THE UNIVERSITY OF MICHIGAN
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Final Report

A FEASIBILITY STUDY ON MEASURING THE SHARPNESS OF SURGICAL SCALPELS

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ABSTRACT

A preliminary investigation demonstrates the feasibility of measuring the sharpness of surgical scalpels by measuring changes which take place during a sample cut. Measurements of force components made while cutting pure gum rubber revealed differences between individual scalpels of the order of ten to one and greater.

The investigation also reveals differences in cutting characteristics and mechanisms of dulling related to the configuration of the cutting edge. Edges consisting of many spurs or asperities appeared to be better than smoother, more continuous edges. The latter exhibited a marked tendency toward spalling or fragmenting of the cutting edge.

I. INTRODUCTION

The purpose of this study was to investigate the feasibility of determining the sharpness of surgical scalpels by measuring forces while cutting a specimen material or by measuring dimensional or other changes resulting from the cutting process. Exploratory work carried out with regard to instrumentation, procedure, and specimen material resulted in a laboratory setup and procedure which permitted an orderly investigation to be carried out with pure gum rubber as a work specimen material.

The results of the investigation indicate a strong feasibility of measuring the sharpness of surgical scalpels by tests wherein actual cutting of a standard specimen material is carried out. By this means individual differences between scalpels of the order of five and six to one were measured repeatedly. Similarly the full range of performance or sharpness of one lot of blades is clearly shown to be distinctly different from that of another lot. Furthermore the study revealed some information on the mechanisms whereby scalpels wear or deteriorate. It was noted also that the nature of wear or wear mechanisms may be influenced by the methods of manufacture.

II. TEST APPARATUS AND PROCEDURE

The test apparatus developed for this investigation is illustrated photographically in Fig. 1 and schematically in Fig. 2. Basically the apparatus consists of a dynamometer for measuring forces and a motor drive unit for alternately drawing and pushing a scalpel across the specimen work material. The scalpel or test blade is mounted in a suitable holder pivoted on the post of the motor drive unit and balanced with an adjustable counterweight.

Provision was made initially for a preload (W) to be added to the counterbalanced carrier, making it possible to conduct tests at different levels of preload. A cam was provided to lower the test blade carefully into the rubber specimen at the start of the cut and to remove it gently near the end of the cut. However, it was found that this procedure would not yield significantly different measurements between blades known to differ in sharpness.

Subsequently the cam was made straight and parallel with the direction of motion and a preload in excess of that required to hold the test blade in position was applied. A micrometer screw was added to make depth adjustments after the test blade had been carefully zeroed at the surface of the rubber specimen. Spirit or bubble levels were mounted on both the blade holder and the dynamometer so as to assure parallelism between the direction of cutting and the direction of the measured cutting forces.

In this procedure a test is carried out by carefully mounting a test blade and rubber specimen in the apparatus, starting the motor drive unit, and permitting the blade to make six complete cutting strokes across the full width of the rubber specimen. The first stroke in each case is a draw stroke equivalent to a draw or pull stroke made with a scalpel mounted in a suitable handle. A two-channel electrical recorder provides a continuous record of both the tangential and normal components of cutting force during the entire run. The gum rubber specimen is prestretched 100% across the cutting direction. The test blade is provided with a constant velocity of 20 inches per minute.

The schematic in Fig. 2(b) shows the relationship of the measured force components to the test blade, the rubber specimen, and the direction of cutting. The force vectors illustrated represent the forces exerted by the blade on the rubber. Throughout this report the vertical or normal component is designated by "N". A subscript designates the stroke number and a prime symbol designates a push stroke. For example N_3' means the normal force on the third push stroke, which would be the sixth stroke in sequence. Similarly T_2 means the tangential or horizontal force on the second draw stroke, which is the third stroke in a test sequence.

III. TEST RESULTS

The formal tests carried out in this program were divided into two major groups. The first group was devoted to an analysis of the behavior of individual blades and the properties of the gum rubber specimen material; the results are illustrated in various ways in Figs. 3 through 9. The second group was devoted to a comparison of blades from two different sources, with results as summarized and illustrated in Figs. 10 through 14.

A. ANALYSIS OF INDIVIDUAL BLADE PERFORMANCE

Figure 3 shows a recorder chart record from a typical test run consisting of three draw strokes and three push strokes. The time is scaled from left to right in the figure so that the force impulses designated T_1 and N_1 represent the forces on the first draw stroke. It will be noted that the pulses representing the tangential forces are alternately below and above the reference line, indicating a change in direction of the force as the direction of cutting is changed. The small oscillations on the recorder lines are caused by variations in velocity and by vibrations arising from the low-speed gears in the motor drive unit; they are not indications of variations in cutting force. It will be noted also that the zero force line drifts during a test. For example the tangential zero force line dropped 1 mm toward the center of the chart during the test run, and the normal zero force line drifted upward nearly 4 mm. These drifts are caused by temperature changes of the strain gages in the bridge, and in turn by changes in the amount of current in the two branches of the bridge as a force is applied. This is normal behavior and does not compromise the accuracy of the measured forces.

The actual forces represented in Fig. 3 are replotted versus the corresponding stroke number on Cartesian coordinates in Fig. 4. At the beginning of the test the blade was set for an interference with the rubber of 0.014 inch or about 0.356 mm. The amount of interference is reduced on each successive stroke by the amount of cutting which took place during the previous stroke. An infinitely sharp blade would reduce the interference to zero on a single stroke, causing the forces for the second stroke to drop to zero. Therefore the rate at which the forces decrease on successive strokes is in itself a measure of sharpness.

It will be noted in Fig. 4 that the smooth lines drawn to represent the forces do not contain the actual data points. It will be noted upon further observation that both the tangential and normal forces for the draw strokes are higher than the average lines whereas the corresponding forces for the push strokes all lie below the average lines. This is due primarily to differences in curvature of the cutting edge in the two different cutting directions. All points would lie on the average line if the curvatures were the same and if the pivot point of the blade holder was always directly in line with the centroid of the area being cut.

It was suggested that the rate of drop of forces in Fig. 4 is a measure of sharpness of the scalpel. The rate of drop and therefore the sharpness can be expressed by an equation by replotting the data of Fig. 4 on semi-logarithmic coordinates as in Fig. 5. As shown in Fig. 5, the slopes of the straight lines drawn to represent the data become exponents in the corresponding equations. For example the equation for the tangential force is $T = 57e^{-.87n}$ where "n" is the number of the stroke. A sharper blade would give an exponent numerically larger than .87 whereas a duller blade would result in a smaller exponent, .5 for example.

Although the exponents or slopes of the lines as drawn in Fig. 5 are a measure of sharpness, it was demonstrated in the second series of tests that a succession of cuts need not be performed in order to determine the sharpness of the scalpel. Because the level of the forces themselves are indicative of sharpness, the constants of the equations shown in Fig. 5 are similarly indicative. For instance, a blade twice as sharp as the one represented in Fig. 5 might have a constant of only 28 instead of 57 in the equation for tangential force.

Another blade was carried through an endurance test involving more than 20 complete test runs, each consisting of six strokes. It was found that the forces had stabilized themselves by the end of the seventh complete run so that little change could be observed on subsequent tests. Results for the first 12 complete runs are plotted in the Fig. 6.

Figure 6 shows the normal and tangential force components for the first stroke on each of the 12 test runs. It will be noted that nearly all the forces increased until the seventh run, after which they remained generally constant. The exceptionally low points for Run No. 4 and the exceptionally high normal force for Run No. 5 are typical of the changes which take place in the deterioration of a blade. The lower forces for Run No. 4 result from the breaking out of part of the cutting edge in such a manner as to concentrate most of the cutting on a new sharp point, whereas the higher normal force for Run No. 5 results from the spalling of a small amount of cutting edge in such a manner as to increase the area of the blade which is in contact with the rubber.

Although the forces on the first stroke of the test runs did not change appreciably after the seventh complete run, it was observed through further analysis that significant changes in the ratios of the forces did take place progressively on successive strokes. Information on this type is shown plotted on Cartesian coordinates in Fig. 7.

Each of the ratios plotted in Fig. 7 is identified by a number for the test run from which it was derived. It will be noted that the general tendency is for the ratios of the tangential forces on later strokes to those on earlier strokes to increase with increasing run numbers. This indicates a gradual dulling of the blade. On the other hand it will be noted also that the progressive dulling trend is accompanied by considerable forward and aft motion. For example, the solid circle with the number 2 shows that there has been substantial dulling both on the first push stroke and on the second draw stroke during Run No. 2 compared with Run No. 1, which is represented by the solid circle with the number 1. On the other hand the solid circle with the number 3 indicates that during Run No. 3 there was some improvement between the first and second strokes and little change on the third stroke. Similarily the circle designated as No. 4 indicates that there was considerable deterioration on the second, third and fourth strokes during Run No. 4 followed by some improvement during Run No. 5, and substantial improvement during Run No. 6. These variations typify the rather random nature of the mechanisms which ultimately contribute to the deterioration of the cutting capability of a scalpel. Later observations indicated that the nature of this deterioration is related to the structure of the blade and to the processes used in its manufacture; however the details of this relationship remain to be clarified and resolved through further study.

The previous tests were all carried out at adjusted depths of cut of 0.014 inches and with the rubber test specimen stretched 100%. These test conditions were arrived at by qualitative observation during the preliminary development of the test procedure. The conditions were then subjected to further analysis, which led to the results reported in Figs. 8 and 9. Figure 8 is a plot of the unit strain of the Goodyear grade 1172 Gum Rubber against corresponding loads used in stretching the rubber. It will be noted that the rubber became substantially elastic after a unit strain of about 35%. Therefore, it was decided to continue with a prestrain of 100% because this value was sufficiently remote from the value at the bend of the curve of Fig. 8 and also because the greater strain assisted in the cutting process and appeared to be more typical of the behavior of human tissue.

Figure 9 shows the results of a series of tests wherein everything was held constant except for the initial depth of cut or interference setting. It will be noted that the forces for the first cut or first stroke in each test run increase linearly with depth of cut up to about .4 mm or 0.016 inches. This indicates that tests can be carried out at much shallower depths of cut than had been used on previous tests. However, the same depth of cut was retained for subsequent tests in order to preserve continuity and to speed up the process of blade deterioration, which was also under investigation. Obviously, any future tests devised for quality control purposes could be carried out with considerably smaller cuts, providing sufficient sensitivity was available in the apparatus for measuring forces.

B. COMPARATIVE SHARPNESS OF SCALPELS

Blades or scalpels from two different sources were compared by the techniques described in Section IIIA. For purposes of this report, the two lots of blades can be identified simply as "Lot A" and "Lot B". Each lot consisted of five blades.

Individual test runs of the type illustrated in Fig. 3 were made; each test run consisted of six strokes, as illustrated in the figure. All tests were carried out with an adjusted depth of cut of 0.014 inches and with the gum rubber specimen prestretched 100%. Three complete test runs were carried out on each blade but the procedure was such that the first test run was carried out on all ten blades of the two lots before proceeding to the second test run. Similarly the second test run was completed on both lots before proceeding to the third.

Figure 10 is a plot of the tangential and normal forces for the first stroke on each of the three test runs. The data points are not identified with the number of the test run because (as was pointed out earlier) the blade deterioration is erratic in nature and the mechanisms of wear are such that a sudden change can constitute an actual sharpening of the blade rather than a dulling. It will be noted that with one exception all of the data points lie close to the straight line drawn through the origin. The one data point which lies considerably below the line corresponds to the Run No. 1 on what proved to be an exceptionally sharp blade. This exceptional sharpness was lost during the first run, however, so that the second and third runs gave results typical of the four other blades in the lot.

One can assume that an infinitely sharp blade would give a data point right at the origin of the straight line; therefore the farther a data point is from the origin, the duller one can consider the blade to be. It will be noted that the open circles, which represent Lot A are distinctly closer to the origin than the X points, which represent Lot B. The overlapping of the two groups is the result of mixing the data for all three test runs. If the data for the two lots are compared for any one of the three runs, there is no overlapping.

It can be assumed generally that a sharper blade or scalpel requires lower forces for the same size of cut, and that in like manner the second cut or stroke in a test run should show lower forces for a sharper scalpel. In accordance with the latter assumption, the tangential and normal forces for the second stroke in all three test runs is plotted in Fig. 11. It will be noted that even after three test runs the dullest blade of Lot A was sharper than the sharpest blade of Lot B during the first test run. It will also be noted that on the second stroke the sharpest blade of Lot A required only 1.5 g. of tangential force whereas the sharpest blade in Lot B required 12.5 g. of tangential force; therefore one can consider the best blade from Lot A to be more than eight times as sharp as the best blade from Lot B. On the basis of data in Fig. 11 the average performance or sharpness of the blades in Lot A could be said to be between three and four times better than the average of the blades in Lot B.

It will be noted that the slope of the straight line in Fig. 10 differs slightly from that in Fig. 11; the former is 0.5 and the latter is 0.43. These slopes can be called coefficients of friction since they represent the ratio of the tangential force to the normal force in the cutting test. The average coefficients of friction for all three tests are summarized in Table I, thus, the value of .512 listed for the first stroke of blades in Lot A is the average for that stroke in all three test runs, the value of .423 is the average for the second stroke in all three test runs, etc. It will be noted that the general trend is for the coefficient of friction to decrease with increasing strokes, which is an indication of progressively greater dullness. In other words, if an individual test run were carried out for a very large number of strokes, it would be found that although the amount of cutting between successive strokes would approach zero, the measured forces would remain constant at finite values whose ratio would yield a coefficient of friction lower than any of those listed in Table I. This coefficient of friction would be appropriate to the blade and gum rubber as a friction pair.

In most tests the measured forces were already so low on the fourth stroke that they could not be determined reliably; consequently the coefficients of friction for the fourth and subsequent strokes are also unreliable. Furthermore the actual contact area between the blade and the rubber specimen changes non-linearly at the very low forces which prevail in the fourth, fifth, and sixth strokes.

The coefficient of friction drops off significantly faster with Lot A than with Lot B, which indicates a higher degree of sharpness in blades of Lot A. If we assume that the minimum coefficient of friction is 0.3, then the difference between .3 and .512, for example, can be attributed to the actual amount of cutting which took place during the first cut. Consequently the drop in coefficient of friction of .089 from the first to the second stroke in Lot A compared with the smaller drop of .075 for Lot B indicates that the blades of Lot A made deeper cuts on the first stroke than did the blades of Lot B.

The coefficients of friction which have been averaged for Table I are regrouped in Table II to illustrate the changes between test runs. These values show a general trend for a reduction in coefficient with increasing number of tests but it will be noted that there is considerable dispersion. This dispersion again indicates the sporadic nature of the mechanisms which contribute to deterioration of the cutting ability of the blades.

Figure 12 is another plot of cutting forces which yields further information on the mechanisms of wear involved in the deterioration of a scalpel. The ratio of the tangential force for the second stroke to that for the first stroke is plotted against the normal force or thrust reaction on both the first and second strokes. Only the averages for all five blades are plotted. It will be noted that the ratio of the tangential force on the second stroke to that on the first stroke is very much higher for Lot B than for Lot A. This is true also for the normal force or thrust reaction on both the first and second cuts.

When the tangential force ratio is plotted against the thrust for the second stroke, both lots show the same general trend even though they are widely separated, as shown by the dashed line at the left in Fig. 12. On the other hand the trend of the ratio with the thrust reaction for the first cut is quite different in Lots A and B, as shown by the solid lines at the right of the figure. Examination of the individual blades under a microscope revealed that the faster increase in thrust reaction for the blades in Lot A was due to a gradual rounding off of very small asperities on the cutting edge of the blade. By contrast the blades in Lot B showed very few asperities so that most of the rounding off took place on the edge itself. Furthermore this was accompanied by a spalling of discrete segments of the edge itself, which caused the cutting edge to do a relatively better job of cutting on the first stroke of the test run so that the ratio increased more rapidly on successive runs with Lot B than with Lot A.

From one viewpoint the spalling could be characterized as a sharpening tendency superimposed on the general dulling trend which resulted from the gradual rounding off of the cutting edge. Thus it would appear that a somewhat ragged cutting edge such as is created by a large number of asperities is functionally sharper than an ideally smooth, straight, or continuous edge. This functional difference has been observed in some metal cutting operations as well. The ordinary hand file is a good example. A file with very straight and regular cutting edges is not satisfactory because it presents too much area for contact with the metal to be cut; therefore entirely too much normal force is required to get it started cutting. By contrast a jagged edge consisting of irregular asperities concentrates the normal force on a very small area, thus permitting or creating penetration with relatively light normal force. It would appear that this property is similarly important in the use of scalpels.

In Figs. 13 and 14 not only the averages but coefficients of friction for individual blades are plotted against the corresponding normal forces. These plots show that on the average the coefficient of friction tends downward for the Lot B blades and upward for the Lot A blades on successive runs. The downward trend for the Lot B blades appears to be caused primarily by improvement of the cutting ability of the blades on the first stroke, and the improvement to be caused in turn by the gross asperities created by spalling of the cutting edge. It should be understood this resharpening tendency merely retards the further dulling of a blade that is already relatively dull.

IV. SUMMARY

The feasibility of evaluating the relative sharpness of surgical scalpels by making measurements during an actual cutting test is believed to be well substantiated by the data presented in this report. However, it can not be proved that low cutting forces are synonymous with sharpness until more is known about the actual mechanisms involved in a sharp cut. Yet it seems highly probable that low cutting forces are at least one of the necessary characteristics of a sharp scalpel.

On the basis of experience gained in this investigation it appears possible to use either of two approaches in designing a quality-control cutting test. One approach would be to measure the actual cutting forces in the manner described in Section II of this report. This approach imposes the necessity for precise positioning of the blade in the test apparatus, however, so that the attempted depth of cut will be uniform from one test to the next. The alternative approach would be to measure the relaxation of the total stretching load in the rubber specimen which results from the cut. Such a test would be carried out with a constant normal pressure and precise positioning of the blade would not be necessary.

The fact that the coefficients of friction are erratic and change relatively little with progressive dulling indicates that the measuring of cutting forces with a constant normal force would not provide a sensitive measure of sharpness.

The following steps would appear advisable in any further work on this problem:

(1) A laboratory investigation on sharpness as indicated by relaxation of the stretching load of a rubber specimen should be carried out. Such an investigation should include ranges of impressed normal force, length of cut, velocity of cut, amount of preload, and length of rubber specimen subjected to preload. Investigation of these variables should establish the necessary conditions for a practical and significant test.

(2) A range of cutting-edge configurations should be investigated in relation to different types and combinations of manufacturing processes. This investigation would yield more information on the nature of the cutting process and on wear mechanisms. In addition it would reveal the directions which further process development should take.

(3) A study with live tissue should be developed in order to obtain more specific information on the full meaning of "sharpness" as applied to surgical scalpels and their desireable functional properties.

TABLE I

COEFFICIENTS OF FRICTION

(Variations Within Test Runs)*

Lot	Stroke Number			
	1	2	3	4
A	.512	.423	.332	.444
B	.502	.427	.380	.423
Average of both lots	.507	.425	.356	.434

*Averages for three consecutive runs.

TABLE II

COEFFICIENTS OF FRICTION

(Variations Between Test Runs)

Stroke Number	Run No. 1			Run No. 2			Run No. 3		
	A*	B**	C***	A	B	C	A	B	C
1	.522	.514	.518	.505	.500	.502	.510	.493	.502
2	.429	.429	.429	.438	.424	.431	.401	.427	.414
3	.305	.390	.347	.325	.389	.357	.365	.359	.362
4	.381	.486	.434	.509	.402	.455	.442	.381	.411

*Blade Lot A
**Blade Lot B
***Average of both lots

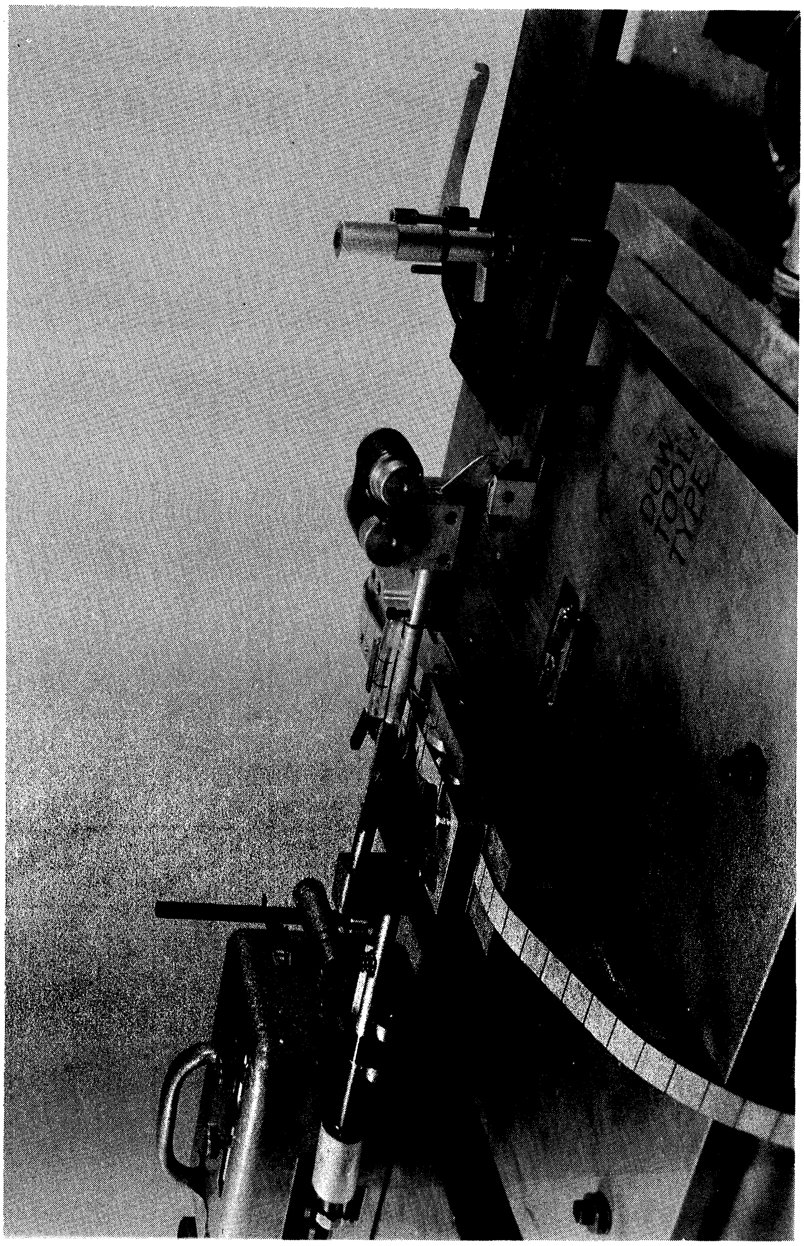

Fig. 1. Test apparatus.

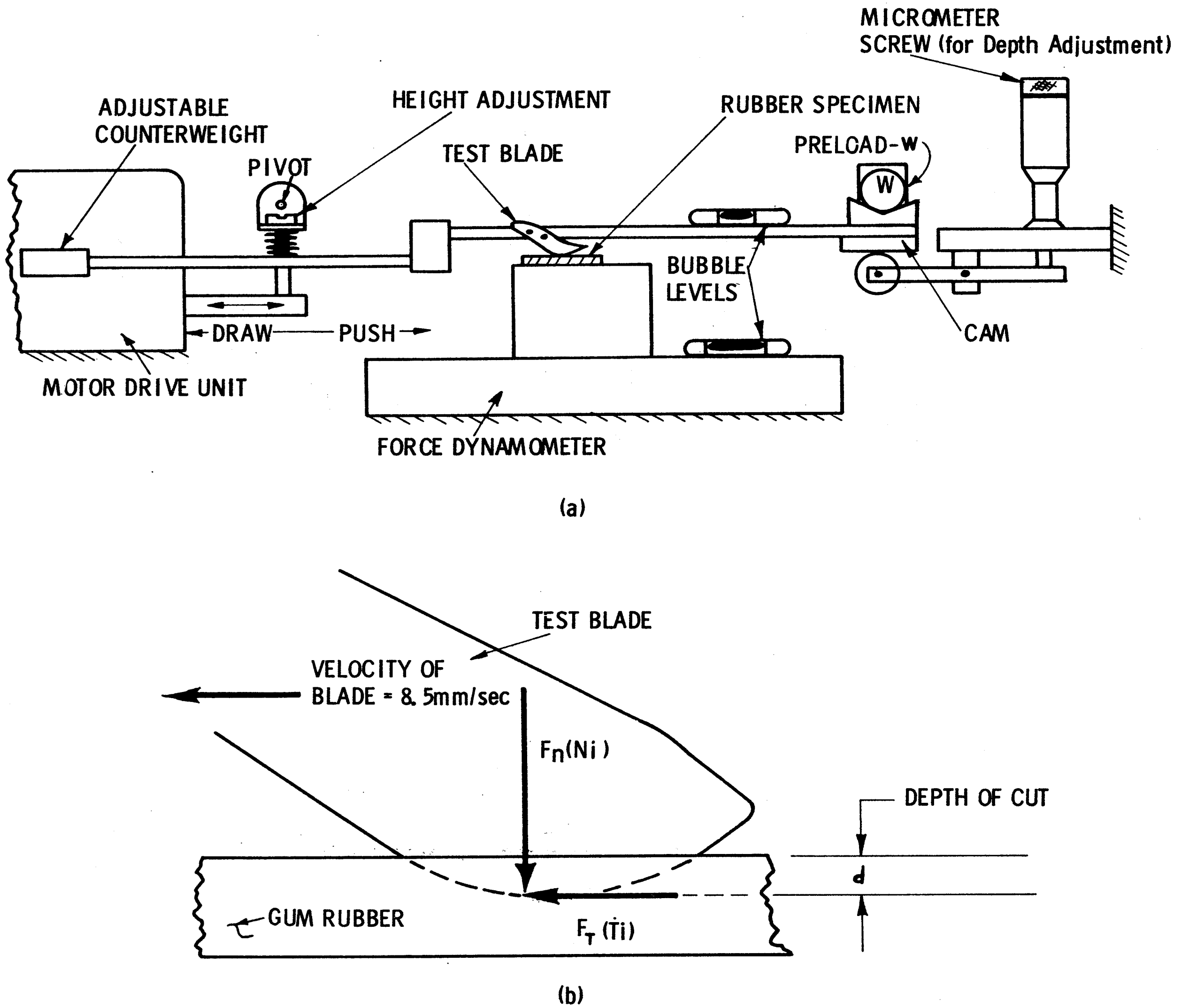

Fig. 2. Test apparatus. (a) Details of apparatus. (b) Relationship of measured forces to other test conditions.

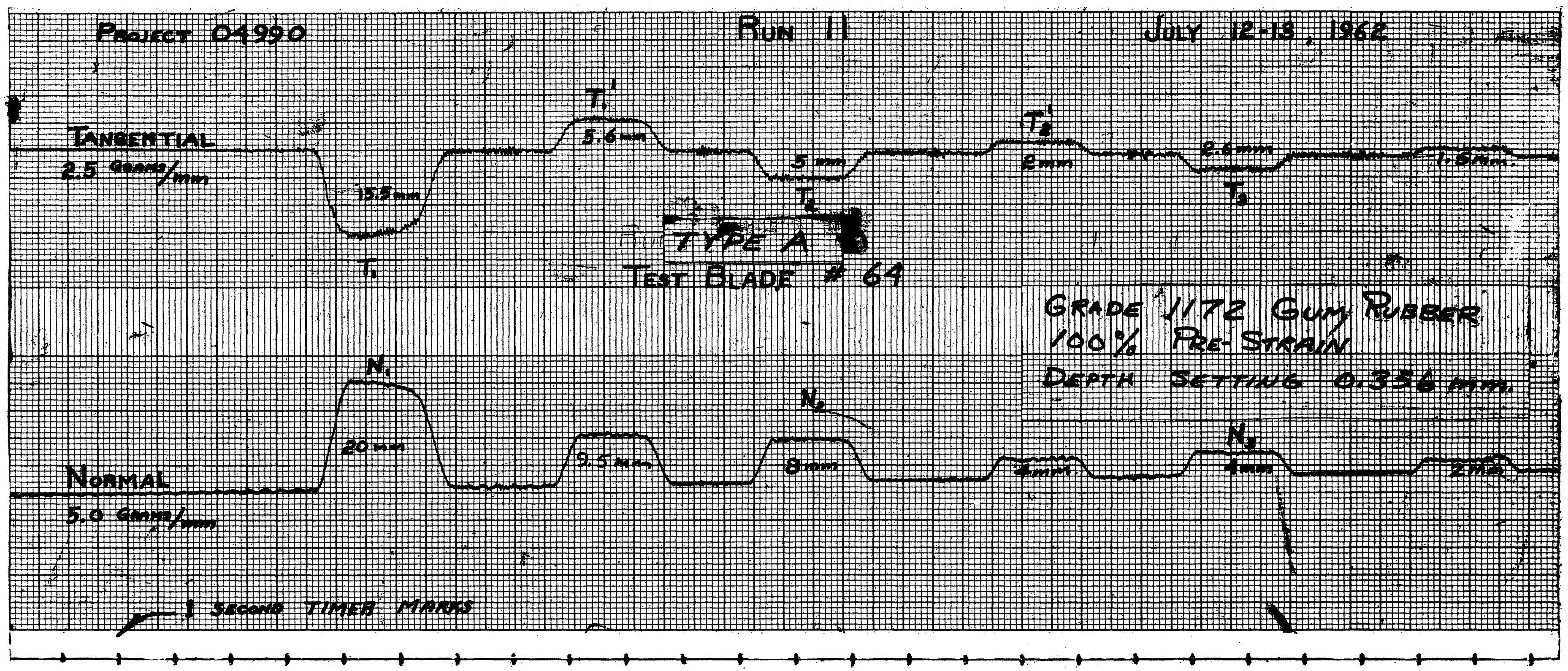

Fig. 3. Record from an actual test run. Test begins at the left and proceeds for 6 complete strokes.

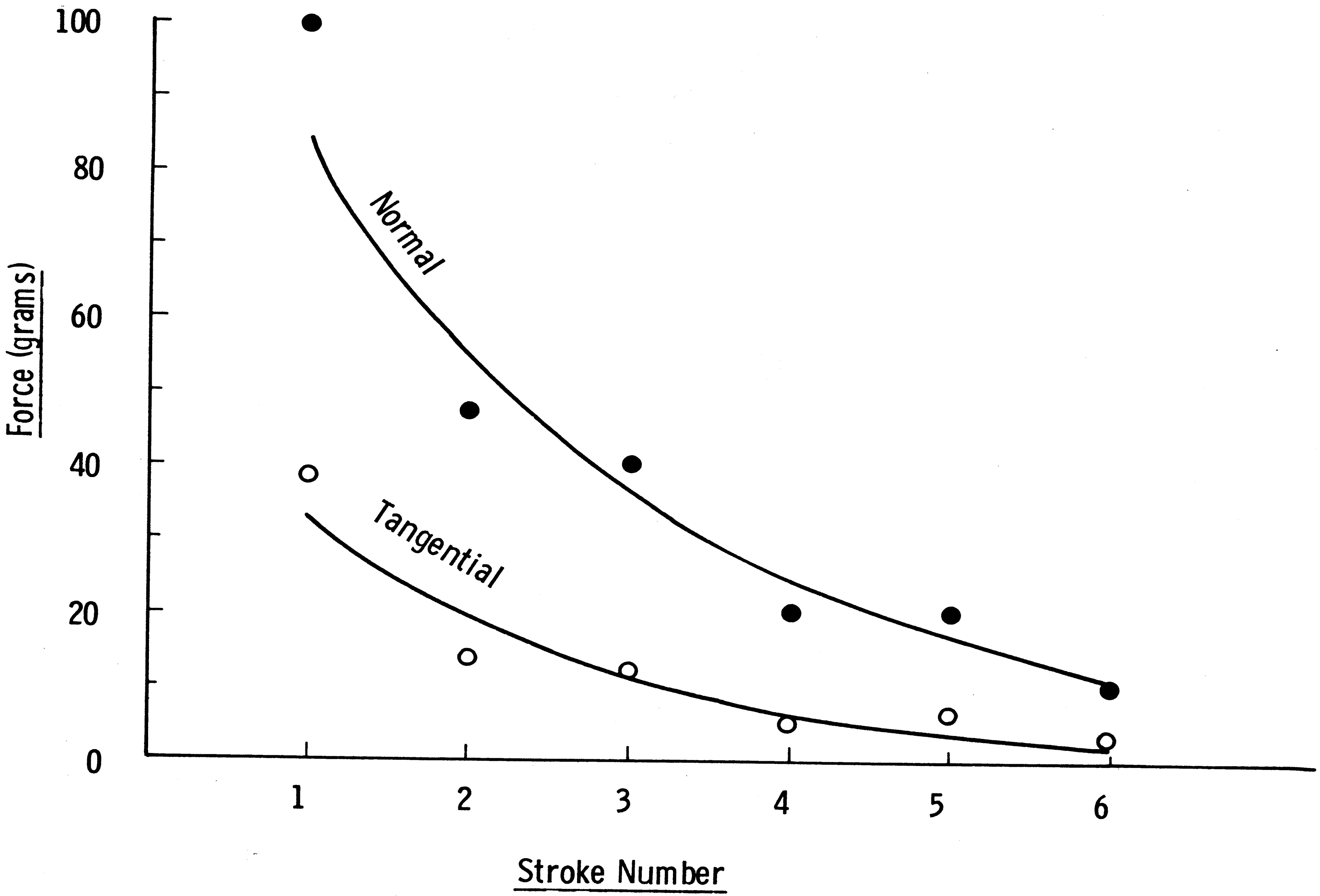

Fig. 4. Force vs. stroke number within a given run. Data taken from Fig. 3.

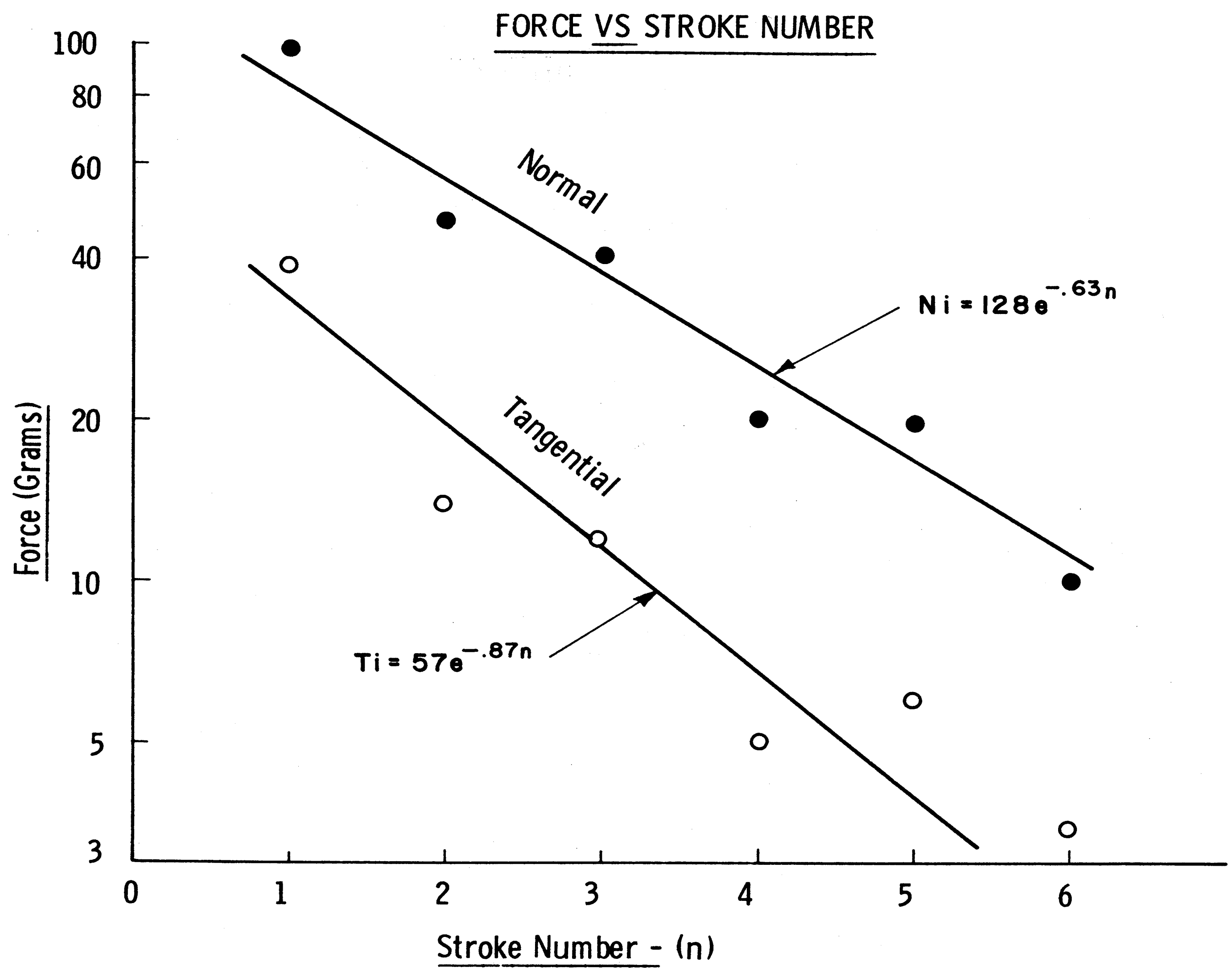

Fig. 5. Force vs. stroke number (semi-logarithmic plot). Data taken from Figs. 3 and 4.

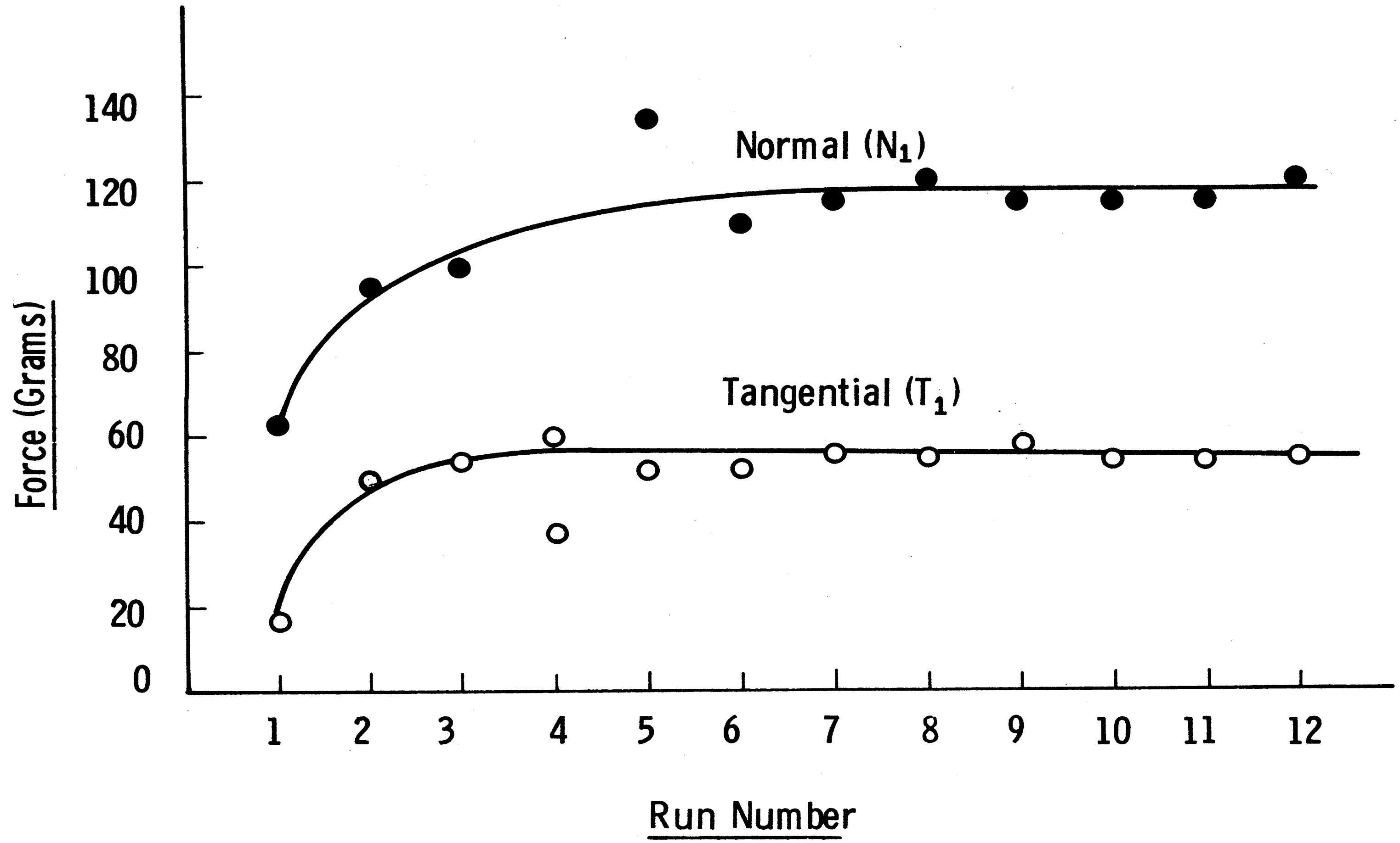

Fig. 6. Measured cutting force (blade endurance test). Plot of force components on the first stroke of each run of 12 successive runs; depth of cut = 0.356 mm on gum rubber specimen prestretched 100%; "A" blade.

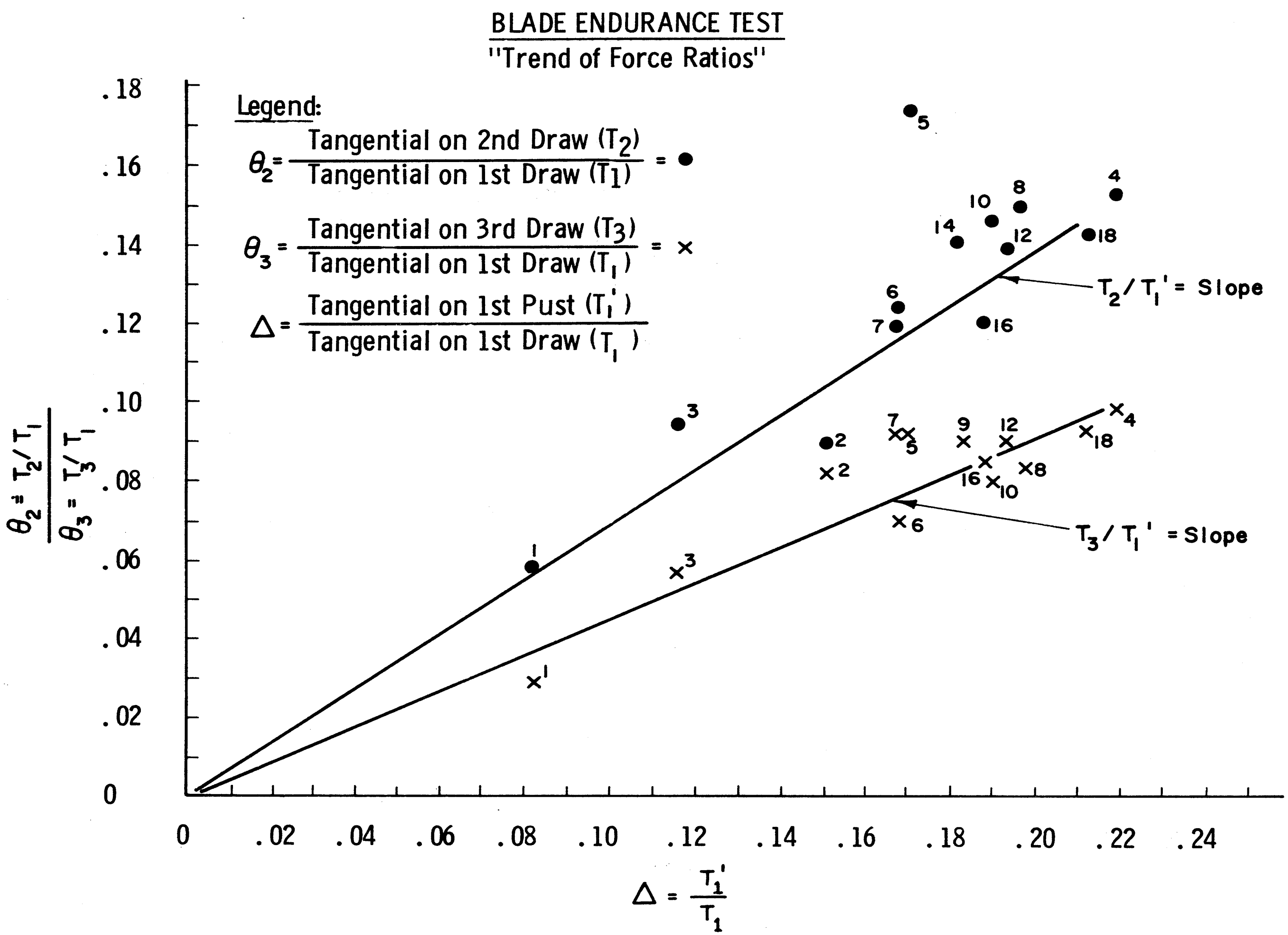

Fig. 7. Trend of force ratios (blade endurance test). Results show that force ratios within test runs continue to change even though the forces on the initial cuts were stabilized after the Run No. 7; test series the same as for Fig. 6.

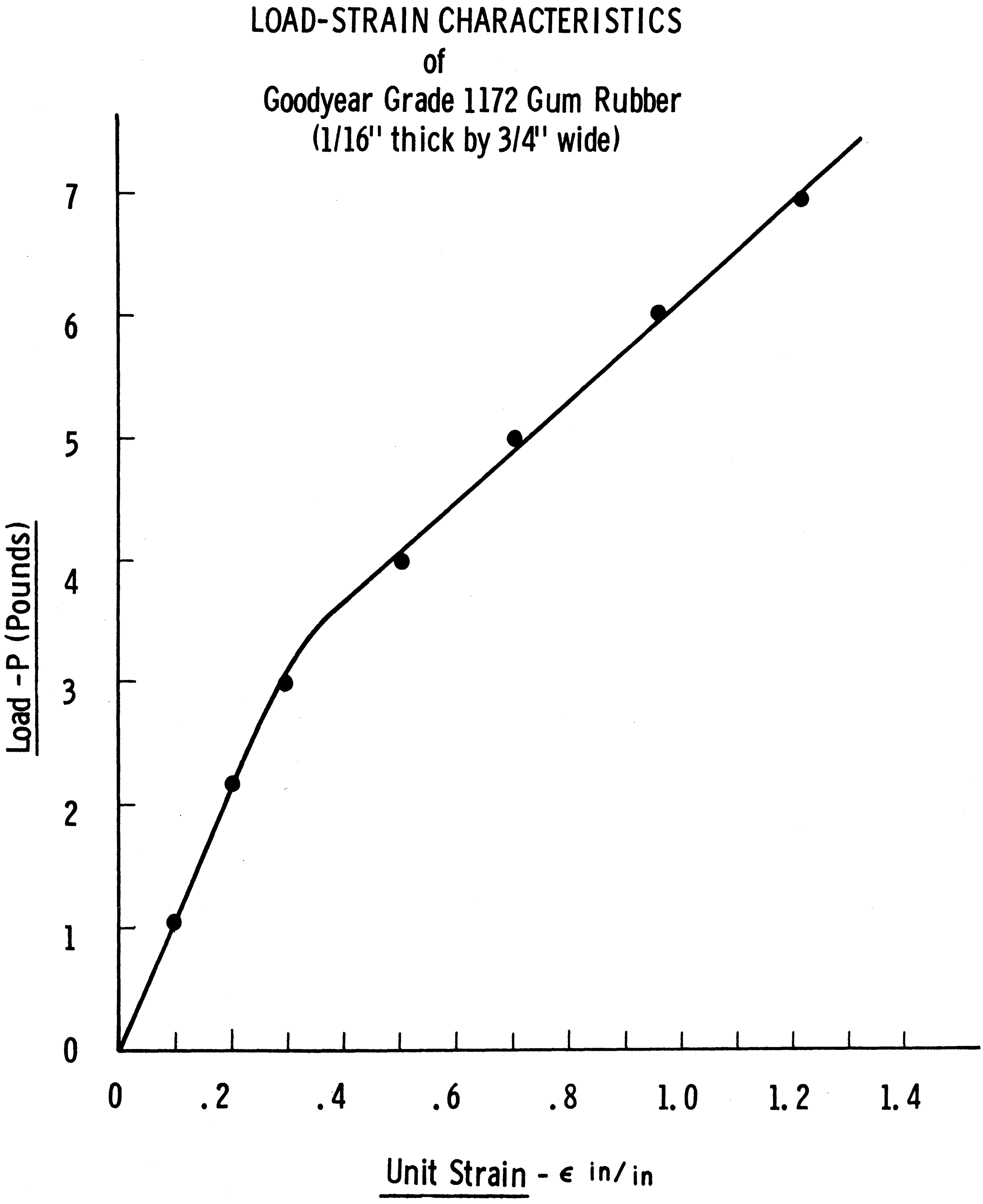

Fig. 8. Load-strain characteristics. Rubber specimen material is substantially elastic after a strain of about 35%; molecules become oriented in the direction of applied load; strain is non-linear until orientation is complete.

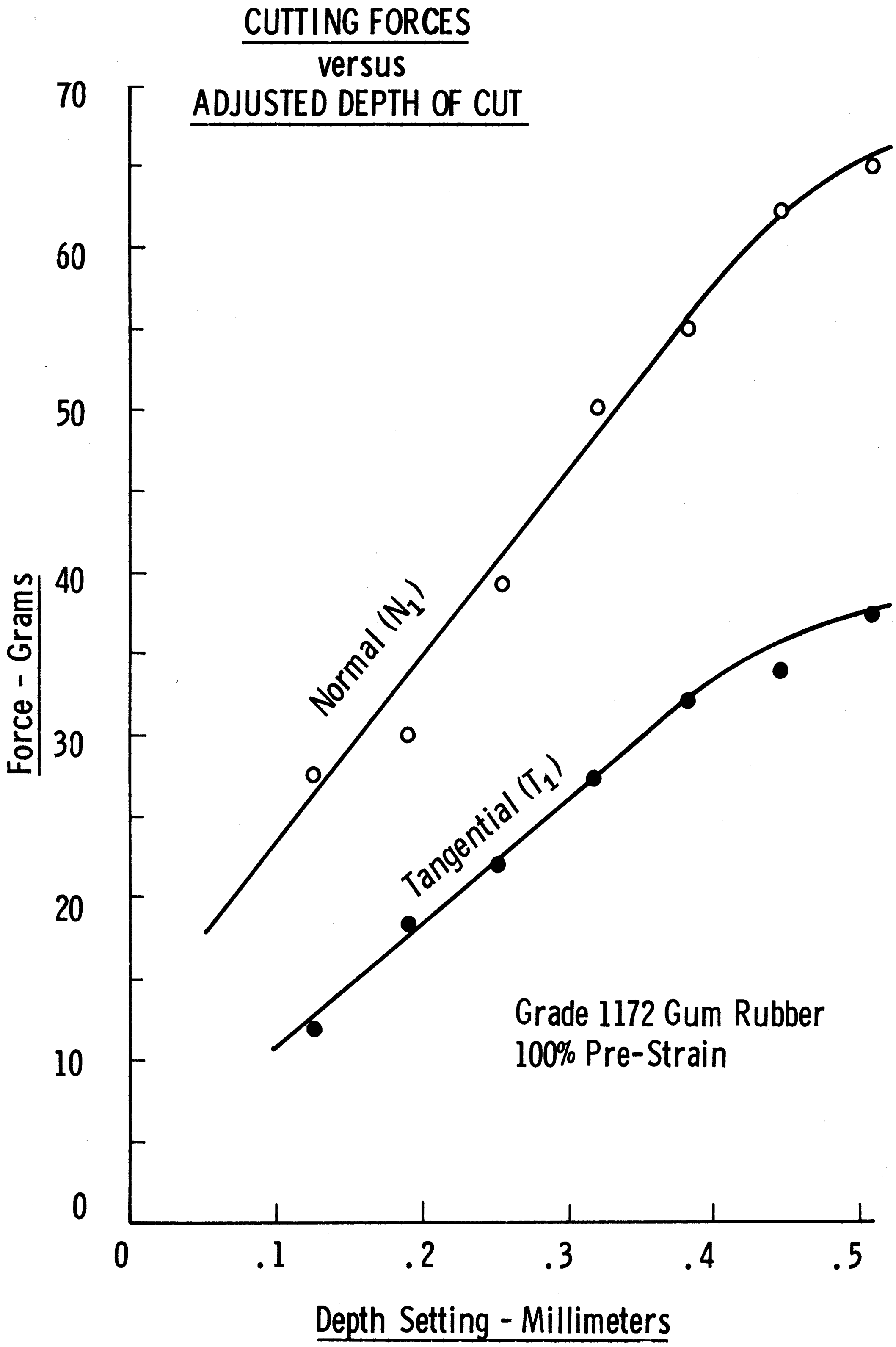

Fig. 9. Cutting forces vs. adjusted depth of cut. Shows effects of adjusted depth of cut or interference between test blade and rubber; forces are for first cut; curvature for large depths is caused by curvature of the cutting edge.

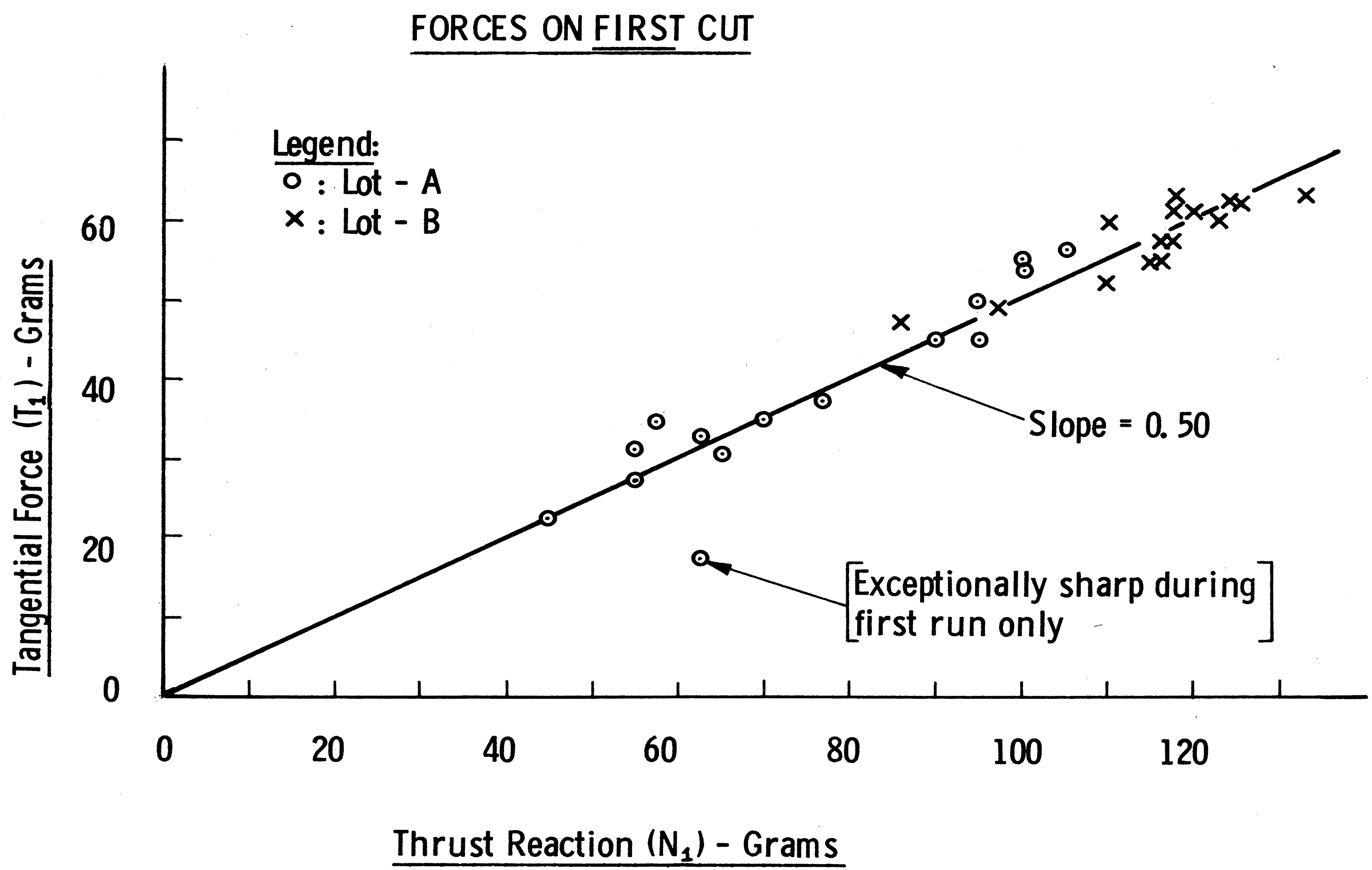

Fig. 10. Forces on first cut. Data correspond to first cuts or strokes only on 3 consecutive test runs, each of which consisted of a total of 6 strokes; "A" blades were made of plain carbon steel and "B" blades of stainless steel; each lot contained 5 blades; the first cut was a draw stroke.

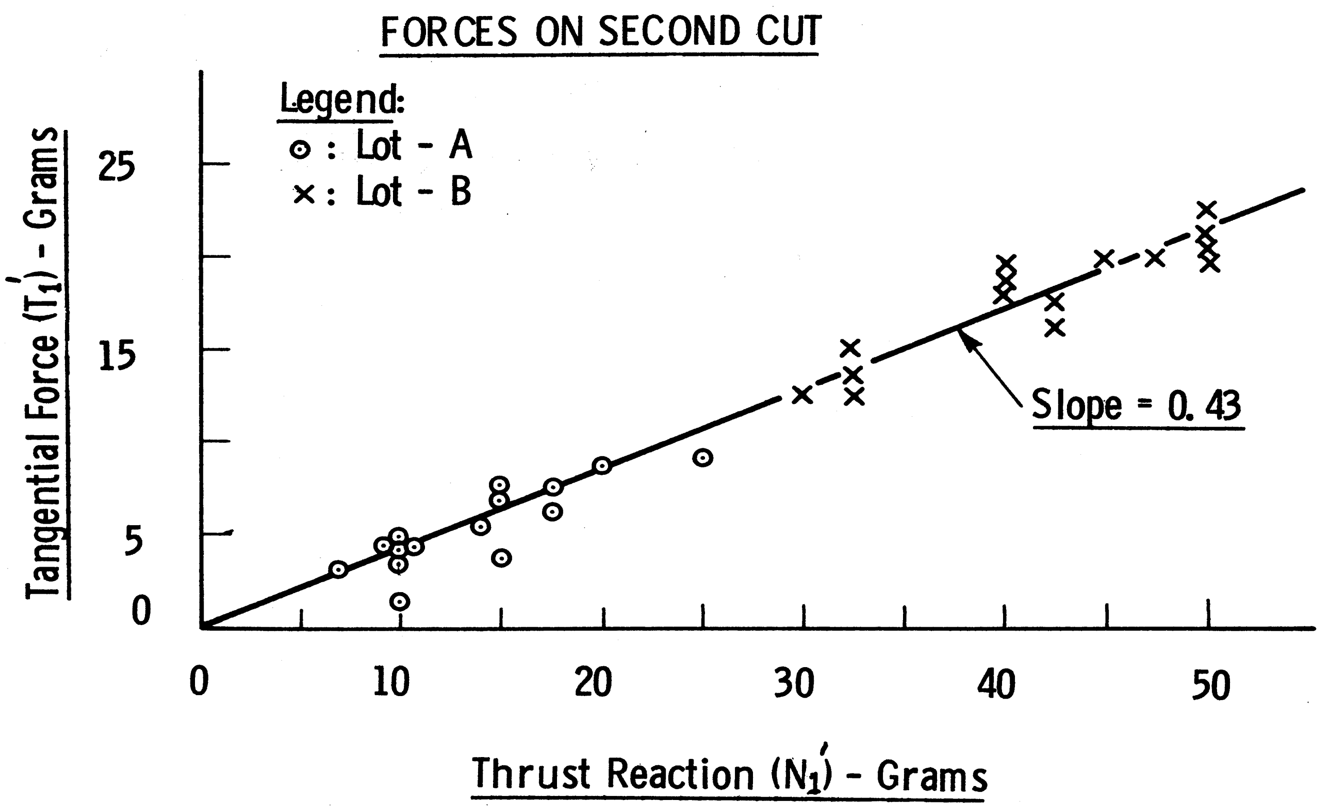

Fig. 11. Forces on second cut. Data obtained for second stroke, which is also the first push stroke in a test run; test series the same as for Fig. 10.

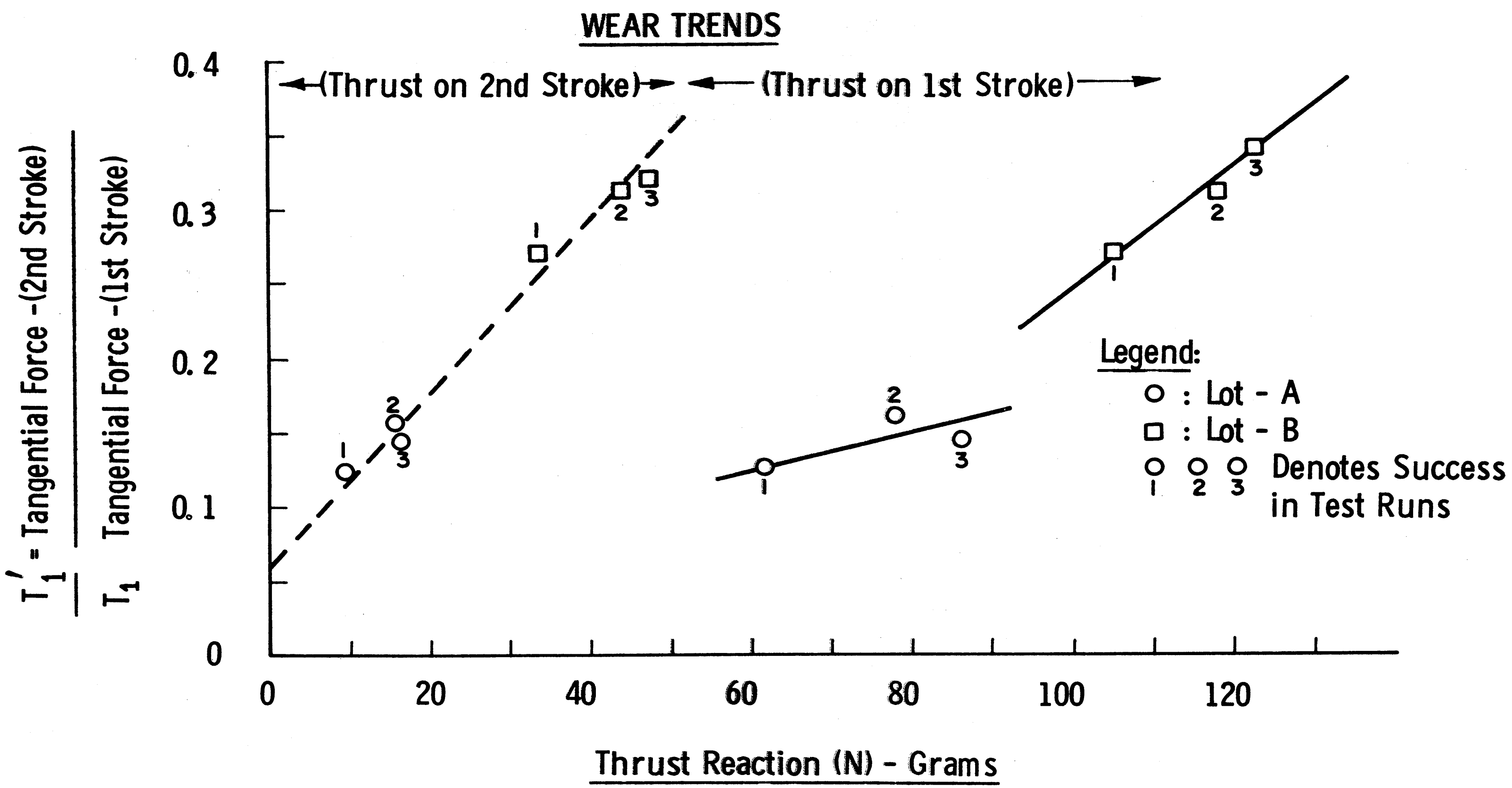

Fig. 12. Wear trends. Shows averages of forces and ratios of forces for Lots A and B; each point is the average for all 5 blades; since the origin represents infinite sharpness the progression from (1) to (2) to (3) represents increasing wear or deterioration; individual blades may backtrack along the wear path, depending on wear mechanisms; these points are averages of data in Figs. 10 and 11.

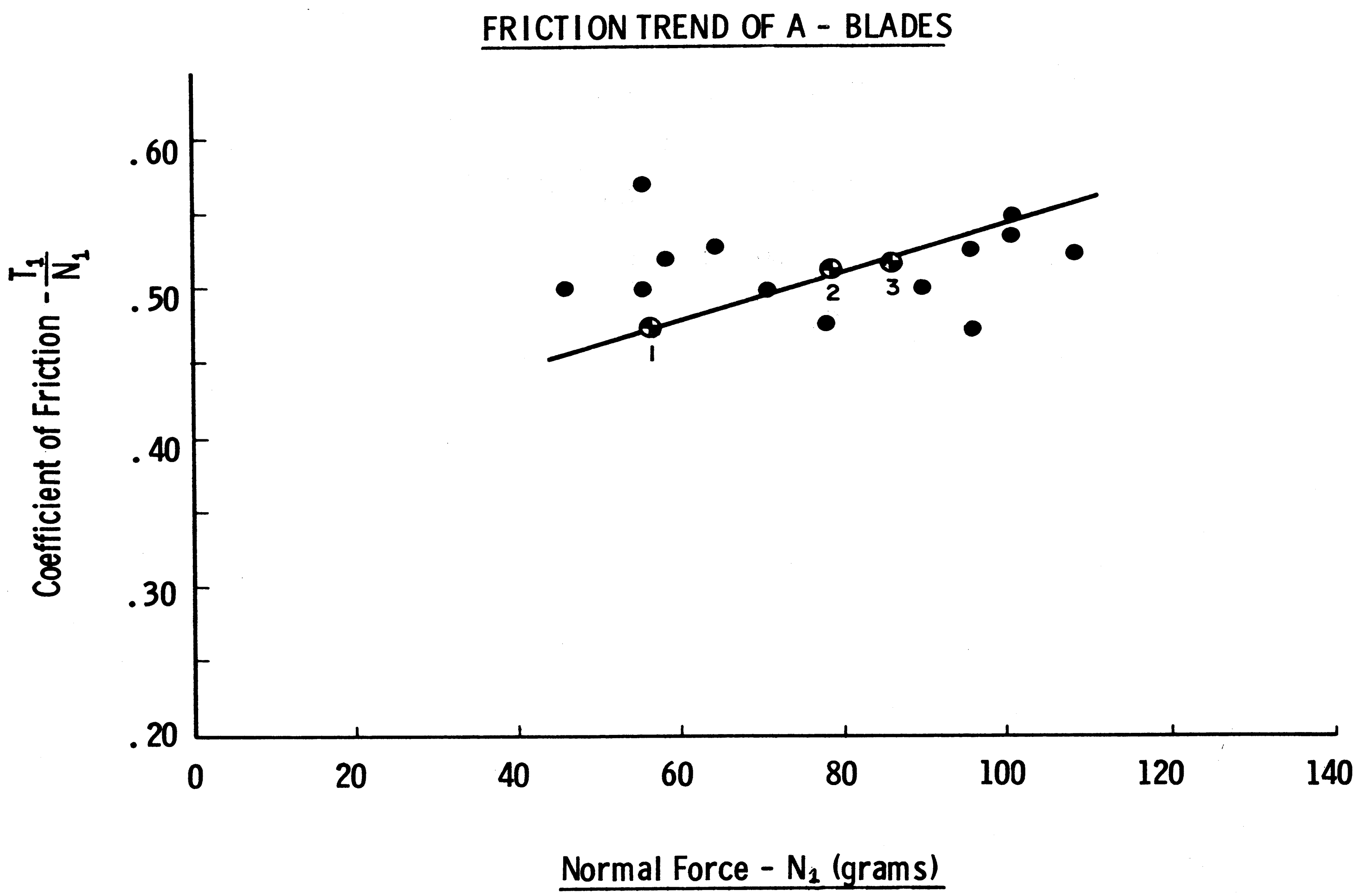

Fig. 13. Friction trend of "A" blades. Increasing coefficient of friction indicates increased rounding off of asperities.

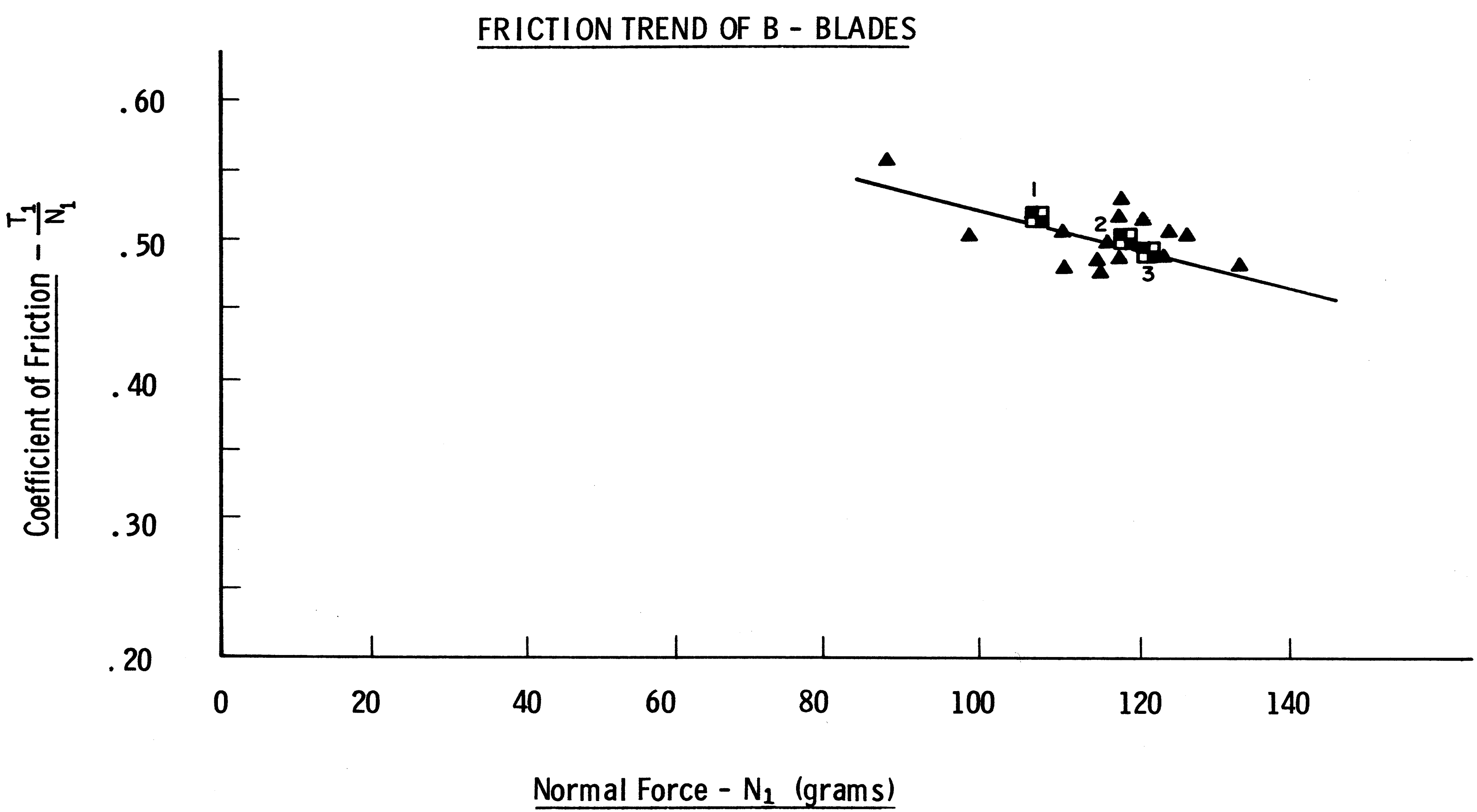

Fig. 14. Friction trend of "B" blades. Decreasing coefficient of friction indicates progressive spalling of cutting edge.