LIGATURE TIE FRICTION IN THE 22 MIL EDGEWISE APPLIANCE

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INTRODUCTION

During orthodontic tooth movement, many factors contribute to the amount and type of movement. Between the physiology and histology of the surrounding structures of the tooth and the force module, is juxtaposed the physics of the interaction of the archwire thickness and resiliency, bracket width and type, ligature type, and moment arms depending on tooth length and area of the restrained portion of the root.

The fundamental basis for tooth movement studies begins with the examination of the histology and physiology of the supporting structures. This has been studied from the inception of orthodontic specialty practice. A particular emphasis has been placed on the determination of the optimal force necessary to move tooth in a physiologic manner.

Friction in the orthodontic appliance has been very sparsely acknowledged in the literature. It was not thought to be so important until recent times, since the movement of teeth has been done by the opening and closing of loops in wire fixed at the bracket, so both wire and tooth moved as one, with no arch wire friction. Recently, more orthodontists are using a method requiring direct translation of teeth along a rigid arch wire thus introducing reaction couples set up between the bracket and the wire. These couples are dependent on the degree of bracket-to-wire angulation placed deliberately by the operator, the amount of slack between the wire and the bracket, and on the bracket binding against the wire by the tooth tipping through the periodontal ligament and bending the surrounding bone. The latter is also dependent on the force system used which may have a couple of its own.

The purpose of this investigation was to determine the amount of friction set up at the translating teeth brackets of one quadrant of teeth in an edgewise orthodontic appliance, by various wire and ligation methods in an in vitro model system.

REVIEW OF THE LITERATURE

Some students of tooth movement believe there is an optimal force relative to the rate of tooth movement. It is essential to know the frictional values that must be allowed for in order to correlate actual delivered force with rate of movement. In a classical study, Storey and Smith[1] retracted canines in five subjects. They used precalibrated helical torsion springs soldered to sectional arches (i.e., a frictionless system) and measured movement weekly into an extraction space using a point in the opposite arch as a reference. They found that canines moved rapidly with light forces of 175-300 grams, but over 300 gram forces caused the bicuspid and molar anchor teeth to move at a faster rate than the canine. If this thesis is correct, then one must know the friction if one is using a frictional system.

Storey and Smith's work is apparently refuted by studies at the University of Oregon.[2,3] Here canines were also retracted but the conclusion was that large differences of individual response determined the rate of tooth movement. That is, movement could not be directly correlated with force, even though higher force values tended to yield a higher rate of tooth movement.

This conclusion was also suggested by Utley[4] using cats with unilateral headgear applying light and heavy forces to canines. No correlation between tooth movement rate and force was apparent. On the other hand, Andreason and Johnson[5] got over two times the movement of molars with 400 grams of pressure as 200 grams. Burstone[6] concurs that one cannot postulate a simple relationship between force magnitude and the rate of tooth movement.

There are strictly physical and mechanical systems where friction should be known. It is the nature of tooth movement that, since we are unable at this stage of the art to apply a perfect couple to the tooth, the tooth must be tipped and uprighted many times as it is moved through a space. This is so because of the long lever arm from the tooth's axis of rotation to the bracket where our force is applied.

The friction of tipping (i.e., binding of the bracket against the arch wire) has been studied in four papers. Buck, Scott, and Morrison[7] in 1963, studied the force systems in various bracket-archwire combinations.

They found that tooth movement explained on the basis of physics alone was suspiciously similar to tooth movement explained on the basis of biological behavior in the optimum force theories. They used an instrument developed by the University of Texas which electrically measures and resolves a force system which may be applied to the tooth crown. They activated coil springs to a known force level and measured the forces resolved at each of the several angles of bracket to arch wire. They found that single brackets with a loose fitting wire permitted the most tooth movement with a minimum of force before binding friction completely stopped the bracket, compared with a double bracket and a close fitting wire. For instance, to deliver 100 grams of force to the root of the tooth through a 22 x 18 mil bracket and an 18 x 25 mil wire, you must have a force of 108 grams. To deliver the same force but using a double bracket takes 100 grams. They also found that the maximum movement was in the 18 x 25 mil wire with the 22 x 28 mil bracket, at 1 mm.; as opposed to 0.52 mm. using the 18 x 25 bracket. Friction of tying the arch wire to the bracket was not mentioned in this study, and indeed in their particular experimental setup they did not have to ligature tie the arches.

Nicolls in 1968[8] measured friction of a 16 mil round wire in various brackets and tubes with the wire being pulled at various angles. He found that the greater the inclination of the wire to the tube or bracket, the greater the friction. This friction could be reduced by burnishing the tube ends and also by bending a loop near the tube end. He also measured the friction of 25 mil soft brass ligature when used as a tie. He found that 0 to 7 ounces of friction was present using a 16 mil wire and a 2.5 mm. ripple bracket. He also measured the friction developed by elastics hooked over the end of the arch wire as it exists from the tube. Here he found values of 0 to 2.75 ounces of friction.

Andreason and Quevedo in 1970[9] reported the friction force of tipped brackets moving along various wires. In their apparatus the arch wire was kept in tension so it was constantly stiff. Instead of using ligature ties, they kept the wire in the bracket by utilizing 660 grams of force against it. They found at 0 degrees of wire to bracket it required 80 to 140 grams to move along the various wires.

At 10 degrees tip it required up to 1500 grams for a wide bracket to move along a 21 x 25 mil wire. They concluded that teeth can move the fastest if light wire is used. However, clinically it is impossible to keep the wire in tension as in their experiment, and the wire would tend to bow, introducing tipping moments which would increase the friction.

Miller[10] in 1970, measured friction in the edgewise system. Rather than hold the ligature tie constant, he tested various types of ties, however, he did not separate out the binding type of friction of bracket on wire from that of the tie; nor did he measure the angle of the bracket to the wire. He measured the friction relative to load applied at the estimated axis of rotation of the tooth. This load would of course result in a different bracket angle depending on the arch wire used and may account for the opposite conclusions he made compared with the previous two studies. He found, using heavy forces, increasing resistance to bracket movement with decreasing wire diameter. Using lighter forces, he found relatively little difference in resistance values.

Echols in 1975,[11] measured the force necessary to pull various arch wires through ligation with Ālastik A-1 and Ormolasts to a standard 22 mil edgewise bracket. The ligatures were taken from patients where they had been in place two weeks. In general, it was found that the heavier the arch wire, the greater the friction. For example, a mean of 50 grams was required to pull a 16 mil wire through a ligature, versus a mean of 112 grams where a 19 x 25 mil arch wire was used.

Many authors in the past have implicated arch wire friction as a major clinical problem. Stoner in 1960,[12] reported in an article promulgating tooth movement by bending loops in arch wires that one reason he does this is to side-step the friction of wires binding in brackets. Begg in 1965,[13] mentions friction as a problem in treatment if the arch wire, during retraction of anterior teeth, becomes accidently engaged in a premolar bracket, or if it binds in a tube because it is too short, or has a bend that impinges on the tube. Stoner advocates in Graber's text[14] that loose ligatures, subdued offsets in the arch wire,and a small diameter wire should be used to decrease friction. Paulson, et al.,[15] mentions friction from tight ligatures as a critical factor when retracting canines. They used a 16 mil wire in an 18 mil bracket slot since they believed binding friction would inhibit movement if any larger wire was used. Thurow[16] believes bracket width to be the definitive factor in creating friction. A wide bracket prevents tipping and thus cannot bind so easily. He believes in light forces since the heavier force will only raise the frictional force relative to the delivered force because of the nature of the system. Jarabak,[17] using Storey and Smith's[1] work as reference for 250 grams being the optimum force to move a canine, show that this force used in a frictional edgewise system to translate a tooth would create 757 grams of frictional resistance in a 3.7 mm. wide siamese bracket. This is an unreasonable force for an orthodontic wire to take. He thinks the frictional system would not work were it not for the exploring tongue and occlusal forces aiding in momentarily relieving adverse couples.

MATERIAL AND METHOD

In this experiment the friction of one-half arch, that is one quadrant, was measured. Four bands with bracket or tube attachments were selected at random from the clinic supply. They were aligned and leveled by being attached to a rigid wire and set into an acrylic block so that only the brackets were exposed. The bands were the canine, second premolar, first and second molars. The second molar had a tube instead of a bracket. All the bands were touching except an "extraction" space of 7 mm. was left between the canine and second premolar. All brackets were siamese (Fig. 1).

A new arch wire* was selected at random and ligated to each bracket. It was marked mesial to the canine bracket by a scratch and then pulled using an Instron machine (Fig. 2) until slippage occurred and was maintained in a narrow consistent range. This was

* Unitek Corporation, Monrovia, California (see Fig. 3)

repeated three times, each time moving the wire back to the original position. Thus, each statistical cell has four trials. The various combinations of ligature ties and wires used are as in Figure 5 and Table I.

The new Ālastiks* were randomly selected from the clinic supplies. In all cases the ligatures were placed on the model and allowed to accommodate a minimum of one day before testing. In the case of the steel ligature,** the arch wire was "worked" by moving the arch wire back and forth in two dimensions for a few minutes. This would have the effect of simulating the loosening of the ties that would happen naturally with chewing occlusal forces.

*Unitek Corporation, Monrovia, California (Fig. 3)

**Unitek Corporation, Monrovia, California (Fig. 3)

FINDINGS

The maximum friction level attained after establishing a constant range in each trial is recorded in Table II. The minimum friction levels at which the static friction were just overcome are also recorded in Table III. The means of these trials are illustrated in Figure 5. A trial graph generated by the Instron is shown in Figure 4.

An analysis of variance was done separately on the maximum readings (Table IV), and on the minimum readings (Table II). All trials were pooled to calculate the standard error. The significant statistic ($P < .01$) was the wire by tie interaction, on which a Least Significant Difference Test was applied to analyse the simple effects of tie on wire. Table II also gives the cell means with the asterisk indicating significantly low friction values. The minimum set of friction values were treated separately from the maximum values and gave identical levels of significance. Therefore, one would consider the type of ligature tie in Table IV optimum for each particular wire if one's objective is to minimize friction.

Conversely, significantly higher friction values were noted. The A-1 Ālastik tie on the 18 mil round wire was 227% higher than the best low friction tie. The A-1 tie on the 20 mil round wire was 356% higher, and the A-1 and C-chain on the 19 x 25 mil wire was 257% and 271% higher, respectively; and the C-chain on the 21 x 25 gave a 148% higher friction value than the low steel tie. These values are figured on the maximum friction levels that were recorded.

DISCUSSION

Webster's New Collegiate Dictionary's definition of friction is: "the rubbing of one body against another; the resistance to relative motion between two bodies in contact." Disregarding the work of Leonardo da Vinci, whose papers were lost until later investigators had repeated his work, the classical laws of friction were developed in the 17th, 18th, and 19th centuries by Amontons, Coulomb and Morin. These laws were:

1) Friction is proportional directly to load.

2) Friction depends on the nature of the sliding surfaces.

3) Friction is independent of the area of contact of the surfaces.

4) Friction is independent of sliding velocity.

The basic reasoning behind these laws was that friction is generated by the intermeshing roughness of the surfaces of contact.

All the foregoing has been challenged or developed further so that modifications of the laws are necessary to understand friction. The more modern theories are:

1) Friction is caused by the cohesion of surfaces through molecular attraction, therefore, frictional force is proportional to the area of actual contact.

2) Friction is caused by electrical attraction, one surface becoming charged positively, the other negatively.

There is evidence that friction decreased with velocity at high speeds, but at very minute speeds, friction decreases with speed. It should be noted that there is a difference between kinetic friction (the force required to maintain motion) and static friction (the force required to initiate friction).

It seems logical to attribute friction to the area of contact. However, it is deceptive to automatically assume that surface area and area of contact are one and the same. This is illustrated by studying polished surfaces. An optically polished mirror has valleys and peaks differing by 600 Angstrom units, much like a land surface of rolling hills. Most surfaces differ by thousands of units; thus, when two such surfaces are opposed, the area of contact is actually very small, with just the "hill tops," so to speak, touching. For steel surfaces, actual contact area is 0.0001 of the surface area. When load is applied, these are flattened proportionate to the degree of load. These hilltop contacts actually flow as plastic from the weight and adhere by welding themselves to their opposite mates, thus friction equates with the area of actual contact multiplied by the sheer strength per unit area.

Another variable is the effect of surface films of oxide and adsorbed gas. In a vacuum, complete metal seizure will occur if these layers are removed.

A way of reducing friction is to lubricate the surfaces. There are two types of lubrication: hydrodynamic, where a thick layer of lubricant separates the metals; and boundary lubrication, which is the case of salivary lubrication of brackets and wires. In this case, the metals do touch and thus they obey the two laws of friction.

Closing space in the usual bicuspid extraction case consists of either pulling the cuspid (guided by the arch wire) against the anchorage of the second bicuspid and first two molars, and when that is completed, pulling the anterior teeth plus the arch wire through the anchorage of the molar and bicuspid unit; or the anterior segment may be moved back without first moving the cuspid. In all cases, the friction is that of the wire sliding through three or four brackets and one tube in the posterior of each arch.

Why is it necessary to know the friction in an orthodontic appliance? Friction is one of the variables upon which the force that is delivered to the root is dependent. Early in the history of orthodontics[18] it was noted that force compresses tissue on the pressure side of the tooth and consequently the bone was thought to become necrotic. Oppenheim[19] showed that the response to force was different for light or heavy forces and that the heavier forces created areas where there was a complete absence of cells. This was physiologically undesirable, relative to the natural forces of growth and development, thus he advocated light intermittant forces. Swartz[20] concurred with this thesis and defined the most physiologic force as that which was less than capillary blood pressure (20 to 26 grams per square centimeter). This range of force is called optimal physiologic force.

Storey and Smith's study[1] pointed out that certain forces have differential effects on the rate of tooth movement. This could be called an optimal force as well, albeit in a different sense. Their work has yet to be confirmed in a translation tooth movement study. Hixon, et al.,[2,3] apparently refuted it, however he was not able to quantitate the friction in his appliance which was considerable, despite his attempts to nullify it.

Thus, the optimal force is still to be found, partly because we do not know how to measure a subject's physiologic response, and partly because we have not separated out the force component actually delivered to the root surface to cause translation from the various frictions that affect our appliances.

This study confirms many orthodontists' intuitive feelings that steel ligatures contribute less friction in the appliance than do plastic modules, however, it is interesting to note that in some cases a plastic module is a significant runner-up in contributing the least friction.

The range of friction values are interesting since it gives an idea of the difficulty of delivering the optimum amount of force to a tooth from a tie friction standpoint alone, ignoring tipping and wire and bracket size friction, as discussed in the REVIEW OF THE LITERATURE. Of peak friction values taken alone, the range of force is 0.206 pounds to 1.450 pounds for all wires and ties. Since it is not possible for an orthodontist to use one wire size only in treatment, this whole range must be considered and subtracted from the force applied to move the teeth to get the net force for tooth movement. In some cases, the gross force applied may be less than the friction force, in which case the teeth would not move.

The range of force orthodontic techniques actually generate are: K-x module (at 24 hours) 0.861 pounds to 1.437 pounds, Hice loops 1.7 pounds, Bull loops 2.75 pounds,[18] elastics 0.13 to 0.38 pounds,[8] closed coil spring (8 mil around 30 mil arbor activated 1 to 3 mm.) 0.25 to 0.50 pounds.[22] Thus, with friction forces approaching 1½ pounds, one can see tie friction is a significant contribution to the physics of tooth movement.

Because of the wide range of tying friction combined with the wide range of force an orthodontist can create, it would be very difficult to consistently generate an optimum physiologic force (see previous DISCUSSION) since these are of such low order.

Another factor the orthodontist should be aware of is, if the friction is of such a magnitude that the force necessary to overcome it exceeds the stiffness of the arch wire, then an undesirable bowing of the whole arch segment will occur, either with or without any tooth movement.[23] This bowing evidently will occur with wire under 20 mil diameter used with plastic force modules.

During trial runs for this investigation, it was noted that occasionally an initial spiking friction value would occur. This was ascribed to either a stick slip phenomena or to a bur of metal on the arch wire. This happened very infrequently and the trial was repeated if it did.

A popular notion is that teeth move along an archwire by a jiggling motion generated by forces of occlusion and mastication. It was noted that static friction in these tests could be reduced considerably by tapping or vibrating the quadrant setup, simulating occlusal force. The kinetic friction could then be maintained at this lower level only if the tapping was continued. This tends to confirm this idea and should be investigated further.

Experimentally, friction could also be consistently reduced by increasing the Instron's rate of movement. The slowest possible rate was used in all the trials (0.002 inches per minute), however this is considerably faster than tooth movement is accomplished clinically (very approximately 0.002 inches per two-day period). The Instron's error is less than 0.25 of 1% and it is accurate to 0.001 pound.[23]

SUMMARY AND CONCLUSIONS

The frictional force created by various archwires and tying combinations was investigated in vitro by a simulated dental arch model. The data was statistically analysed by Anova and Least Significant Difference. It was found, in general, 10 mil steel ligature had significantly less friction than the plastic modules, and that, of the four wires tested, 20 mil round or 19 x 25 mil rectangular would be the arch wire of choice for tooth movement used in conjunction with the steel ligature.

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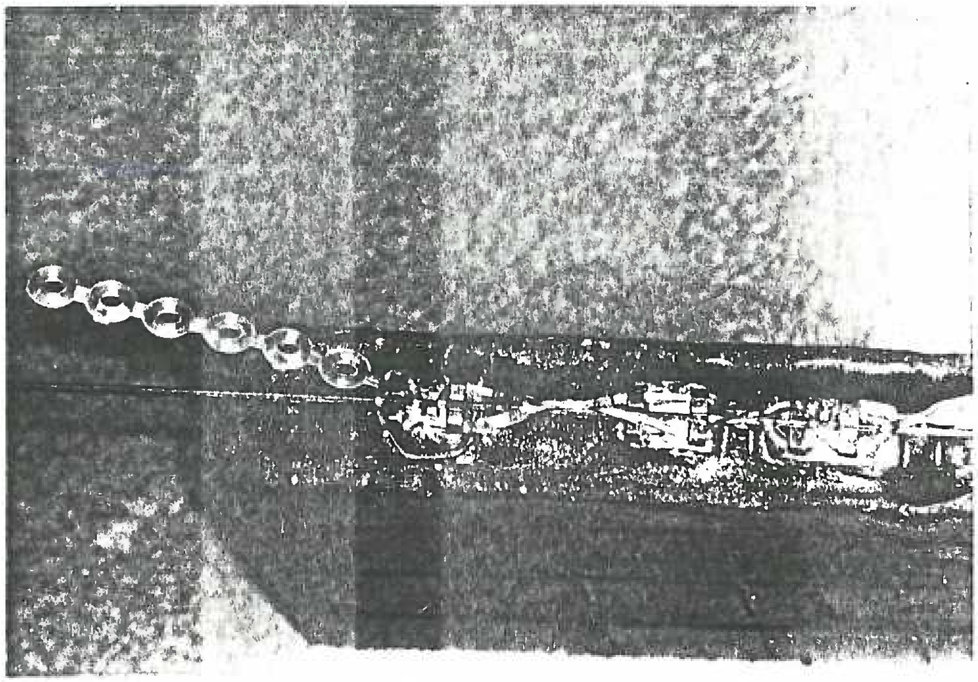


Fig. 1 Arch wire-bracket setup.

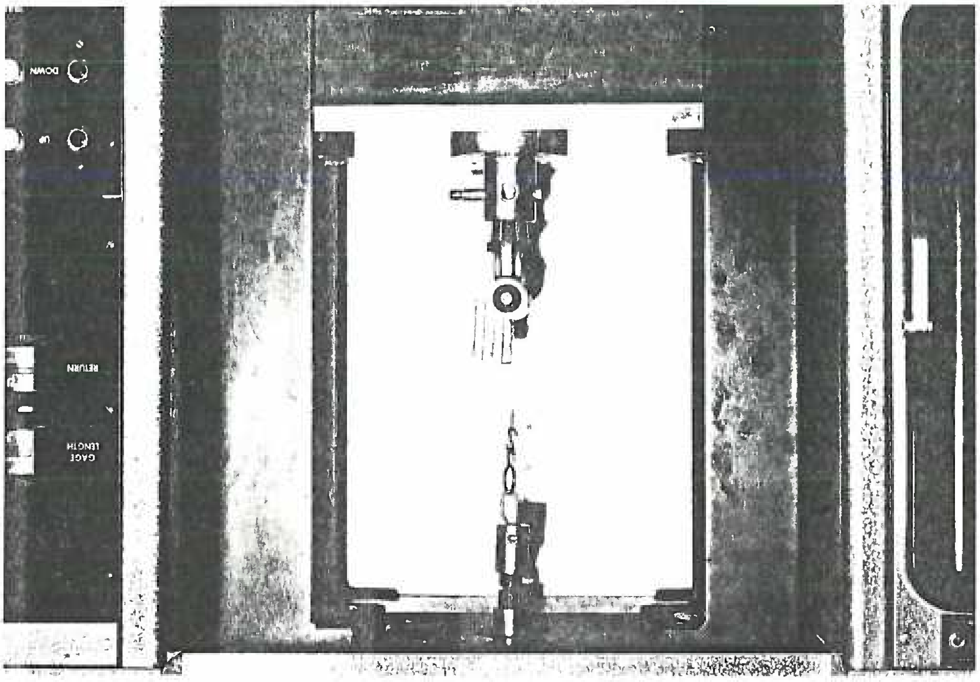


Fig. 2 Setup in Instron.

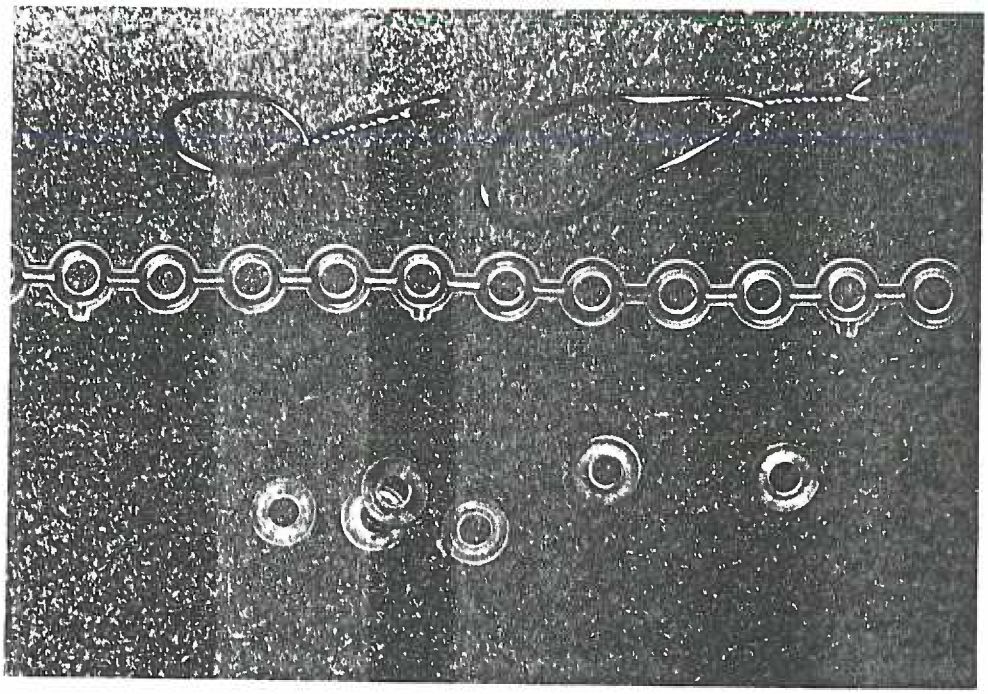


Fig. 3 Various ligature ties used on setup.

Top - A-1 ĀlastiKs

Middle - C-chain ĀlastiKs

Bottom - Steel ligature

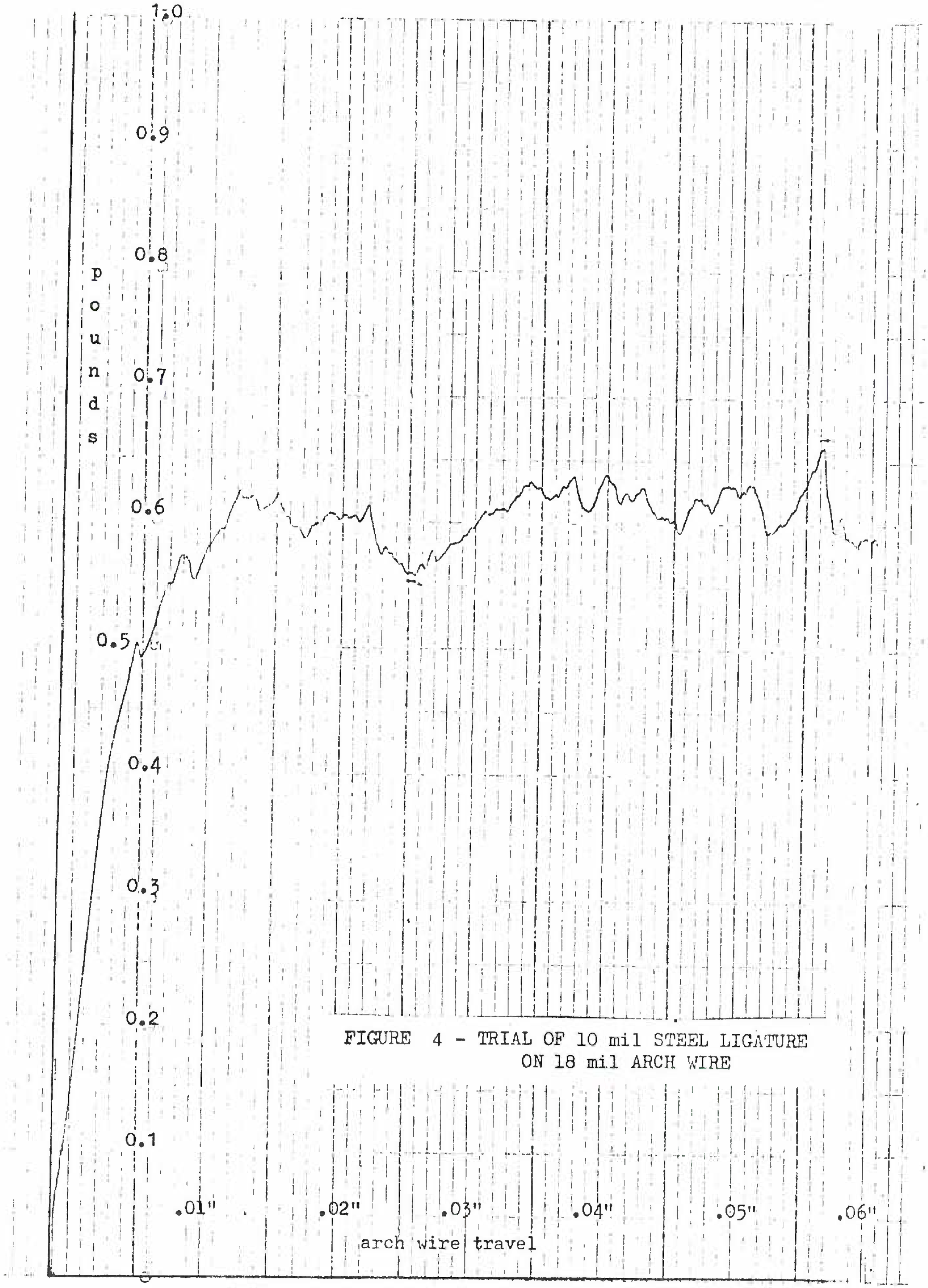
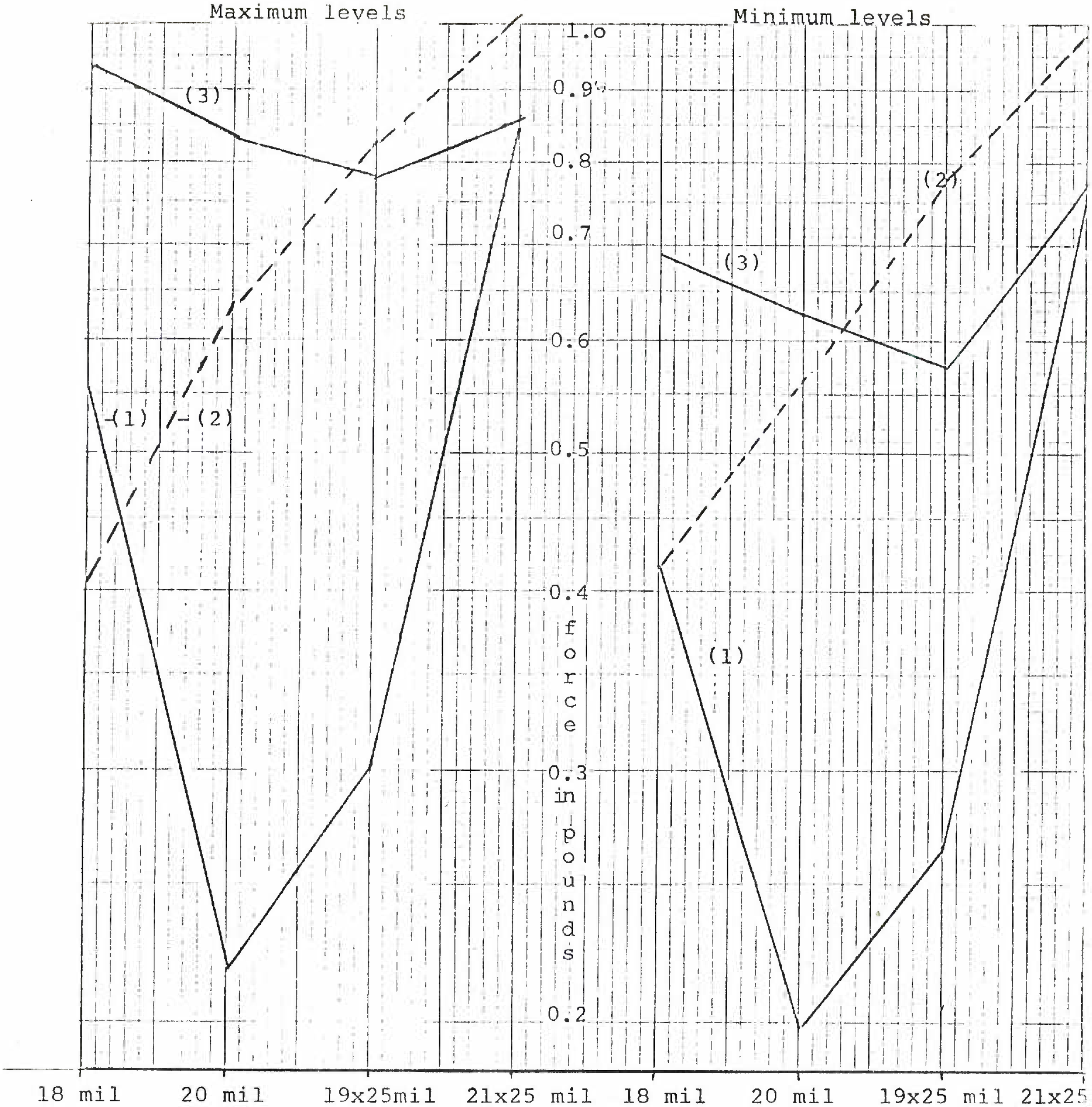


FIGURE 4 - TRIAL OF 10 mil STEEL LIGATURE ON 18 mil ARCH WIRE



WIRE TYPE

)= 10 mil steel ligature

)= A-1 plastic module

)= C-chain plastic module

FIGURE 5

FRICTION GENERATED BY VARIOUS LIGATURE TIES ON ARCH WIRES IN EXPERIMENTAL SET-UP

(vertical axis logarithmic)

Wire / Tie	18 mil	20 mil	19x25 mil	21x25 mil
10 mil steel	x	x	x	x
A-1 ĀlastiK	x	x	x	x
C-chain	x	x	x	x
ĀlastiK				

Table I Ligature tie x arch wire used.

Wire / Tie	18 mil		20 mil		19x25 mil		21x25 mil	
10 mil	.542	.661	.213	.206	.328	.302	1.320	.940
steel	.407	.613	.220	.296	.307	.282	.822	.800
	$\bar{x}$ .556*		$\bar{x}$ .234*		$\bar{x}$ .305*		$\bar{x}$ .846*	
A-1	.822	.810	.840	.778	.825	.770	.940	.868
plastic	.982	1.108	.822	.892	.815	.724	.855	.782
module	$\bar{x}$ .931		x .833		$\bar{x}$ .784		$\bar{x}$ .861*	
C-chain	.447	.439	.602	.583	.876	.786	1.450	1.360
plastic	.442	.310	.680	.671	.860	.784	1.270	0.930
module	$\bar{x}$ .410*		$\bar{x}$ .634		$\bar{x}$ .827		$\bar{x}$ 1.253	

Table II Maximum friction values--from Instron, in pounds.

.070

LSD 0.109

$\bar{x}$ = cell mean

* = significantly low friction P 0.01

Wire / Tie	18 mil	20 mil	19x25 mil	21x25 mil
10 mil	.424 .558	.180 .170	.302 .288	.752 .813
steel	.489 .339	.177 .260	.277 .258	.700 .723
	$\bar{x}$ .453*	$\bar{x}$ .198*	$\bar{x}$ .281*	$\bar{x}$ .747*
A-1	.660 .719	.629 .605	.575 .552	.844 .752
plastic	.927 1.050	.680 .601	.560 .614	.760 .738
module	$\bar{x}$ .689	$\bar{x}$ .629	$\bar{x}$ .575	$\bar{x}$ .774*
C-chain	.334 .343	.560 .464	.770 .756	1.030 1.030
plastic	.350 .271	.621 .601	.846 .754	1.130 0.708
module	$\bar{x}$ .432*	$\bar{x}$ .561	$\bar{x}$ .782	$\bar{x}$ .974

Table III Minimum friction values--from Instron, in pounds.

Wire	Tie
18 mil	10 mil steel $\bar{x}$ .556 or C-chain $\bar{x}$ .410
20 mil	10 mil steel $\bar{x}$ .234
19 x 25 mil	10 mil steel $\bar{x}$ .305
21 x 25 mil	10 mil steel $\bar{x}$ .846 or A-1 $\bar{x}$ .861

Table IV Significantly low mean friction values in pounds, tie by wire.

LSD ~~0.116~~ .096

$\bar{x}$ = cell mean

* = significant low friction P 0.01

Table V Analysis of variance table for maximum friction values.

Units = 0.001 pound

Component	Sum of Square	Degrees of Freedom	Mean Square
Wire	4764568.01	3	1588189.25
Tie	25880.66	2	12940.33
Wire x Tie	572522.00	6	95420.32
Error		36	3961.45

$F_{36}^{6} = 24.09$ t_{36} at .01 = 2.03 LSD = 90.35

Table VI Analysis of variance table for minimum friction values

Units = 0.001 pound

Component	Sum of Square	Degrees of Freedom	Mean Square
Wire	3247353.50	3	1082451.25
Tie	38642.00	2	19321.00
Wire x Tie	670590.25	6	111765.03
Error		36	4493.69

$F_{36}^{6} = 24.87$ t_{36} at .01 = 2.03 LSD = 96.22