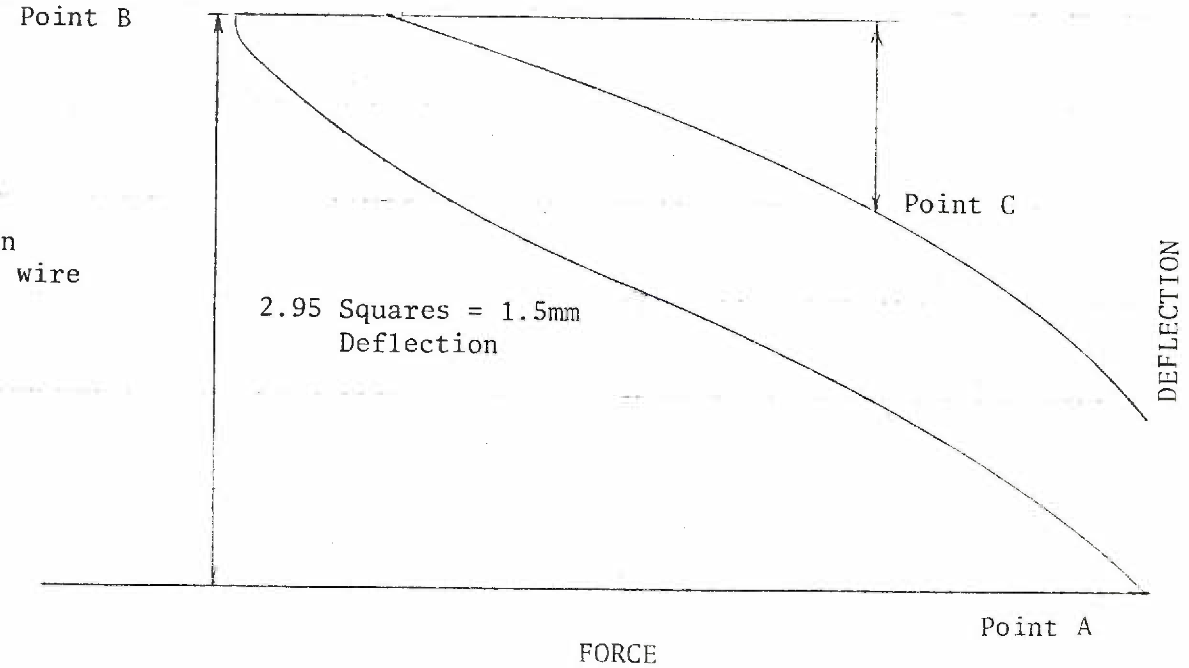


Fig. 2 Testing model clamped in a supporting jig with movable testing pin in the position of the right canine tooth.



Example of Force-Deflection
Curve for an .020 in. Hi T wire
Deflection = 1.5 mm
Full Load Scale =20 Pounds
Return = .5 mm.

Fig. 3 An extrapolated force deflection curve showing the typical parameters of force produced during deflection.

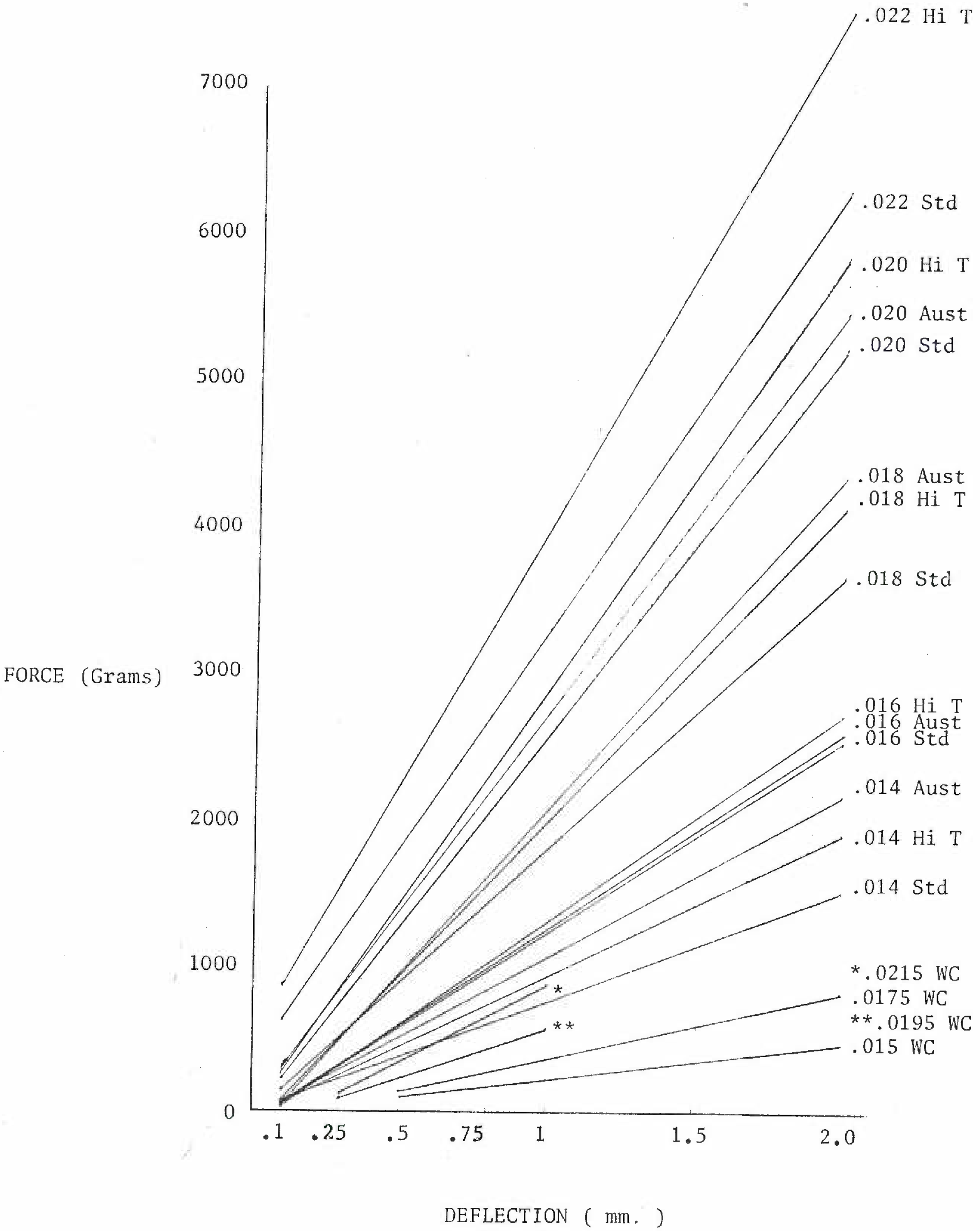


Fig. 4 Best fitting regression lines comparing the force produced with changing deflection for the 14 different types and sizes of round wire and the four sizes of cat wires for parameter 1.

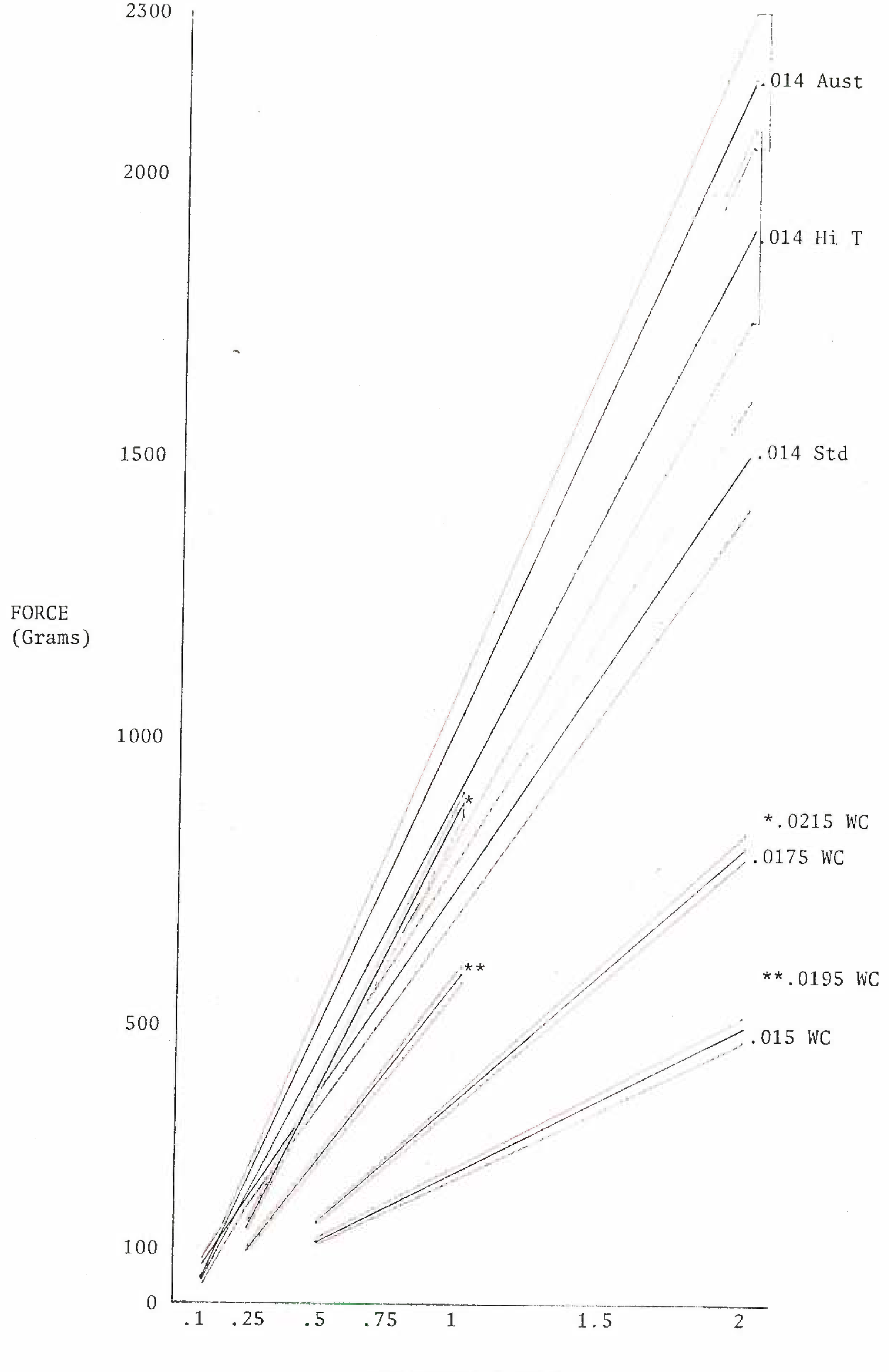


Fig. 5 Best fitting regression lines with an envelope of one standard error of the slope comparing the force produced with changing deflection for the .014-inch round wires and wild cat wires in parameter 1.

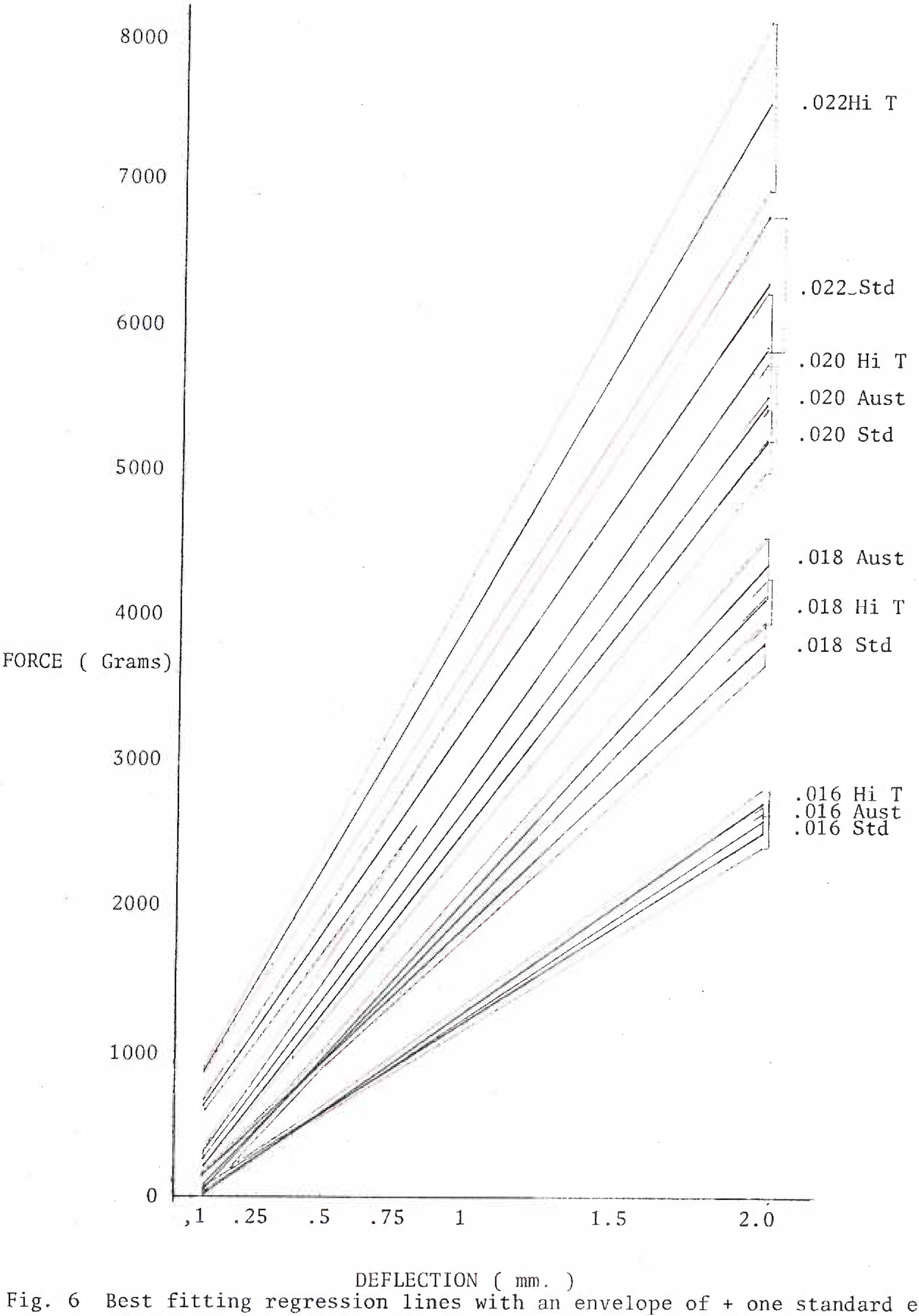


Fig. 6 Best fitting regression lines with an envelope of ± one standard error of the slope comparing the force produced with changing deflection for the .016, .018, .020, and .022-inch round wires in parameter 1.

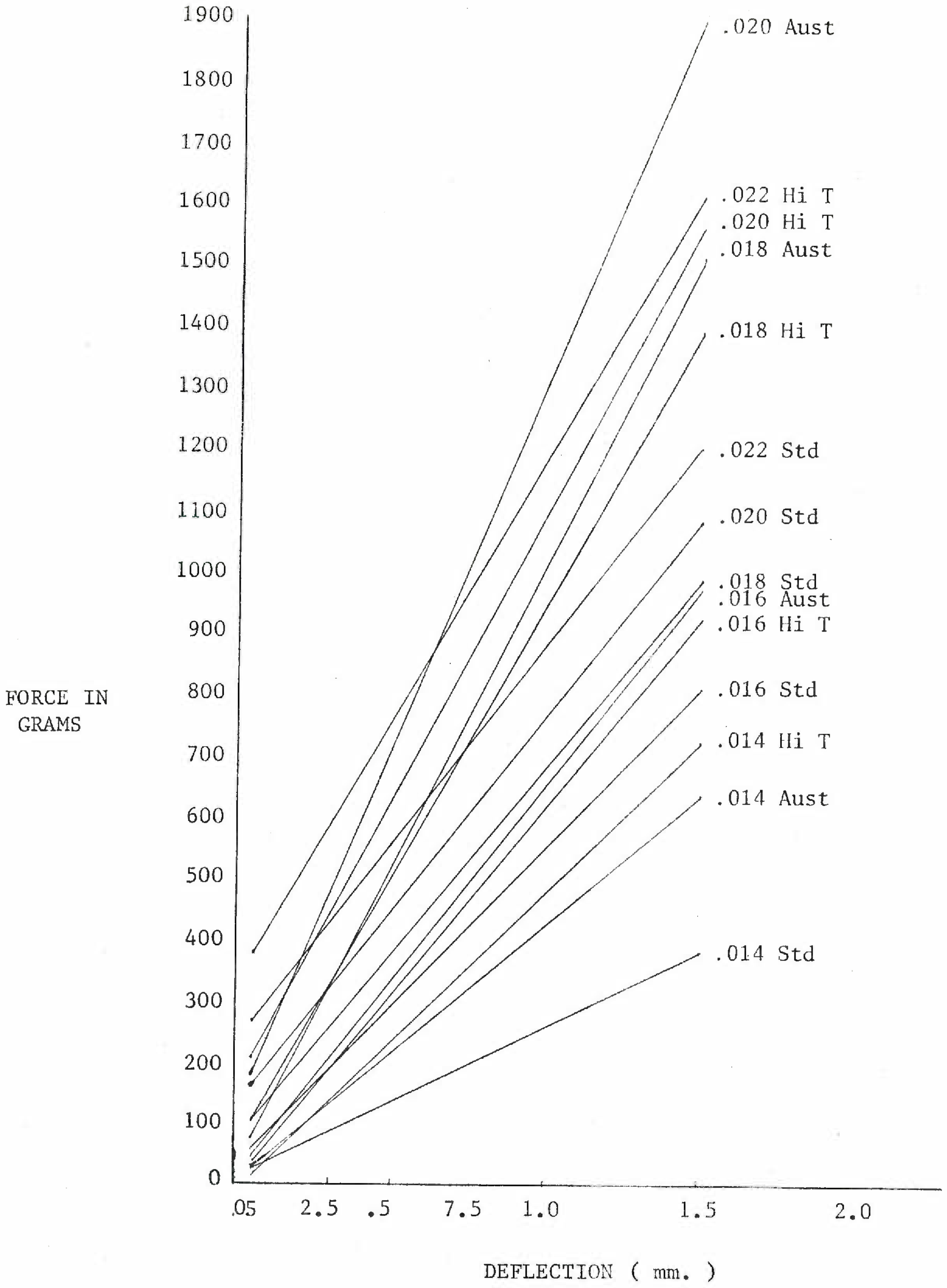


Fig. 7 Best fitting regression lines comparing the force produced with changing deflection for the 14 different types and sizes of round wire for parameter 2.

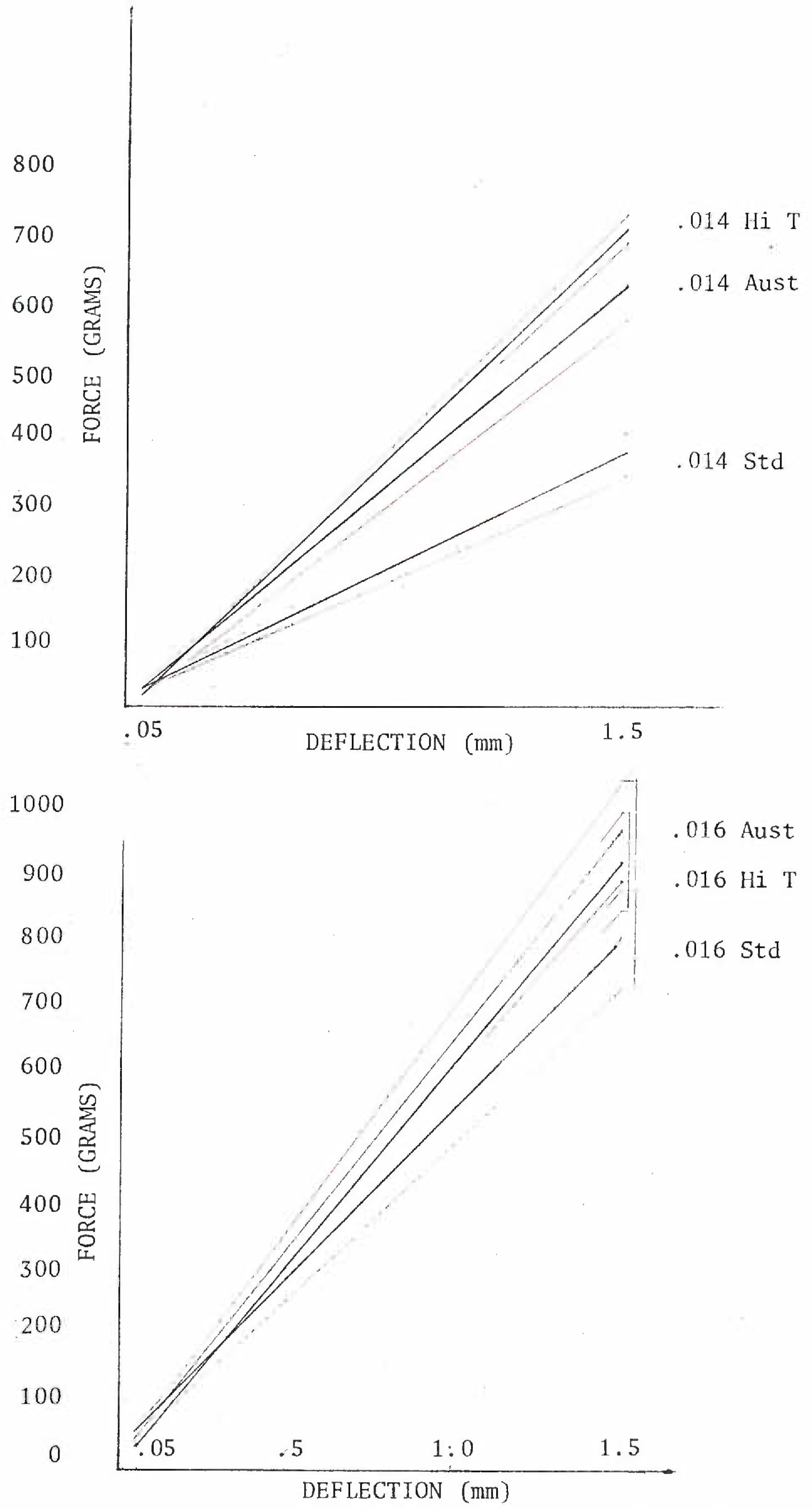


Fig. 8 Best fitting regression lines with an envelope of one standard error of the slope comparing the force produced with changing deflection for the three different .014-inch round wires and the three different .016-inch round wires.

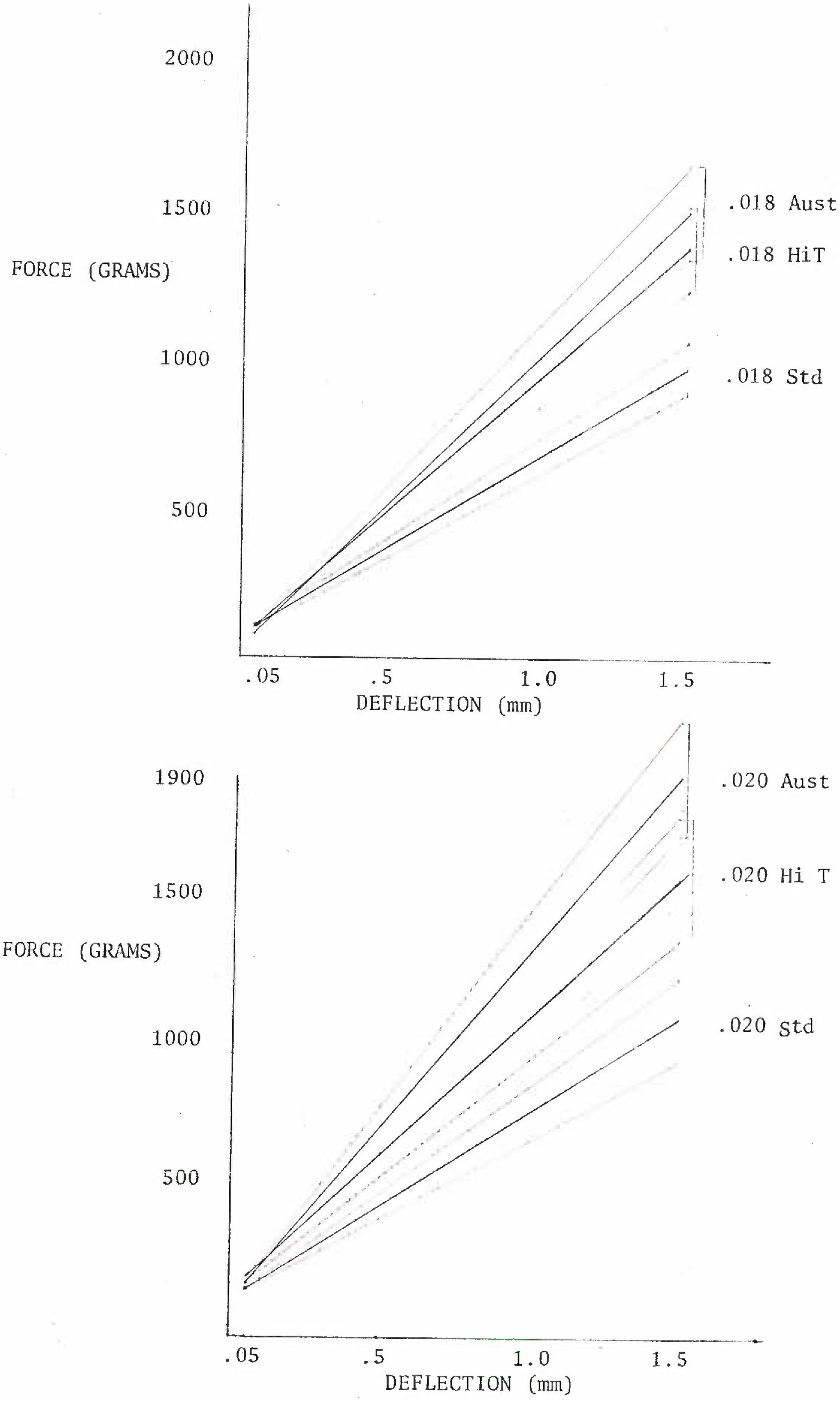


Fig. 9 Best fitting regression lines with an envelope of one standard error of the slope comparing the force produced with changing deflection for the three different .018-inch round wires and the three .020-inch round wires.

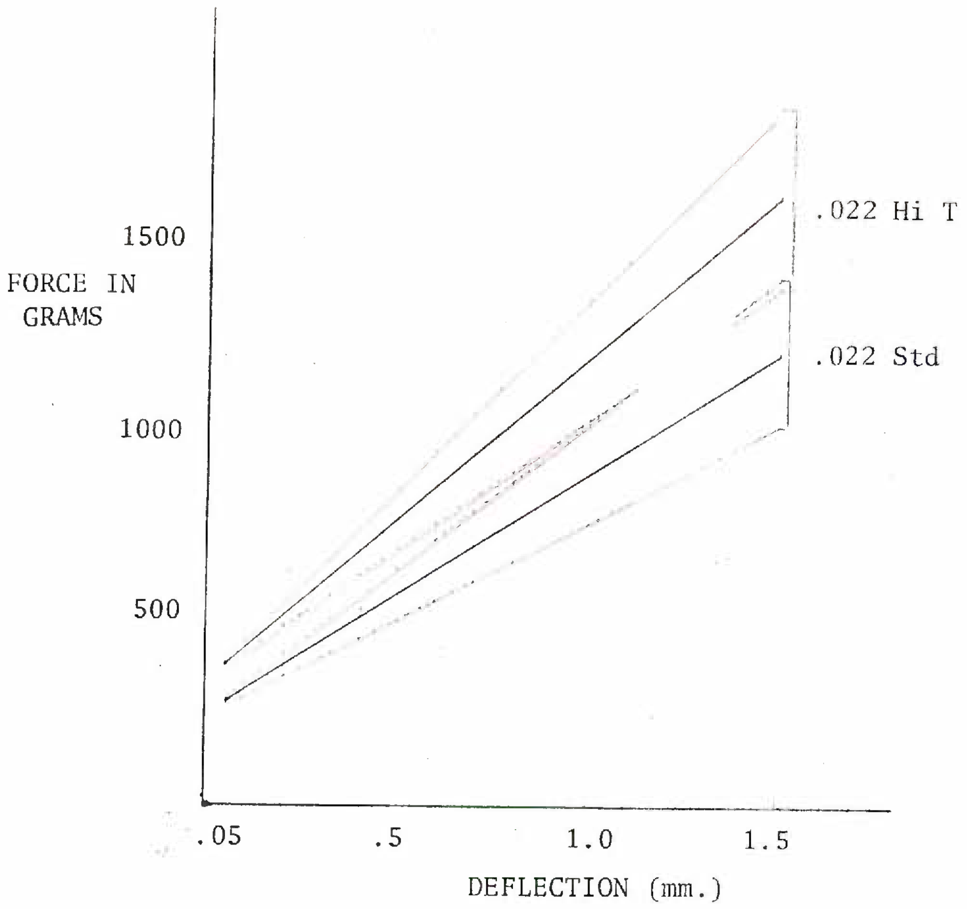


Fig. 10 Best fitting regression lines with an envelope of one standard error of the slope comparing the force produced with changing deflection for the two different types of .022-inch round wire.

Table I "t" test data comparing two methods of testing wires

METHOD A: One piece of 14-inch Australian wire pulled through the brackets on the test model. Replicate tests were performed on this single wire at different positions as it is pulled through.

METHOD B: Ten pieces of .014-inch x .014-inch Australian wire tested one time for each piece of wire.

		METHOD A	METHOD B	T VALUE*
Parameter 1 (Force at 1.0 mm. of deflection (grams)	$\bar{X}$	895.85	884.89	.337
	S^2	3910.48	6639.78	
	S	62.53	81.48	
	SEM	19.77	25.76	
Parameter 2 (Force after .5 mm. of unloading (grams)	$\bar{X}$	219.54	232.69	1.437
	S^2	170.09	667.74	
	S	13.04	25.84	
	SEM	4.12	8.171	

$\bar{X}$: Mean

S^2 : Variance

S : Standard deviation

SEM: Standard error of the mean

*18 degrees of freedom

Table II

Standard error of the measure, for construction of the force deflection curves. Values given are: first, the SEMeasure in grams; then, the load scale used for that particular wire and deflection.

PARAMETER 1

Initial Deflection (mm.)	Wire Size .014	.016	.018	.020	.022
.1	1.39 (1 lb.)	1.39 (1 lb.)	1.39 (1 lb.)	1.39 (1 lb.)	6.94 (5 lb.)
.25	1.39 (1 lb.)	6.94 (5 lb.)	6.94 (5 lb.)	13.87 (10 lb.)	13.87 (10 lb.)
.5	6.94 (5 lb.)	6.94 (5 lb.)	6.94 (5 lb.)	13.87 (10 lb.)	27.74 (20 lb.)
.75	6.94 (5 lb.)	13.87 (10 lb.)	13.87 (10 lb.)	13.87 (10 lb.)	27.74 (20 lb.)
1.0	13.87 (10 lb.)	13.87 (10 lb.)	13.87 (10 lb.)	13.87 (10 lb.)	27.74 (20 lb.)
1.5	13.87 (10 lb.)	27.74 (20 lb.)	27.74 (20 lb.)	27.74 (20 lb.)	27.74 (20 lb.)
2.0	13.87 (10 lb.)	27.74 (20 lb.)	27.74 (20 lb.)	27.74 (20 lb.)	69.4 (50 lb.)

PARAMETER 2

Initial Deflection	Return mm.					
.1	.05	4.13 (1 lb.)	4.13 (1 lb.)	4.13 (1 lb.)	4.13 (1 lb.)	20.64 (5 lb.)
.25	.125	4.13 (1 lb.)	20.64 (5 lb.)	20.64 (5 lb.)	41.28 (10 lb.)	41.28 (10 lb.)
.5	.25	20.64 (5 lb.)	20.64 (5 lb.)	20.64 (5 lb.)	41.28 (10 lb.)	82.56 (20 lb.)
.75	.25	20.64 (5 lb.)	41.28 (10 lb.)	41.28 (10 lb.)	41.28 (10 lb.)	82.56 (20 lb.)
1.0	.5	41.28 (10 lb.)	41.28 (10 lb.)	41.28 (10 lb.)	41.28 (10 lb.)	82.56 (20 lb.)
1.5	1.0	41.28 (10 lb.)	82.56 (20 lb.)	82.56 (20 lb.)	82.56 (20 lb.)	82.56 (20 lb.)
2.0	1.5	41.28 (10 lb.)	82.56 (20 lb.)	82.56 (20 lb.)	82.56 (20 lb.)	206.39 (50 lb.)

Table III

Linear regression formulas

PARAMETER 1 (force (grams) at the initial deflection

		Regression formula	Standard Error of slope
.014	S	761.12199 X - 11.00916	48.10813
.014	A	1173.35599 X - 165.7445	59.68173
.014	HT	990.07783 X - 62.26068	86.09377
.016	S	1303.91712 X - 74.29349	59.06568
.016	A	1354.57628 X - 110.99362	53.73738
.016	HT	1430.59733 X - 129.95768	39.54629
.018	S	1856.75419 X - 43.68579	67.38739
.018	A	2274.89708 X - 200.22603	100.45635
.018	HT	2134.70068 X - 139.51345	76.37277
.020	S	2642.54372 X - 56.04667	106.83551
.020	A	2748.44595 X - 21.00719	129.94988
.020	HT	2947.93313 X - 30.92173	175.00413
.022	S	3001.73425 X + 306.32300	233.03740
.022	HT	3507.42414 X + 523.49181	292.45608
.015	WC	254.33000 X - 17.88000	10.99883
.0175	WC	448.42400 X - 82.555	11.38832
.0195	WC	658.14680 X - 71.56400	11.94494
.0215	WC	1011.19600 X - 121.21000	21.77176

PARAMETER 2 (force at unloading)

		Regression formula	Standard Error of slope
.014	S	244.20335 X + 12.87895	20.80630
.014	A	420.04522 X + 3.83197	36.69729
.014	HT	486.80014 X - 10.50864	13.86093
.016	S	515.39737 X + 29.2678	50.26693
.016	A	637.57447 X + 11.17768	51.08819
.016	HT	607.44697 X + 8.60462	48.30457
.018	S	606.5124 X + 70.6723	61.6639
.018	A	985.7320 X + 30.2449	104.1067
.018	HT	886.8087 X + 57.7054	97.4887
.020	S	633.2652 X + 129.5914	91.9464
.020	A	1182.4761 X + 119.7900	128.3402
.020	HT	934.3661 X + 155.3220	137.3235
.022	S	644.1655 X + 231.1730	131.9101
.022	HT	850.6656 X + 333.6848	163.0000

Unitek Standard = S
Unitek Hi T = HT
TP Lab. Australian = A
TP Lab. Wildcat = WC

Table IV

Means, variance, standard deviation, and standard error of the means for all .014-inch wires

Wire size (ins.)	Deflection (mm.)	Force at initial deflection (gms.)				Amt. of unloading (mm.)	Force at unloading (gms.)			
		$\bar{X}$	S^2	S	SEM		$\bar{X}$	S^2	S	SEM
.014 Standard	.1	68.94	42.24	6.49	2.05	.05	26.17	41.79	6.46	2.04
	.25	148.14	79.82	8.93	2.82	.125	37.60	93.26	9.65	3.05
	.5	328.17	862.52	28.75	9.09	.25	82.09	350.73	18.72	5.92
	.75	527.17	895.57	29.92	9.97	.5	37.87	222.93	14.93	4.72
	1.0	855.92	2411.49	49.10	15.52	.5	159.99	348.68	18.67	5.90
	1.5	1222.74	864.83	29.40	9.29	.5	289.64	291.67	17.07	5.4
	2.0	1415.70	27704.97	166.44	52.63	.5	354.24	489.05	22.11	6.99
.014 Australian	.1	66.62	36.55	6.04	1.91	.05	25.62	3.63	1.90	.602
	.25	191.05	222.70	14.92	4.71	.125	65.49	109.75	10.47	3.31
	.5	329.08	443.98	21.07	6.66	.25	84.14	58.81	7.66	2.42
	.75	650.00	730.69	27.03	8.54	.5	83.45	87.77	9.36	2.96
	1.0	895.85	3910.48	62.53	19.77	.5	219.54	170.09	13.04	4.12
	1.5	1594.85	12336.94	111.01	35.12	.5	510.30	481.13	21.93	6.93
	2.0	2269.81	5963.21	77.21	24.44	.5	581.96	1655.53	40.68	12.86
.014 Hi T	.1	69.98	33.82	5.81	1.83	.05	30.84	14.77	3.84	1.21
	.25	183.75	127.29	11.28	3.56	.125	52.60	79.34	8.90	2.81
	.5	361.97	1144.35	33.82	10.69	.25	119.52	222.98	14.93	4.72
	.75	622.11	2291.74	47.81	15.13	.5	77.11	246.85	15.71	4.96
	1.0	913.09	10210.25	101.04	31.95	.5	240.40	516.59	22.72	7.18
	1.5	1689.20	4239.51	65.11	20.59	.5	470.12	680.20	26.08	8.24
	2.0	1763.55	22399.19	149.66	47.32	.5	724.84	470.03	21.68	6.85

$\bar{X}$ = Mean

S^2 = Variance

S = Standard deviation

SEM = Standard error of the mean

Table V

Means, variance, standard deviation, and standard error of the means for all .016-inch wires

Wire size (ins.)	Deflection (mm.)	Force at initial deflection (gms.)				Amt. of unloading (mm.)	Force at unloading (gms.)			
		$\overline{X}$	S^2	S	SEM		$\overline{X}$	S^2	S	SEM
.016 Standard	.1	102.33	48.23	6.94	2.19	.05	40.05	20.48	4.52	1.43
	.25	256.73	913.16	30.21	9.55	.125	96.39	828.99	28.79	9.10
	.5	493.97	598.64	24.46	7.13	.25	142.65	197.14	14.04	4.44
	.75	866.82	509.45	22.57	7.13	.5	114.35	383.44	19.58	6.19
	1.0	1217.92	4554.67	67.48	21.34	.5	323.87	339.27	18.41	5.82
	1.5	2054.80	26725.47	163.47	51.69	.5	654.99	672.98	25.94	8.20
	2.0	2441.27	9390.35	96.90	30.64	.5	726.66	977.05	31.26	9.88
.016 Australian	.1	103.42	40.44	6.35	2.01	.05	42.68	30.69	5.54	1.75
	.25	245.39	415.84	20.39	6.44	.125	89.36	210.60	14.51	4.58
	.5	488.75	849.59	29.14	9.21	.25	153.76	416.75	20.41	6.45
	.75	838.25	1690.84	41.11	13.00	.5	121.11	512.33	22.63	7.15
	1.0	1192.51	2923.66	54.07	17.09	.5	357.88	75.20	8.67	2.74
	1.5	2060.25	12151.94	110.23	34.85	.5	763.86	215.76	14.68	4.64
	2.0	2557.39	7159.22	84.61	26.75	.5	892.68	314.57	17.73	5.6
.016 Hi T	.1	88.40	21.45	4.63	1.46	.05	34.42	6.23	2.49	.78
	.25	264.36	527.73	22.97	7.26	.125	73.03	267.26	16.34	5.16
	.5	501.45	224.58	14.98	4.73	.25	137.19	34.60	5.88	1.86
	.75	883.15	2825.79	53.15	16.81	.5	113.38	73.28	8.56	2.7
	1.0	1311.35	3175.18	56.34	17.81	.5	377.84	1467.6	38.30	12.11
	1.5	1981.32	6789.15	82.39	26.05	.5	705.79	983.4	31.35	9.91
	2.0	2786.91	12524.4	111.91	35.38	.5	850.95	1697.23	41.19	13.02

$\overline{X}$ = Mean

S^2 = Variance

S = Standard deviation

SEM = Standard error of the mean

Table VI

Means, variance, standard deviation, and standard error of the means for all .018-inch wires

Wire size (ins.)	Deflection (mm.)	Force at initial deflection (gms.)				Amt. of unloading (mm.)	Force at unloading (gms.)			
		$\overline{X}$	S^2	S	SEM		$\overline{X}$	S^2	S	SEM
.018 Standard	.1	170.32	71.48	8.43	2.66	.05	62.86	226.08	15.03	4.75
	.25	377.16	458.42	21.41	6.77	.125	107.25	1132.7	33.65	10.65
	.5	812.62	612.73	24.75	7.82	.25	265.13	389.09	19.7	6.23
	.75	1293.66	1503.3	38.77	12.26	.5	172.82	522.96	22.86	7.23
	1.0	1940.95	9782.2	98.9	32.27	.5	433.64	156.39	12.5	3.95
	1.5	2883.99	512.88	71.61	22.64	.5	792.89	479.1	21.88	6.92
	2.0	3541.7	9350.2	96.69	30.57	.5	889.05	1335.08	36.53	11.55
.018 Australian	.1	116.34	36.62	6.05	1.91	.05	49.03	37.48	6.12	1.93
	.25	333.16	408.52	20.21	6.39	.125	111.81	34.33	5.85	1.85
	.5	801.28	272.05	16.49	5.21	.25	253.33	57.21	7.56	2.39
	.75	1419.76	1815.27	42.6	13.47	.5	206.38	42.29	6.5	2.05
	1.0	2143.7	5460.2	73.89	23.36	.5	633.67	297.43	17.24	5.45
	1.5	3482.55	20605.9	143.54	45.39	.5	1231.97	435.29	20.86	6.59
	2.0	4178.5	20103.7	141.78	214.83	.5	1348.09	1064.47	32.62	10.31
.018 Hi T	.1	134.58	14.13	3.76	1.18	.05	53.25	10.93	3.3	1.04
	.25	342.92	601.06	24.51	7.75	.125	105.48	65.45	8.09	2.55
	.5	815.79	68.63	8.28	2.61	.25	258.32	32.51	5.70	1.80
	.75	1404.34	1290.35	35.92	11.35	.5	245.39	1931.34	43.94	13.89
	1.0	2131.56	1562.34	39.52	12.5	.5	637.3	1075.6	32.79	10.37
	1.5	3217.84	18472.7	135.9	42.97	.5	1124.92	2011.88	44.8	14.1
	2.0	3998.05	13827.64	117.59	37.18	.5	1238.32	1705.47	41.29	13.05

$\overline{X}$ = Mean

S^2 = Variance

S = Standard deviation

SEM = Standard error of the mean

Table VII

Means, variance, standard deviation, and standard error of the means for all .020-inch wires

Wire size (ins.)	Deflection (mm.)	Force at initial deflection (gms.)				Amt. of unloading (mm.)	Force at unloading (gms.)			
		$\overline{X}$	S^2	S	SEM		$\overline{X}$	S^2	S	SEM
.020 Standard	.1	182.81	173.82	13.18	4.16	.05	75.56	130.20	11.41	3.6
	.25	495.78	154.77	27.47	8.68	.125	142.42	549.67	23.44	7.41
	.5	1133.54	4341.19	65.88	20.83	.25	360.15	2049.48	45.27	14.31
	.75	2023.95	4722.34	68.71	21.73	.5	223.16	1686.26	41.06	12.98
	1.0	2839.08	8580.37	92.63	29.29	.5	590.58	899.93	29.99	9.48
	1.5	4029.78	13127.77	114.57	36.23	.5	886.33	769.05	27.73	8.76
	2.0	5022.25	61474.33	247.94	78.40	.5	956.19	2911.59	53.95	17.06
.020 Australian	.1	166.64	115.82	10.76	3.4	.05	69.81	54.14	7.35	2.32
	.25	498.50	1373.60	37.06	11.72	.125	170.55	773.06	27.14	8.58
	.5	1355.13	3800.94	61.65	19.49	.25	496.69	755.54	27.48	8.69
	.75	2097.90	4966.47	70.47	22.28	.5	349.22	3243.67	56.95	18.01
	1.0	3018.25	3329.51	57.70	18.24	.5	875.90	660.47	25.69	8.126
	1.5	4288.33	22497.01	149.99	47.43	.5	1516.83	1111.91	33.34	10.54
	2.0	5193.72	83566.81	289.07	91.41	.5	1704.63	1489.69	38.59	12.20
.020 Hi T	.1	194.41	242.36	15.56	4.92	.05	75.75	54.23	7.36	2.32
	.25	519.37	1000.52	31.66	10.01	.125	166.47	562.59	23.71	7.50
	.5	1305.00	379.76	19.48	6.16	.25	455.86	293.81	17.14	5.42
	.75	2304.74	5273.92	72.62	22.96	.5	331.58	514.13	22.67	7.17
	1.0	3289.05	11958.72	109.35	34.58	.5	835.98	1829.12	42.76	13.52
	1.5	4666.63	18713.28	136.79	43.25	.5	1295.48	599.92	24.49	7.74
	2.0	5486.74	22236.26	149.11	47.15	.5	1359.93	2280.54	42.25	15.10

$\overline{X}$ = Mean

S^2 = Variance

S = Standard deviation

SEM = Standard error of the mean

Table VIII

Means, variance, standard deviation, and standard error of the means for all .022-inch wires

Wire size (ins.)	Deflection (mm.)	Force at initial deflection (gms.)				Amt. of unloading (mm.)	Force at unloading (gms.)			
		$\overline{X}$	S^2	S	SEM		$\overline{X}$	S^2	S	SEM
.022	.1	307.31	456.30	21.36	6.75	.05	119.06	181.99	13.49	4.266
	.25	802.41	2502.55	50.07	15.83	.125	281.23	1335.21	36.54	11.555
	.5	1896.05	8412.20	91.71	29.00	.25	629.59	1814.35	42.59	13.46
Standard	.75	2751.54	50734.55	225.24	71.22	.5	214.09	7154.62	84.58	26.74
	1.0	3822.94	9916.24	99.58	31.49	.5	678.58	9415.40	97.03	30.68
	1.5	5054.91	12670.64	112.56	35.59	.5	978.87	7999.51	89.44	28.28
	2.0	5819.68	72607.93	269.45	85.21	.5	1084.10	3520.66	59.33	18.76
.022	.1	398.03	278.01	16.67	5.27	.05	168.51	232.12	15.23	4.817
	.25	1098.61	1073.58	32.76	10.38	.125	457.68	633.11	25.16	7.95
	.5	2464.86	25825.31	160.70	50.87	.25	887.24	1733.59	41.63	13.16
Hi T	.75	3574.32	23396.6	152.95	48.36	.5	349.19	8600.67	92.73	29.32
	1.0	4512.4	5508.56	74.21	23.47	.5	814.66	3800.52	61.64	19.49
	1.5	6073.70	249.19	62096.14	78.80	.5	1290.03	2319.13	48.15	15.22
	2.0	6937.81	84410.15	290.53	91.87	.5	1503.68	17266.10	131.40	41.55

Unitek Standard = S

Unitek Hi T = HT

TP Lab. Australian = A

Table IX

Two-way analysis of variance

PARAMETER 1 (Force at initial deflection)

Variables	Sum of squares	Degrees of freedom	Mean square	F. ratio
A (Deflections)	218.93781266	6	36.48963544	60291.787120
B (Wires)	52.63314204	13	4.04870323	6689.668190
AB	1.69774829	78	.02176600	35.963947
Error	.53380170	882	.00060521	1.000000

Means of Variable A

Deflection (mm.)

.1	2.1251071
.25	2.5434857
.5	2.8826642
.75	3.1088357
1.0	3.2679928
1.5	3.4528071
2.0	3.5371142

Contrasts for means (Scheffé)

A Contrast = .0104869
B Contrast = .0198339
Cell contrast = .1230690

Comparison of Variable A

	0.1	.25	0.5	.75	1.0	1.5	2.0
.1		S	S	S	S	S	S
.25	S		S	S	S	S	S
.5	S	S		S	S	S	S
.75	S	S	S		S	S	S
1.0	S	S	S	S		S	S
1.5	S	S	S	S	S		S
2.0	S	S	S	S	S	S	

Means of Variable B

Wires

.014	S	2.6293857
.014	A	2.7057142
.014	HT	2.6981714
.016	S	2.8329714
.016	A	2.8301142
.016	HT	2.8287000
.018	S	3.0177857
.018	A	3.0194428
.018	HT	3.0226000
.020	S	3.1533714
.020	A	3.1710714
.020	HT	3.1997428
.020	S	3.3080142
.022	HT	3.4089285

Comparison of Variable B

	.014S	.014A	.014H	.016S	.016A	.016H	.018S	.018A	.018H	.020S	.020A	.020H	.022S	.022H
.014S		S	S	S	S	S	S	S	S	S	S	S	S	S
.014A	S		NS	S	S	S	S	S	S	S	S	S	S	S
.014H	S	NS		S	S	S	S	S	S	S	S	S	S	S
.016S	S	S	S		NS	NS	S	S	S	S	S	S	S	S
.016A	S	S	S	NS		NS	S	S	S	S	S	S	S	S
.016H	S	S	S	NS	NS		S	S	S	S	S	S	S	S
.018S	S	S	S	S	S	S		NS	NS	S	S	S	S	S
.018A	S	S	S	S	S	S	NS		NS	S	S	S	S	S
.018H	S	S	S	S	S	S	NS	NS		S	S	S	S	S
.020S	S	S	S	S	S	S	S	S	S		NS	S	S	S
.020A	S	S	S	S	S	S	S	S	S	NS		S	S	S
.020H	S	S	S	S	S	S	S	S	S	S	S		S	S
.022S	S	S	S	S	S	S	S	S	S	S	S	S		S
.022H	S	S	S	S	S	S	S	S	S	S	S	S	S	

Table X

Groups of wire-deflection combinations, that give no significantly different force values for the initial deflection at the 95% level of confidence. (Wire sizes are given in inches and deflection in mm.)

GROUP	1	2	3	4	5
FORCE RANGE (grams)	68.94-88.4	102.33-134.58	147.14-194.41	256.73-307.31	328.17-398.42
Wire-deflection combinations	.014S .1 mm. .014A .1 .014HT .1 .016HT .1	.016S .1 .016A .1 .018A .1 .018HT .1	.014S .25 .014A .25 .014HT .25 .018S .1 .020S .1 .020A .1 .020HT .1	.016S .25 .016A .25 .016HT .25 .022S .1	.014S .5 .014A .5 .014HT .5 .018S .25 .018A .25 .018HT .25 .022HT .1

GROUP	6	7	8	9	10
FORCE RANGE	488.75-622.11	650.00-855.92	866.82-1133.54	1192.51-1419.36	1594.95-2097.9
	.014HT .75 .014S .75 .016S .5 .016A .5 .016HT .5 .020S .25 .020A .25 .020HT .25	.014S 1.0 .014A .75 .016A .75 .018S .5 .018A .5 .018HT .5 .022S .25	.014A 1.0 .014HT 1.0 .016S .75 .016HT .75 .020S .5 .022HT .25	.014S 1.5 .014S 2.0 .016S 1.0 .016A 1.0 .016HT1.0 .018S .75 .018A .75 .018HT .75 .020A .5 .020HT .5	.014A 1.5 .014HT 1.5 .014HT 2.0 .016S 1.5 .016A 1.5 .016HT 1.5 .018S 1.0 .020S .75 .020A .75 .022S .5

GROUP	11	12	13	14	15
FORCE RANGE	2131.56-2464.8	2551.4-3289.05	3482.5-45124	4666.6-6073.7	6937.81
	.014A 2.0 .016S 2.0 .018A 1.0 .018HT1.0 .020HT .75 .022HT .5	.016A 2.0 .016HT2.0 .018S 1.5 .018HT1.5 .020S 1.0 .020A 1.0 .020HT1.0 .022S .75	.018S 2.0 .018A 1.5 .018A 2.0 .018HT 2.0 .020S 1.5 .020A 1.5 .022S 1.0 .022HT .75 .022HT 1.0	.020S 2.0 .020A 2.0 .020HT1.5 .020HT2.0 .022S 1.5 .022S 2.0 .022HT1.5	.022H 2.0

Unitek Standard = S
Unitek Hi T = HT
TP Lab. Australian = A

Table XI

One-way analysis of variance, comparison of the slopes of the regression lines for Parameter 1 (force at initial deflection).

Variable	Sum of squares	Degrees of freedom	Mean squares	F ratio
A (wires)	670948725.10200000	13	51611440.39240000	43.549685
Error	.112823068496 ex10	952	1185116.26571000	1.000000

Means of Variable A

Contrasts for means of A 878.9530137

Wires	
.014S	761.1219900
.014A	1173.3559900
.014H	990.0778300
.016S	1303.9171200
.016A	1354.5762800
.016H	1430.5973300
.018S	1856.7541900
.018A	2274.8970800
.018H	2134.7000680
.020S	2642.5437200
.020A	2748.4459500
.020H	2947.9331300
.022S	3001.7342500
.022H	3507.4241400

Comparison of Variable A

	.014S	.014A	.014H	.016S	.016A	.016H	.018S	.018A	.018H	.020S	.020A	.020H	.022S	.022H
.014S		NS	NS	NS	NS	NS	S	S	S	S	S	S	S	S
.014A	NS		NS	NS	NS	NS	NS	S	S	S	S	S	S	S
.014H	NS	NS		NS	NS	NS	NS	S	S	S	S	S	S	S
.016S	NS	NS	NS		NS	NS	NS	S	S	S	S	S	S	S
.016A	NS	NS	NS	NS		NS	NS	S	S	S	S	S	S	S
.016H	NS	NS	NS	NS	NS		NS	NS	NS	S	S	S	S	S
.018S	S	NS	NS	NS	NS	NS		NS	NS	NS	S	S	S	S
.018A	S	S	S	S	S	NS	NS		NS	NS	NS	NS	NS	S
.018H	S	S	S	S	S	NS	NS	NS		NS	NS	NS	NS	S
.020S	S	S	S	S	S	S	NS	NS	NS		NS	NS	NS	NS
.020A	S	S	S	S	S	S	S	NS	NS	NS		NS	NS	NS
.020H	S	S	S	S	S	S	S	NS	NS	NS	NS		NS	NS
.022S	S	S	S	S	S	S	S	NS	NS	NS	NS	NS		NS
.022H	S	S	S	S	S	S	S	S	S	NS	NS	NS	NS	

Unitek Standard = S
Unitek Hi T = HT
TP Lab. Australian = A

Unitek Standard = S
Unitek Hi T - HT
TP Lab. Australian = A

Table XII

Two-way analysis of variance

PARAMETER 2 (Force at unloading)

Variables	Sum of squares	Degrees of freedom	Mean square	F. ratio
A (Deflections)	179.15808049	6	29.85968008	8768.829275
B (Wires)	52.18711441	13	4.02439341	1178.898448
AB	7.21512816	78	.09250164	27.164762
Error	3.00339270	882	.00340520	1.000000

Means of Variable A

*	**	
.1	.05	1.7250928
.25	.125	2.0484357
.5	.25	2.3761642
.75	.5	2.1904142
1.0	.5	2.6553142
1.5	.5	2.9119214
2.0	.5	2.9742928

Contrasts for means of A: .0470465
Contrasts for means of B: .0248751
Contrasts for means of cells: .2919211

Means of Variable B

.014S	1.9469714
.014A	2.1244857
.014HT	2.1520857
.016S	2.2795857
.016A	2.3170142
.018HT	2.2760000
.018S	2.4266714
.018A	2.4964571
.018HT	2.4986285
.020S	2.5168285
.020A	2.6650571
.020HT	2.6346000
.022S	2.6381714
.022HT	2.7907142

Comparison of Variable A

	.1	.25	.5	.75	1.0	1.5	2.0
.1		S	S	S	S	S	S
.25	S		S	S	S	S	S
.5	S	S		S	S	S	S
.75	S	S	S		S	S	S
1.0	S	S	S	S		S	S
1.5	S	S	S	S	S		S
2.0	S	S	S	S	S	S	

Comparison of Variable B

	.014S	.014A	.014H	.016S	.016A	.016HT	.018S	.018A	.018H	.020S	.020A	.020HT	.022S	.022H
.014S		S	S	S	S	S	S	S	S	S	S	S	S	S
.014A	S		NS	S	S	S	S	S	S	S	S	S	S	S
.014H	S	NS		S	S	S	S	S	S	S	S	S	S	S
.016S	S	S	S		NS	NS	S	S	S	S	S	S	S	S
.016A	S	S	S	NS		NS	S	S	S	S	S	S	S	S
.016H	S	S	S	NS	NS		S	S	S	S	S	S	S	S
.018S	S	S	S	S	S	S		S	S	S	S	S	S	S
.018A	S	S	S	S	S	S	S		NS	NS	S	S	S	S
.018H	S	S	S	S	S	S	S	NS		NS	S	S	S	S
.020S	S	S	S	S	S	S	S	NS	NS		S	S	S	S
.020A	S	S	S	S	S	S	S	S	S	S		NS	NS	S
.020H	S	S	S	S	S	S	S	S	S	S	NS		NS	S
.022S	S	S	S	S	S	S	S	S	S	S	NS	NS		S
.022H	S	S	S	S	S	S	S	S	S	S	S	S	S	

* Initial deflection (mm.)
** Amount of unloading (mm.)

Table XIII

Groups of wire-deflection combinations, that give no significantly different force values for the unloading deflection at the 95% level of confidence. (Wire sizes are given in inches and deflection in mm.)

GROUP	1	2	3	4	5	6	7
FORCE RANGE (grams)	25.62-49.03	52.6-96.4	105.5-214.1	219.5-377.8	433.6-835.9	850.9-1516.8	1704.6
	.014S .1 mm.	.014S .5	.014S 1.0	.014S 1.5			
	.014S 2.5			.014S 2.0			
	.014S .75						
	.014A .1	.014A .25		.014A 1.0	.014A 1.5		
		.014A .5			.014A 2.0		
		.014A .75					
	.014HT .1	.014HT .25	.014HT .5	.014HT 1.0	.014HT 1.5		
		.014HT .75			.014HT 2.0		
	.016S .1	.016S .25	.016S .5	.016S 1.0	.016S 1.5		
			.016S .75		.016S 2.0		
	.016A .1	.016A .25	.016A .5	.016A 1.0	.016A 1.5	.016A 2.0	
			.016A .75				
	016HT .1	.016HT .25	.016HT .5	.016HT 1.0	.016HT 1.5	.016HT 2.0	
			.016HT .75				
		.018S .1	.018S .25	.018S .5	.018S .5	.018S 2.0	
			.018S .75		.018S 1.5		
	.018A .1		.018A .25	.018A .5	.018A 1.0	.018A 1.5	
			.018A .75			.018A 2.0	
		.018HT .1	.018HT .25	.018HT .5	.018HT 1.0	.018HT 1.5	
				.018HT .75		.018HT 2.0	
		.020S .1	.020S .25	.020S .5	.020S 1.0	.020S 1.5	
				.020S .75		.020S 2.0	
		.020A .1	.020A .25		.020A .5	.020A 1.0	.020A 2.0
				.020A .75		.020A 1.5	
		.020HT .1	.020HT .25	.020HT .75	.020HT .5	.020HT 1.5	
					.020HT 1.0	.020HT 2.0	
			.022S .1	.022S .25	.022S .5	.022S 1.5	
			.022S .75		.022S 1.0	.022S 2.0	
			.022HT .1	.022HT .75	.022HT .25	.022HT .5	
					.022HT 1.0	.022HT 1.5	
						.022HT 2.0	

Unitek Standard = S
Unitek Hi T = HT
TP Lab. Australian = A

Table XIV

One-way analysis of variance, comparison of the slopes of the regression lines for Parameter 2 (force at unloading).

Variable	Sum of squares	Degrees of freedom	Mean squares	F ratio
A (wires)	56541681.79080000	13	4349360.13775000	7.274086
Error	569224875.40000000	952	597924.28928500	1.000000

Means of Variable A

Wires	.014S	244.2000000
	.014A	420.0400000
	.014H	486.8000000
	.016S	515.3900000
	.016A	637.5700000
	.016H	607.4400000
	.018S	606.5100000
	.018A	985.7300000
	.018H	886.8000000
	.020S	633.2600000
	.020A	1182.4700000
	.020H	934.3600000
	.022S	644.1600000
	.022H	850.6600000

Contrasts for means of A 624.3220034

Comparison of Variable A

	.014S	.014A	.014H	.016S	.016A	.016H	.018S	.018A	.018H	.020S	.020A	.020H	.022S	.022H
.014S		NS	NS	NS	NS	NS	NS	S	S	NS	S	S	NS	SN
.014A	NS		NS	NS	NS	NS	NS	NS	NS	NS	S	NS	NS	NS
.014H	NS	NS		NS	NS	NS	NS	NS	NS	NS	S	NS	NS	NS
.016S	NS	NS	NS		NS	NS	NS	NS	NS	NS	S	NS	NS	NS
.016A	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS	NS	NS
.016H	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS	NS
.018S	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS	NS
.018A	S	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS	NS
.018H	S	NS	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS	NS
.020S	NS	NS	NS	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS
.020A	S	S	S	S	NS	NS	NS	NS	NS	NS		NS	NS	NS
.020H	S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		NS	NS
.022S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		NS
.022H	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	

Unitek Standard = S
Unitek Hi T = HT
TP Lab. Australian = A