FORCE PRODUCTION AND DECAY RATE IN C1 ĀLASTIK MODULES WITH SIMULATED TOOTH MOVEMENT

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TABLE OF CONTENTS

INTRODUCTION

Orthodontists have been using ĀlastiKs* for a number of years without really knowing the amount of force deformation which was being exerted by the different modules and chains. Research reports[6] have documented that excess force may initiate a necrotic response on the pressure side of the tooth which takes time to organize and induce osteoclastic action. This often yields an unnecessary delay in the tooth movement response which is necessary for tooth movement. The possibility exists that perhaps excess force could delay the tooth movement response.

The ĀlastiK chain which Andreasen and Bishara[2] described as permanently elongated and appeared to have very little force left after three or four weeks may, if left as a tie-back around the whole arch, produce adverse effects. These effects appear as slipped contacts and lapping of anterior teeth. Therefore, there may be more residual force than what the appearance of the ĀlastiK would indicate.

Work has been done by Hershey and Reynolds[8], Andreasen and Bishara[2], Varner and Buck[15], and others since 1970 to provide the orthodontist with clinically useful data describing the behavior of

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* ĀlastiK is a trade name for an elastomer of polyurethane resin that is isocyanate terminated and marketed by Unitek Corportaion of Monrovia, California.

plastic modules when used as orthodontic space-closing devices.

Many testing models have been used which include metal frames at set distances, an Instron Testing Machine, and other stainless steel jigs. The model in this research project will consist of: An average size second molar, first molar, and a second premolar band set on a section of plexiglass in such a way to represent an average dentition with tight contacts. The bands will be filled with clear acrylic to give them rigidity and to keep the arch symmetrical. The cuspid band will be on a movable arm which will be able to contact the second premolar or with a screw stand-off device, be held at a fixed distance from the second premolar. There will be an electrical contact on both the arm and the stand-off device so that when measuring the amount of force with a Chatillon Testing Gauge, the slightest break of the contact can be determined electrically.

In this study, there will be a decreasing amount of separation each week which will represent closure of the extraction site of tooth movement. This information has not been previously published using Cl chains on a simulated dental arch form.

The second part of this study will compare the forces generated by the injected molded C-chains and the punched C-chains. The punched C-chains have become popular lately because of the ease of manipulation of the continuous spool with the feed arm.

REVIEW OF THE LITERATURE

Although ĀlastiKs have been used for approximately 10 years, very little has been published about specific modules that are routinely used in clinical practice. Andreasen and Bishara[2] found that there was no statistical difference between test conditions when ĀlastiKs were tested in 37^{o} C. water or saliva. They reported that when C1 chains were stretched various distances, a force-decay for the first 24 hours was 74% and 56% of this was in the first hour. The remaining rate of decay from the first day to three weeks was 8% for a total force loss of about 82%.

In another report by Bishara and Andreasen[4], ĀlastiK "K" modules were studied. The mean force decay for the first 24 hours was 55% of which 45% was in the first hour. From one day to three weeks, there was a 13% force decay for a total of 67% at the end of three weeks. The authors had the following observations: 1) When the ĀlastiK material was allowed to dry out, the force increased. 2) The greater the distance the plastic ĀlastiK was stretched, the more was the deformation. 3) The limits of the range for the deviation of the ĀlastiKs tested was 14.6 grams to 130.4 grams. Therefore, more quality control of the material was indicated. 4) The ĀlastiK chains were effective in condensing arches that had generalized spacing but were less effective than other means when retracting canines on a continuous arch wire. 5) The ĀlastiK material appeared discolored with changes in shades of colors when left in the oral invironment.

Ware[16] tested C2 regular ĀlastiKs and latex elastics by placing a load on them for ten minutes. He found that the force of the ĀlastiK decreased by 200 gm and the latex elastic decreased by 10 gm and when the load was reduced to zero, the latex elastic returned to its original length and the module was appreciably deformed. He concluded that the design of the available plastic modules was excellent and they had a large range of applications. However, he felt that the material had a number of limitations. They were: 1) The load/extension ratio was very high resulting in appreciable variation in loading during application. 2) The effect of temperature and/or moisture absorption on the elastic properties made it difficult or impossible to predict the applied loads in the oral environment.

In 1975, Hershey and Reynolds[8] tested 540 assorted plastic modules by placing them on edgewise brackets which were welded to a metal frame. The initial interbracket distance ranged from 12 to 34 mm with 2 mm increments. All modules were aged in distilled water at 37^{o} C. and the framework was closed at rates of both 0.25 mm and 0.50 mm per week to simulate tooth movement. At a fixed distance, 64% of the force remained after one hour, 47% after 24 hours, and 42% after six weeks. When the stretched distance was decreased at the rate of 0.25 mm per week, 32% of the force remained after four weeks and 28% after six weeks as compared to 25% after four weeks and 18% after six weeks when decreased at the rate of 0.5 mm per week. They concluded that although the loss of force was rather large at the 4 to 6 week period, there was sufficient force during the total period to produce tooth movement. They also stated that modules by other manufacturers exhibited similar force decay curves and were judged to be clinically equivalent.

Wong[17] used stainless steel plates (which were stored in water) to which edgewise brackets were welded 17 mm apart. The Ālastik C2 chains were stretched between the brackets which represented the distance between the cuspid and second premolar. He found that there was a 73% loss of force in 24 hours and another 6% loss from 1 day to 3 weeks for a total of 79%. When he compared the Ālastik C2 initial force of 641 grams with Ormco Power chain initial force of 342 grams, in one day, both materials decayed to 171 grams. He concluded that the higher initial force of Ālastik C2's increased patient discomfort and the the remaining force may not be sufficient to move teeth. He also stated that by prestretching the synthetic elastomers one-third of their length which prestresses the molecular polymer chain, there was an increase in the strength of the material.

An Instron Testing Machine was used by Kovatch and others[11] when they tested K2 clear ĀlastiKs. They were stretched at room temperature in tension to breaking at cross-head speeds of 0.2, 2, and 20 inches per minute. To simulate clinical conditions and application of forces available for tooth movement, other groups of modules were soaked in 37^{o} C. saliva for one week. They were stretched in tension at room temperature exactly one inch at the three different cross-head speeds and were maintained up to several weeks at that constant deformation. With a total of some 50 specimens tested, they found the following results: 1) There was accurate sizing and a small standard deviation in each group which indicated that the modules could be manufactured uniformly. This would permit accurate prediction of forces generated provided the variables for the amount of extension and rate of extension were very precisely known. 2) The initial load could be varied widely by both the rate and amount stretching. 3) After the Ālastik was stretched to one inch, the material was not capable of maintaining a contant force. The material stress relaxed and quickly fell to one half of its initial load. The decrease was exponential and therefore took longer to reduce to one third of the initial force. They found that when the modules were stretched more quickly, the fall off rate was faster and therefore, the ĀlastiKs should be stretched slowly to position. Even in doing so, the inevitable was delayed for only a few hours.

In a 1978 article by Varner and Buck[15], ĀlastiK KX modules were tested for the magnitude of force developed and the amount of force decay during the time interval corresponding to a routine orthodontic visit. Forty patients were measured who were undergoing space closure to obtain the range of module elongation. This range proved to be 28.0 - 38.6, with a mean of 34.5 mm. Therefore, the KX modules were tested in 2 mm increments from 28 to 40 mm by being stored at 37^{o} C. and held at a constant elongation on brass jigs. The results showed that the modules had the same decay rate regardless of the initial stretch increment. For all modules tested during the 2 hr to 4 weeks time interval, the average force decay was 26%. The initial elongation of 26 mm had a mean force of 1.1 lbs at 2 hrs and 0.8 lb at 4 wks. The initial elongation of 40 mm had a mean force of 1.7 lb at 2 hrs and 1.3 lb at 4 weeks. The authors concluded that the force decay subsequent to 2 hrs to be relatively small and therefore, would not affect the rate of tooth movement significantly. Also, it would not appear necessary to change the modules prior to four weeks of clinical service.

Ash and Nikolai[3] conducted an in vitro and in vivo testing of medium grey CK ĀlastiK chains and regular clear K1 ĀlastiK modules. They used stainless steel jigs for their in vitro testing which had brass wire spurs soldered 28 mm apart. The samples were stored in a 37^{o} C. water bath and a Chatillon spring-tension gauge was used to obtain force magnitude data at 0 hour, 30 minutes, 1, 8, 24 hours, and 1, 2, and 3 weeks. The in vivo testing was done on 5 males and 6 females, in the initial stages of active orthodontic treatment, ranging in age from 11.5 to 13.2 years. The data showed a 67% force decay rate of CK chain in 37^{o} C. water. Of this, 58% was in the first 24 hours and 9% from day one to the end of 3 weeks. The in vivo showed an overall of 75% with 61% in the first 24 hours and 14% for the rest of the three week period. In conclusion, the authors stated that a significant difference in relaxation of the vivo versus the water did not appear until the ĀlastiKs had been loaded for a continuous period of 1 week. At the end of the 3 week period, the difference in force level exceeded 1.5 ounces for both elements and therefore, difficult to judge this to be of clinical significance in view of the initial load and the very substantial degree of relaxation overall.

In 1979, Young and Sandrik[18] tested medium grey CK and medium grey C2 ĀlastiK chains on an Instron Universal Testing Machine. Their objective was to determine whether prestretching would decrease the rapid force loss of the elastic polymers. The results indicated that

ĀlastiK CK chains showed a significant decrease in force loss whereas the C2 chains were unaffected. The amount of force remaining, depended on the distance of the prestretching. They predicted an unstretched CK would have 21% of its force left after 4 weeks; whereas, a prestretched CK of 18 mm would have 34.5% remaining force and a 23 mm prestretched CK would have 40.6% remaining after 4 weeks.

MATERIALS AND METHODS

Since the purpose of the project was to test medium grey C1 chains on an in vitro model which represented the in vivo tooth extraction situation, ten models were constructed with a second molar, first molar, second premolar, and a cuspid band and brackets mounted on ¼ inch plexiglass (Fig. 3). The cuspid to second premolar extraction space was adjustable and in this study was set at 5 mm at the beginning of the test. The adjustment of the extraction space was made by incorporating a palatal expansion screw against which the cuspid lever arm rested (Fig. 2). By adjusting the expansion screws, the extraction space could be varied. The distance represented less that the average first premolar extraction site*. This distance was adjusted by using a 5 mm feeler gauge (Figs. 4 & 5). The bands were medium size Unitek bands with standard twin brackets and were placed on the plexiglass to represent normal arch curvature. A .019 x .025 rectangular arch wire was then bent to fit the arch. All bands were attached to the plexiglass by using clear orthodontic resin.

The cuspid band was attached to its own lever arm which was free to move. A stainless steel screw eye was imbedded in the clear acrylic of the cuspid band for attachment of the measuring device. The lever arm

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* The average mesial-distal width for the first premolar of 500 North American white children is 6.9 mm[10].

was then attached to the larger plexiglass table via a stainless steel machine screw which was threaded into the large plexiglass bases. Two machine nuts were used to prevent the screw from turning. This method gave the arm freedom of movement and in an arch which would represent the normal dentition. On the end of the lever arm, ¼ inch band material was cemented to the acrylic with a one inch section of .025 dead soft stainless steel wire welded to the end. A one inch section of dead soft wire was also welded to the rapid palatal expander. When the band material rested against the rapid palatal expander and a flashlight modified so that two leads could be attached to the sections of dead soft wire, an electrical circuit was completed which was evident by the light in the flashlight (Fig. 6).

The medium C1 chains were purchased from Unitek to duplicate the normal acquisition of the material. The chains come either injected molded (12 rings with short sections between) or punched from flat Ālastik material (Fig. 1). We used both types in this study. In the first part of the study, injected molded chains were used. Randomization was accomplished by cutting each 12-ring chain into three sections of four rings. This was done to ten of the 12 ring chains.

Using Anderson's[1] method for retracting cuspids (one chain attached to the lingual buttons and one chain attached to the buccal brackets), twenty of the thirty 4 section rings were randomly used in the first study. The rest were discarded. At room temperature, two of the C-chain sections were placed on each test model as described above. Each test model was then measured and immediately placed in a preheated Napco (model 210) water bath maintained at 37^{o} C. The test models were kept submerged in the water bath except for the period of time a measurement was done.

The procedure for measuring consisted of removing five test models from the bath and replacing the lid. An air hose with a small tip was then used to blow water out of the electrical contact. Two or three short (2 - 3 seconds) jets of air did an adequate job. The small tip was placed at the contact area and away from the ĀlastiK material for the cleaning process. After the first five models were measured, the next five were removed and the first five replaced in the water bath. Using this method, models 1 - 5 would be out of the bath first but next time, they would be last out. The mean time that the five models were out of the bath for each measurement was 11.8 minutes. The entire procedure took approximately 24 minutes with a temperature drop in the water bath of 1^{o} C.

The measuring device was a Chatillon dial push/pull force gauge (model DPP) with a hook attachment. The gauge was scaled in 10 gm graduations with a capacity of 1.0 kg. It was calibrated with standard weights before and after the study and found to be accurate within 10 gm. The test models were placed on a special plywood jig which was C-clamped to a table. The flashlight was attached to the plywood and the two wires from the light were attached to each model. The Chatillon gauge hook was placed into the screw-eye on the cuspid and was held level. The gauge was then pulled slowly until the light went out on the flashlight. This indicated that the cuspid lever arm broke contact with the expansion screw. A magnetic clutch would hold the needle on the maximum reading.

The force measurements were recorded at initial placement (0 hour), 2 hours, 6 hours, 24 hours, 1 week, and then the expansion screw was reduced ½ turn. Another force reading was taken at 2 weeks and again the expansion was reduced ½ turn. At 3 weeks another reading was taken and a ½ turn reduction in the expansion screw. At 4 weeks, a final force reading was taken. The total reduction of the simulated extraction space over the 4 week period (3 reductions) was between .81 and .99 mm for the 10 test models for both runs.

The second part of this study used the spool punched cut C1 medium grey chain in the same manner as the injected molded. All measurement times and adjustments of the extraction space were identical to the first part of this study. To obtain randomization of the chains, thirty 4-ring sections were cut with twenty randomly selected and the rest discarded.

To determine the accuracy of the investigator to duplicate the measurement of the force across the extraction site, a second force measurement was done at one of the measurement time periods. On the injected molded chains, this measurement was repeated at the three week interval. After recording the first measurement on the first five models, those five models were rearranged so that the second measurement of the model was random. This procedure was then repeated on the second five models. This method was the same for the punched C-chains except it was done at the second week interval. The standard error of the measure ($\sqrt{\frac{\Sigma d^2}{2N}}$) was calculated for the difference (d) between the first and second force readings for each of the 10 test models in both runs.

RESULTS

The mean force for the injected molded C1 $\bar{A}$lastiK chains at 0 hour with a 5 mm simulated extraction space was 1057 grams. At the end of four weeks with a mean space of 4.08 mm, the mean force was 214 grams. As for the punched C1 chains, 0 hour showed a mean force of 986 grams with a 5 mm space and at the end of four weeks with a space of 4.06 mm, the mean force measured was 264 grams. The injected molded C1 $\bar{A}$lastiK chains started with more force but had less force at the end of four weeks (Appendix A).

A two-way analysis of variance with time being the repeated measure showed that there was a significant difference between the punched and injected C1 grey chains. An "F" ratio of F^{1}_{18} = 10.8943 with 8.29 or greater rejected the null hypothesis at $p < .01$ level of confidence. When the different times were compared for the amount of force, an "F" ratio of F^{7}_{126} = 686.5704 with 2.79 or greater rejecting the null hypothesis at $p < .01$ level of confidence. Therefore, an analysis of simple effects was performed to separate the different time intervals. Appendix B demonstrates that the null hypothesis was broken at a significant level of confidence which showed that there was a significant difference in force at 0 time, 2 hours, 6 hours, 24 hours, 1 week, and 4 weeks. There was no significant difference at the end of the second or third week.

Figure 9 indicates that the injected molded C1 chains had significantly more force until the third week. Between the second and the third week, the punched C1 chains retained more force and had a significantly larger force than the injected molded chains at the end of the fourth week to break the null hypothesis at a $p < .05$ (Appendix B). The analysis of variance showed that the C-chains did lose force with time and that there was a significant difference between the injected molded C1 chains and the punched chains. The analysis of simple effects showed the difference in force between the injected and punched C-chains at prescribed time intervals.

If the variances at the different time intervals were examined, there is a 10 time reduction between 0 hour and the end of the fourth week (Appendix A). This showed that the variation in the material decreased with time. At the end of the fourth week, it was still high but the punched C-chains were consistently lower during all the test periods.

A regression curve was plotted (Figs. 7 & 8, Appendix C) which was based on the relationship of the total force (buccal and lingual chains) vs. log times. A correlation coefficient (Pearson r) of -.94 was found for the injected molded C-chains and -.91 for the punched C-chains. This test correlated the log of the observed times with the observed forces from 2 hours to 4 weeks. The standard error of estimate for predicting force values from the observed times of 2 hours to 4 weeks was .46 grams for the injected molded and .38 grams for the punched C-chains.

DISCUSSION

The past research[2,17,18] performed on ĀlastiK C1 chains involved stretching C1 chains over a specific distance for a period of time. One paper by Doyle[7] showed an initial mean force of 1346 grams, 868 grams after two hours, 826 grams after 24 hours, and 748 grams after four weeks. The extraction site for his study was 7 mm. In the present study with an initial extraction site of 5 mm which was decreased approximately .33 mm after the first week, second week, and third week for a total approximately .90 mm, the mean initial force was 1057 grams, 601 grams after 2 hours, 498 grams after 24 hours, and 214 grams after four weeks.

The purpose of reducing the extraction site was to simulate tooth movement and to record the ability of the ĀlastiK material to recovery after it had set for one week with that simulated tooth movement. Past literature[12,13] indicates that tooth movement occurs at approximately 1 mm per month and therefore this study was set-up to simulate that amount. When this study was compared with a similar study[7] that did not have simulated tooth movement, the initial mean forces were different but this can be explained by the increased extraction space. Previous studies[2,4,15] of ĀlastiK chains and modules have demonstrated that with increased elongation, mean force values increased. This study showed that when the extraction space was reduced to simulate tooth movement, there was a marked reduction in the amount of force (748 grams vs. 214 grams at the end of four weeks) that the C1 chain produced. Hershey and Reynolds[8] showed that with a .25 mm reduction per week of the stretch distance of four types of modules held on a framework, the mean force of the modules decreased 68% in four weeks. This study on medium grey C1 chains showed an 80% reduction on injected molded and a 73% reduction on the punched C-chain.

In examination of the regression curves, the correlation coefficient for the injected molded C-chains was -.94 and the punched was -.91. This proved that the mean force of the chains was highly correlated to the log transforms of the time intervals of measurements from 2 hours to 4 weeks. The log of each measurement time placed the time intervals in an exponential relationship for comparing hours with weeks. In past studies[7,15] this regression line was straight as indicated by a high correlation coefficient. In this study there were high correlation coefficients but the regression lines are curved (Figs. 7 & 8).

When injected molded vs. punched medium grey C1 ĀlastiK chains are compared, the punched C-chain retained more force at the end of the four week period. There was a statistical significance but the question is raised as to the clinical significance. The injected molded chains showed a mean force of 214 grams after four weeks vs. 264 grams with the punched C-chain. Past research[5,9,14] has shown that canine retraction will occur with force range of 140-300 grams.

When the mean forces of both types of C-chains were plotted on graph paper (Fig. 9), it showed the following: 1) A relatively constant force was being applied to the teeth at a level sufficient for tooth movement, 2) C-chains should be changed by the end of the fourth week, otherwise, there may not be enough force to sustain tooth movement, and 3) there was a cross-over in the amount of force between the second and third week. This showed that the injected molded C-chains started with more force but ended with less.

This study was designed so that the observer's error in measurement would be as small as possible. Electrical contacts were used to signal the slightest break between the cuspid lever arm and stainless steel expansion device. With the injected molded C-chains, the second force measurement was taken at the third week. The standard error of the measure was 12.04 grams or 4.3%. The punched C-chains were measured a second time at the two week interval and showed a standard error of the measure of 8.94 grams or 2.5%. With the Chatillon push/pull gauge measuring accurately to within 10 grams, this error was felt to be within the range of acceptability. Before this study was conducted, it was the opinion of the observer that the injected molded C-chain would outperform the punched C-chains at all time intervals. Therefore, the observer's bias was in direct opposition with the results.

When the force measurements are reviewed (Appendix A) it was noted that the C-chains that started with the largest amount of force at time 0, did not necessarily end with the most force at the end of the four week period. Special care was taken in this study to obtain the C-chains through the distributor rather than directly from the place of manufacture. It was conjectured that this would fairly represent the C-chains that most orthodontists have in their offices.

SUMMARY AND CONCLUSIONS

ĀlastiK C1 medium grey chains were used for canine retraction with simulated tooth movement to represent clinical usage. A two-way analysis of variance and an analysis of simple effects were used to statistically analyze the data. The following statements could be concluded from the findings:

1) There was a definite statistical variation in force production between molded and punched C-chains, but probably not clinically significant.

2) There was a decrease of 64.4% in the injected molded and a 44.1% in the punched C-chain force production from the 2 hour measurement period through the fourth week. The C-chains were still producing enough force for cuspid retraction at that time.

3) The decay rate was approximately the same for the C-chain units and therefore, the same at different time intervals.

The clinical implications of the findings are:

1) Either injected molded or punched C-chains may be used to produce the same amount of force for cuspid retraction.

2) The clinical use of C-chains for a four week period would be within the range of force necessary for tooth movement.

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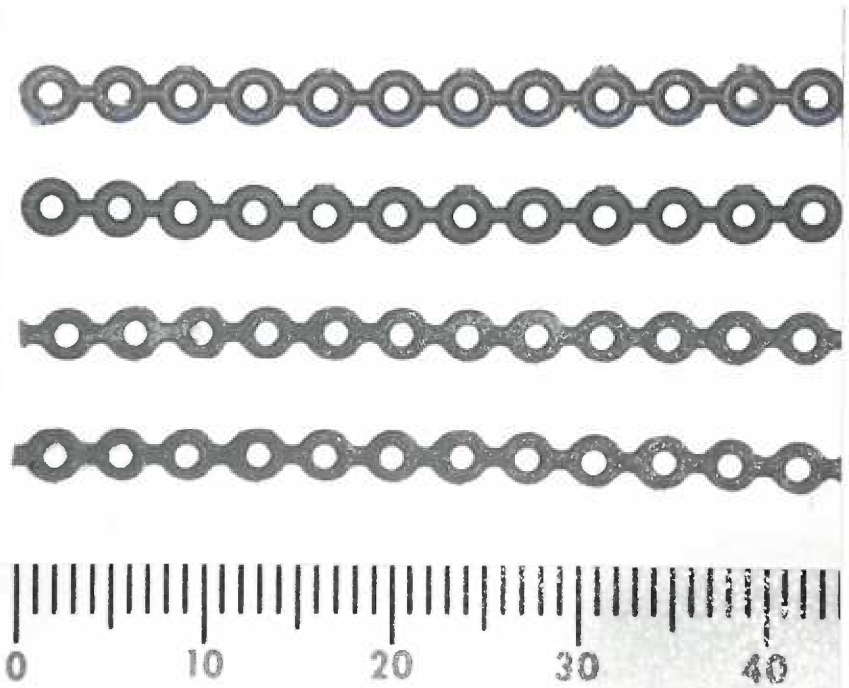

Fig. 1: Injected Molded $\overline{\text{A}}$lastiK C1 Chains (top two)
Punched $\overline{\text{A}}$lastiK C1 Chains (bottom two)

Fig. 2: Expansion Screw Mechanism (Buccal View)

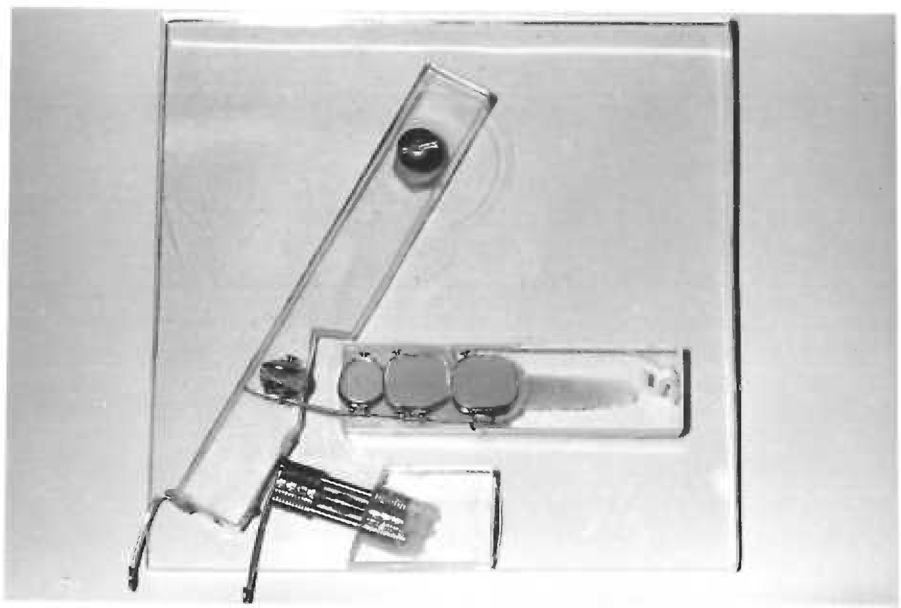

Fig. 3: Test Model

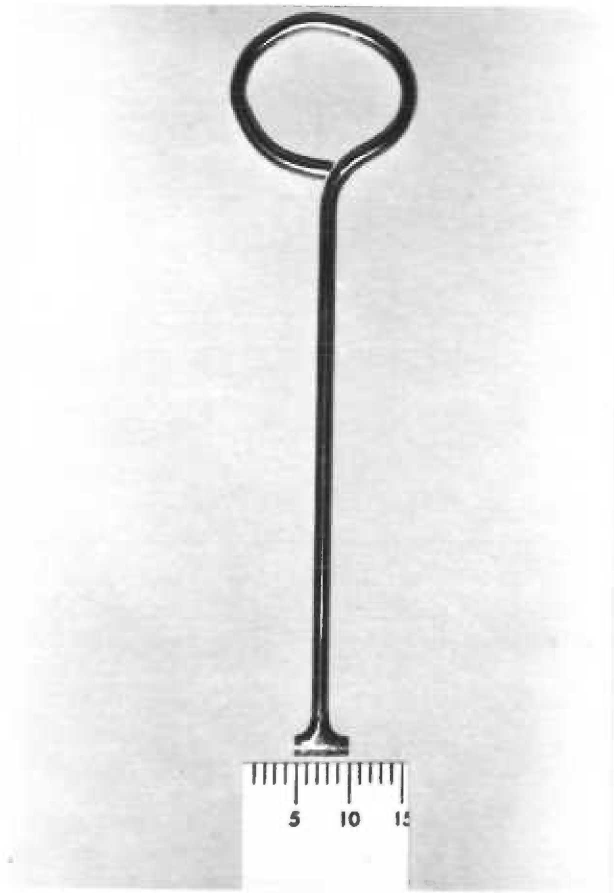

Fig. 4: 5 mm Extraction Guage

Fig. 5: Guage with Test Model (Lingual View)

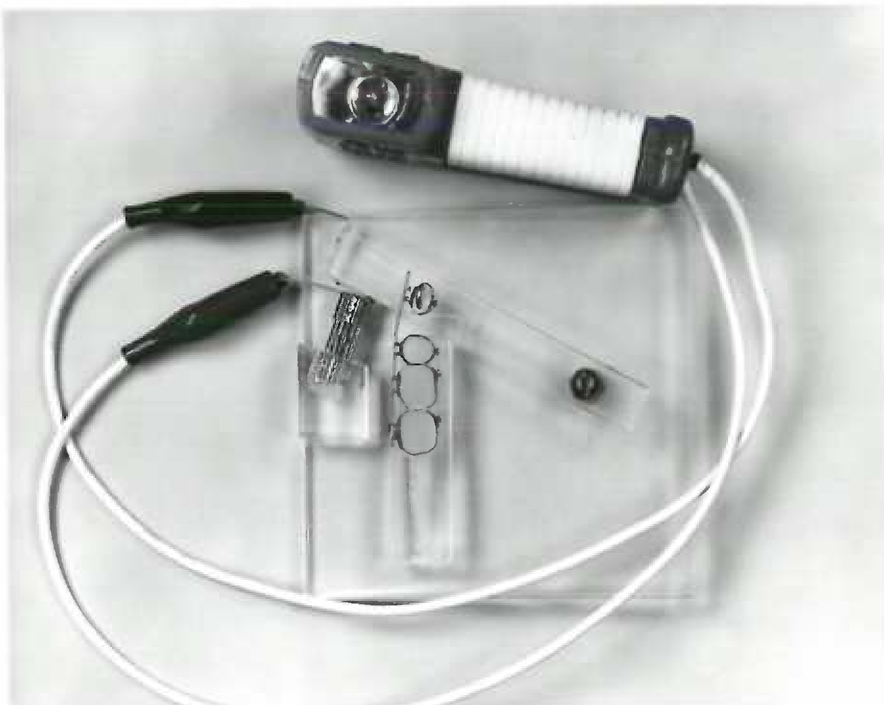

Fig. 6: Electrical Device to Show Contact of Cuspid Lever Arm

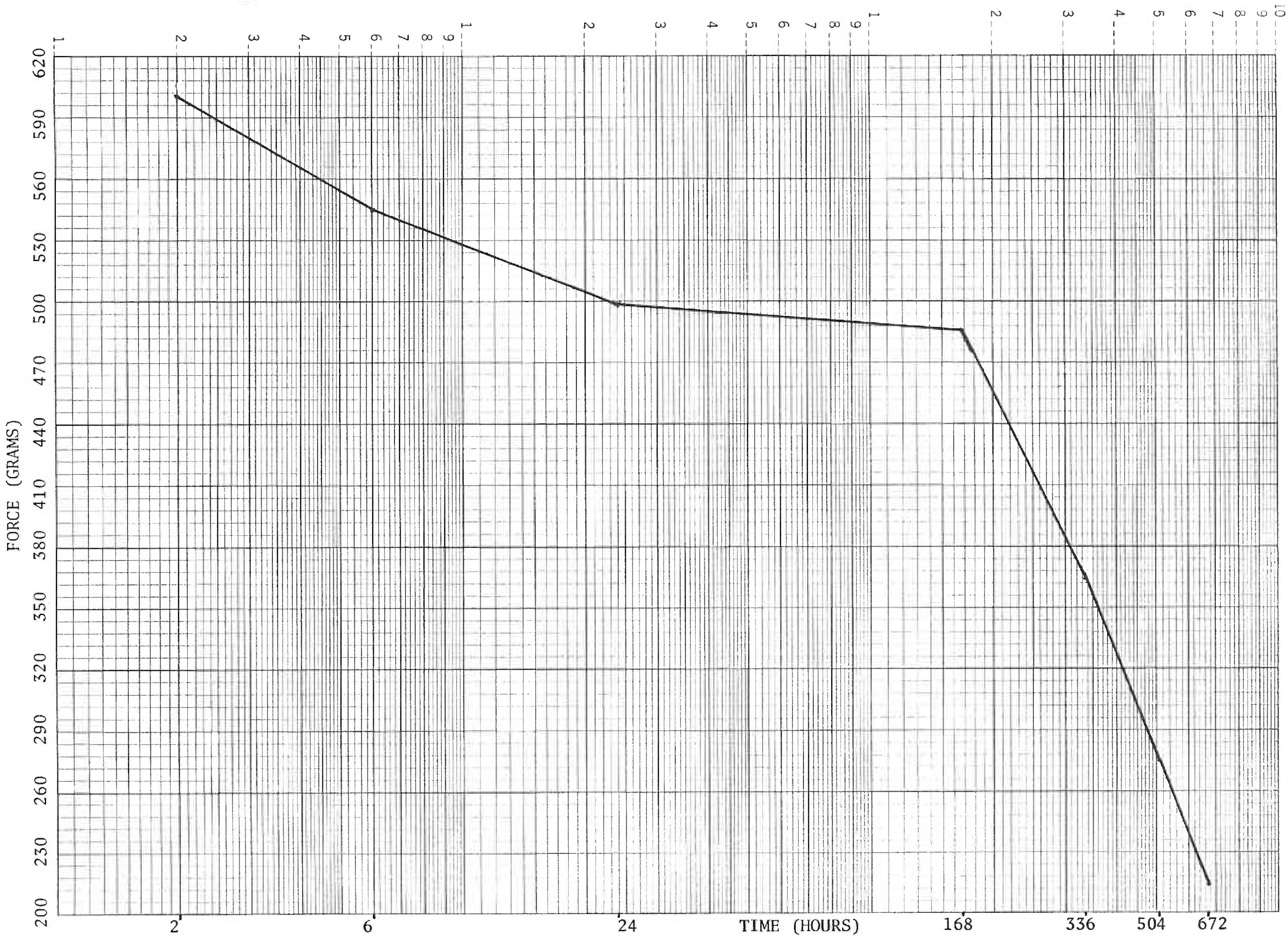

Fig. 7: Regression Curve of Force Vs. Time of Injected Molded C1 Chains.

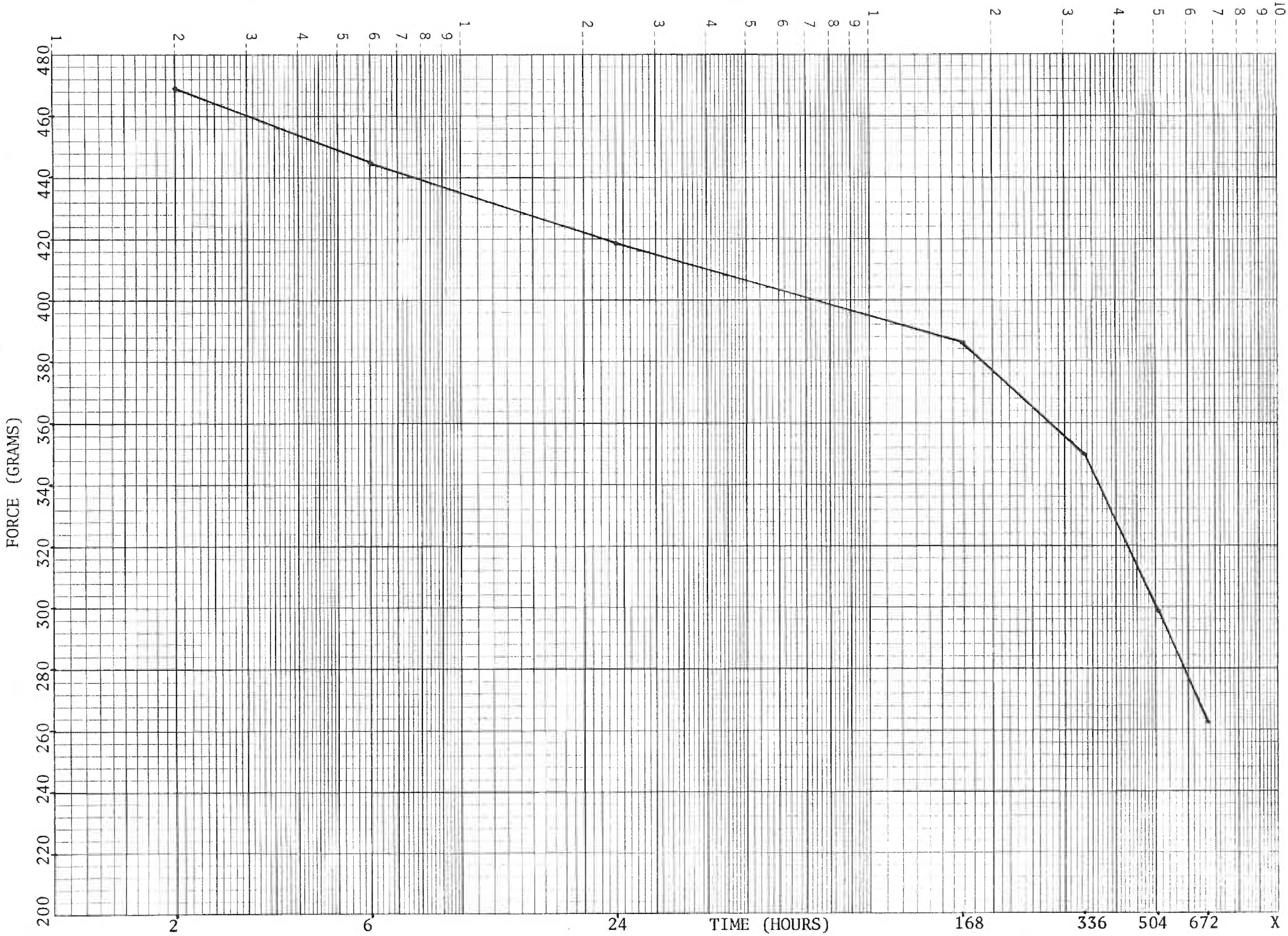

Fig. 8: Regression Cruve of Force Vs. Time of Punched C1 Chains.

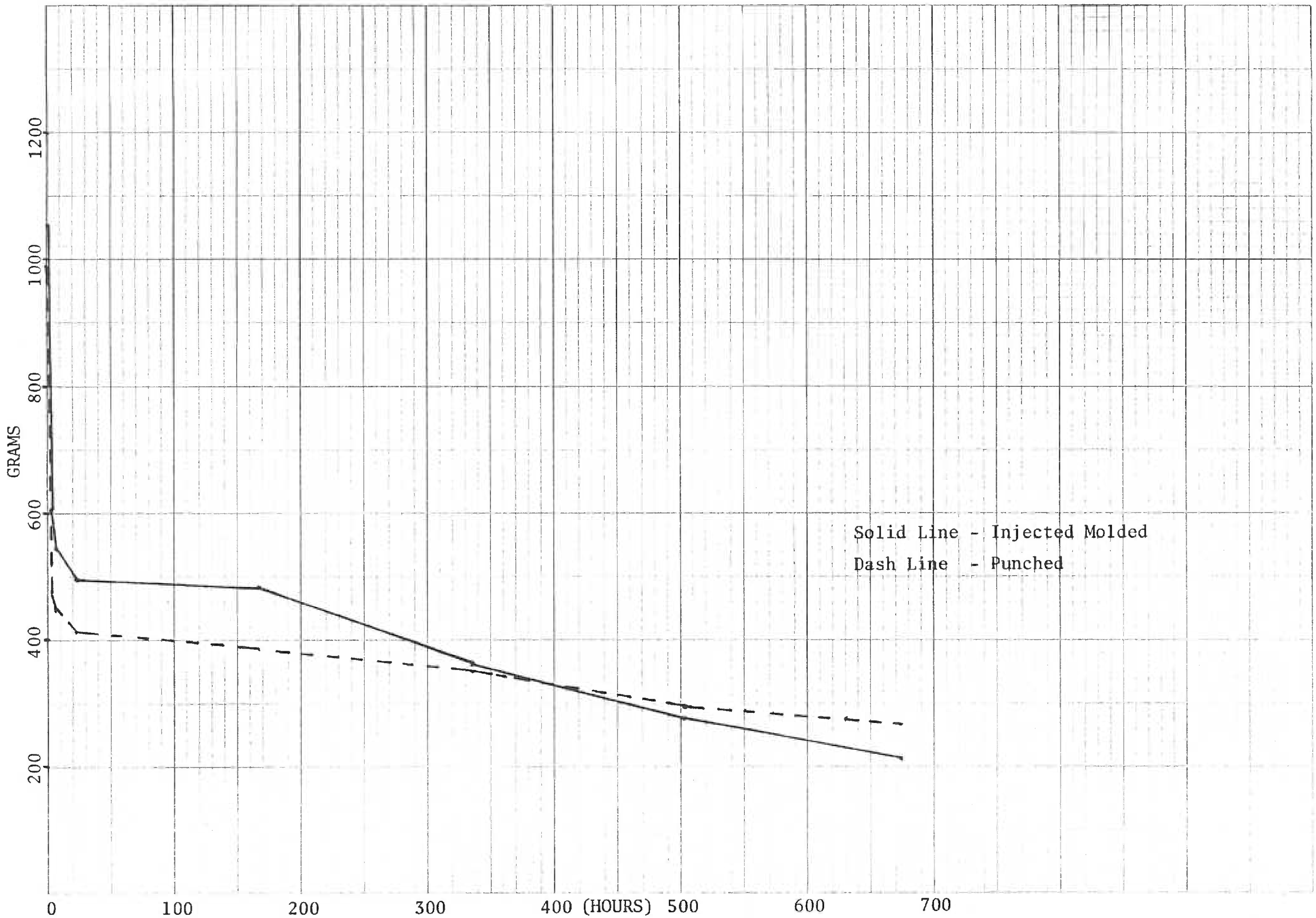

Fig 9: Force Vs. Time

Appendix A

Experimental Data of Force (Grams) Vs. Time

	0	2 hrs	6 hrs	24 hrs	1 wk	2 wks	3 wks	second measure	4 wks
Injected Molded	1170	630	540	470	450	370	290	300	230
	1040	620	560	500	530	400	350	320	220
	1070	620	540	490	470	400	280	300	230
	1220	690	620	560	560	360	270	280	240
	1080	670	590	560	530	450	280	290	220
	1050	580	530	460	480	380	320	350	240
	950	570	530	520	490	370	270	280	220
	1150	590	550	530	500	270	200	210	160
	920	520	490	480	440	310	220	230	200
	920	520	490	410	390	320	270	260	180
$\overline{X}$	1057	601	544	498	484	363	275	282	214
S^2	10890	3210	1604.44	2173.33	2493.33	2667.78	1850	1684.44	693.33
SD	104.36	56.66	40.06	46.62	49.93	51.65	43.01	41.04	26.33
SEM	32.99	17.92	12.67	14.74	15.79	16.34	13.60	12.98	8.33

$\overline{X}$ = Mean

S^2 = Variance

SD = Standard Deviation

SEM = Standard Error of Mean

Appendix A (Continued)

Experimental Data of Force (Grams) Vs. Time

	0	2 hrs	6 hrs	24 hrs	1 wk	2 wks	second measure	3 wks	4 wks
Punched	1090	400	390	360	330	300	310	260	240
	1020	460	430	390	360	300	320	260	240
	1030	400	370	360	310	290	280	240	230
	1000	470	450	420	410	380	380	320	290
	1030	520	490	480	460	440	430	300	280
	1080	530	470	420	410	360	370	350	290
	880	520	480	440	390	340	360	300	270
	850	480	470	450	420	380	360	360	290
	980	490	470	440	380	370	370	290	270
	900	450	430	420	390	340	340	300	240
$\overline{X}$	986	472	445	418	386	350	352	298	264
S^2	6893.33	2151.11	1583.33	1484.44	1937.78	2133.33	1751.11	1484.44	582.22
SD	83.03	46.38	39.79	38.53	44.02	46.19	41.85	38.53	24.13
SEM	26.26	14.67	12.58	12.18	13.92	14.61	13.23	12.18	7.63

Appendix B

Two-Way Analysis of Variance - Repeated Measure on One

Source	Sum of Squares	Degrees of Freedom	Mean Square	F
Between Subjects	288246.8750	19	15170.8881	
Model	108680.6250	1	108680.6250	10.8943
Subjects Within Groups	179566.250	18	9975.9027	
Within Subjects	8557462.50	140	61124.7321	
Time	8197794.3750	7	1171113.4821	686.5704
Model x Time	144744.3750	7	20677.7678	12.1224
Time x Subjects	214923.750	126	1705.7440	
TOTAL	8845709.3750	159		

Appendix B (Continued)

Analysis of Simple Effects

Source	Sum of Squares	Degrees of Freedom	Mean Squares	F	P
Model at Time 0	25205.0	1	25205.0	9.2005	$p < .005$
" 2 hrs	83205.0	1	83205.0	30.3721	$p < .001$
" 6 hrs	49005.0	1	49005.0	17.8882	$p < .001$
" 24 hrs	32000.0	1	32000.0	11.6809	$p < .001$
" 1 wk	48020.0	1	48020.0	17.5286	$p < .001$
" 2 wks	845.0	1	845.0	.3084	NS
" 3 wks	2645.0	1	2645.0	.9654	NS
" 4 wks	12500.0	1	12500.0	4.5628	$p < .05$
Pooled Error	394490.0	144	2739.5138		

Appendix C

Regression Analysis of Force Vs. Time for the Four Week Run of C1 Chains.

		Means of Observed Values	Log Transforms of Observed Time
Injected Molded	2 hrs	601.0	.3010
	6 hrs	544.0	.7781
	24 hrs	498.0	1.3802
(1 wk)	168 hrs	486.0	2.2253
(2 wk)	336 hrs	363.0	2.5263
(3 wk)	504 hrs	275.0	2.7024
(4 wk)	672 hrs	214.0	2.8273

The correlation coefficient of time variable (X) to mean force variable ($\tilde{Y}$) = -.9076237

The equation for the straight line in regression analysis is $\tilde{Y}$ = bx + a

Regression Parameters for the data are:

$$\tilde{Y} = -.0063\ X + 4.5077732$$

Standard Error = .46148832 grams