INSTITUTE OF PAPER CHEMISTRY
*Appleton Wisconsin*

# INSTRUMENTATION STUDY OF THE FRAG TESTER

**Project 2033**

**Progress Report Five**

**to**

**MULTIWALL SHIPPING SACK PAPER MANUFACTURERS**

**February 5, 1959**

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SUMMARY

The Frag tester, which was developed in Austria by Ludwig Ragossnig, is the subject of this instrumentation study. The tester was designed to simulate the type of impact fatigue stress which might be experienced by sack paper under service conditions. The simulation is achieved by subjecting a flat paper specimen to repeated impacts by a mass of small steel balls until the paper specimen is ruptured. A component test such as this one that would predict field performance reliably would have many advantages over the drop test which is the best means now available for predicting field performance. Among its advantages could be listed the modest laboratory space required, its mobility, its low material and manpower requirements, and its adaptability to quality control uses on the paper machine. Summarized below are the variables that were evaluated in this instrumentation study of the Frag tester.

INSTRUMENTAL VARIABLES

1. It was found that the mass used to impact the paper was comprised of a variety of sizes of steel balls which ranged in diameter from 1/32 to 1/16 inch and were not uniform in shape.

2. The two drop heights obtained by means of two different anvil assemblies were found to be slightly lower than the heights prescribed by the manufacturer. The height discrepancies could result in an error of approximately 1/4% in the calculated values of burst energy.

3. Pressure patterns of the impacting mass hitting the specimen showed the steel balls to be well distributed over the impact area of the specimen on any one impact. Patterns of repeated impacts, however, showed that only a portion of the impact area received repeated impacts.

4. Pressure patterns of the drop assembly hitting the anvil showed that consistent flat drops were not attained. The relative tautness of the two lift chains, and the rigidity of the lifting arms and the impact anvil appeared to influence the flatness of drop. Lack of flatness of drop apparently caused high variability in the drop number and fictitiously high values of burst energy.

OPERATIONAL VARIABLES

1. The effect of varying the level of input energy was studied by maintaining the same drop height and varying the weight of the impacting mass in order to check (a) the ability of the Frag tester to duplicate burst energy values for a given sample of bag paper at these different input energy levels and (b) to check Ragossnig's hypothesis that absolute burst energy is proportional to the cube root of the drop number.

From the results for six samples of sack paper evaluated at four different input energy levels, it was concluded that the samples were ranked in approximately the same order regardless of the energy level used, although an upward trend in burst energy is evident in 50% of the comparisons as higher levels of energy were used.

Ragossnig's hypothesis suggests the following empirical formula for relating drop number to the burst energy of sack paper: Absolute burst energy = $(\underline{N})^{1/3}\ \underline{W}\ \underline{h}$ in which $\underline{N}$ = number of drops to failure, $\underline{W}$ = weight of the impacting mass, and $\underline{h}$ = height of drop. The exponent of $\underline{N}$ in the above formula (purportedly 1/3) may be determined from the slope of a log-log plot of drop number corresponding to various levels of input energy, $\underline{Wh}$. Using four levels of input energy on six different samples of sack paper, it was found that the value of the exponent was 1/2.745, on the average, as compared to the exponent 1/3 recommended by the inventor. Inasmuch as the exponents for the six samples ranged from 1/1.47 to 1/3.35, it appears that the exponent is related to the grade and mill origin of the sack paper. To further support this statement, it was found that both fiber directions of a given sample usually resulted in nearly equal exponents.

2. Different sizes of steel balls used to compose the impacting mass show that as the ball size was increased, the burst energy obtained with the Frag tester decreased.

Testing with different grits of silicon carbide powder show that for the same energy level more drops are required to rupture the specimen using carborundum powder compared to steel balls. The fineness of powder used also influences results in that a fine powder requires more drops than a coarse powder. This observation may indicate that the commodity will greatly influence the performance of the bag.

3. Provision is made in the Frag tester for two drop heights, 14 and 21 cm., which, in conjunction with varying the weight of the impacting mass,

permits selection of an optimum level of input energy with which to test a given sample of paper. For this feature to have a practical value, the same sample tested with different input energies should result in similar values of burst energy for each case tried.

Using the two drop heights and keeping the weight of the impacting mass constant, values of burst energy for both fiber directions of six samples tested using the 21 cm. height ranged within ± 20% of the values obtained at the 14 cm. height. The average of the six samples gives a decrease of about 2% for machine direction and an increase of about 4% for across-machine direction comparing the 21 cm. to the 14 cm. height. These results suggest that there is no pronounced trend for burst energy to change with a 50% increase in input energy obtained by varying the height of drop.

4. The test specimen is clamped at two parallel edges between strips of abrasive paper affixed to the platens of the drop assembly. A study of specimen clamping showed that either a high or low clamping pressure influenced the test results adversely, as manifested by high variability and abnormally high burst energy. Lower values of burst energy were obtained when the abrasive paper was fastened with an adhesive which formed a solid bond as compared with a nonrigid bond. Burst energy values were the same when clamping strips made of different size carborundum grit were used. Decreasing the width of the clamping strips, which resulted in an increase in the free span of the specimen, gave higher values of burst energy.

Clamping the specimen around the entire edge of the cylindrical openings of the drop assembly rather than along two parallel edges enables a specimen to be stressed in a biaxial manner rather than along a specific fiber direction. This biaxial test of sack paper resulted in burst energy readings comparable to the values for the weaker fiber direction obtained with a uniaxial test. It would seem that a bag subjected to impacts would result in a biaxial rather than a uniaxial stress. If it could be shown that the stresses induced in the biaxial Frag test simulate biaxial stresses in an impacted sack, then the results cited above suggest that the properties in the weaker direction of the sack paper may be important to sack strength.

MATERIAL VARIABLES

1. The Frag tester ranked samples from a given mill in the order expected on the basis of ream weight. High stretch papers give high burst energy values on the Frag tester when compared with lower stretch papers of the same ream weight from a given mill.

2. Inasmuch as the test specimen is clamped along two opposite edges, it may be expected that the Frag test is influenced by the directional properties of the paper. Higher values of burst energy usually were obtained with across-machine specimens than with in-machine specimens. However, in one sample having greater stretch in the machine direction than in the across-machine direction, the in-machine orientation gave higher burst energy. Thus, it may be noted that higher burst energy was always associated with the direction of greatest stretch, suggesting that Frag test results may be more directly related to stretch than to fiber orientation.

3. Testing multiple plies of bag paper in the Frag tester resulted in larger values of burst energy as the number of plies tested was increased. For the material used in this study, average results indicate that two plies increased the burst energy for both fiber directions about two times. Three plies for the same material resulted in an increase in burst energy of about four times for machine direction and five times for across-machine direction. This indicates, on the basis of burst energy, that a bag made of several plies of light paper may be superior to a few plies of heavy paper.

4. The atmosphere in which the test is conducted does not appear to have a large influence in results when going from a 50 to a 25% relative humidity (R.H.) atmosphere. However, lower values of burst energy were obtained in the 25% R.H. atmosphere as compared to the values of burst energy obtained when the same samples of sack paper were tested on the Frag tester in the 50% R.H. atmosphere.

OTHER FACTORS STUDIED

1. Results indicate that good correlation is not evident between Frag burst energy and tensile, stretch and work data obtained with the Baldwin. The burst energy shows a better indication of correlation with work than with tensile load or stretch.

2. The reproducibility of the Frag tester was evaluated by testing one sample of sack paper on ten successive days. A statistical analysis revealed that the given sample was characterized by the Frag test as having three significantly different levels of drop number and burst energy. These

results cast doubt on the suitability of the Frag tester as a quality control instrument.

Consideration was given to the question of whether or not conventional statistical methods are appropriate for fatigue data such as obtained from the Frag test. This question is discussed in detail in this report, although the extent of available data prevented drawing any firm conclusions.

3. Some difficulties were experienced with the Frag tester due to the type of test performed, which requires constant impacting of the drop assembly on the impact anvil. (a) The lights and electrical circuit fail intermittently from the constant impacting. (b) The impact anvil and lift arms on the drop assembly tend to loosen with constant impacting; this appears to have an effect on the flatness of drops. (c) Various parts of the instrument, besides the electrical circuit, failed after a number of tests were completed, namely, the counter, the drop assembly, one anvil clamp arm and one clamping bracket on the replacement drop assembly. (d) A new drop assembly, acquired to replace the original holder which failed with usage, resulted in higher values of burst energy and greater variability in comparison with the original holder. (e) The test itself is a noisy test because of the constant impacting, which may have some bearing on its adoption as a routine laboratory test.

## INTRODUCTION

For many years sacks have been evaluated by means of the drop test (1) in an attempt to determine how well they will perform in actual use. Many investigators, manufacturers, and users of sacks feel that the drop test is the best way now available to predict field performance (2). For this reason it is widely used in spite of some major disadvantages--namely, it is time-consuming and arduous, requires a relatively large space in the laboratory, is not easily mobilized, and does not distinguish between deficiency of material and conversion. A component test that would predict field performance would be preferable to the drop test if it had certain characteristics. Some desirable characteristics which this test should have are the following: It should require modest laboratory space, be mobile, and use minimum material and manpower for its operation. The Frag tester was developed with these ideas in mind and is the subject of this instrumentation report (3, 4, 5).

The Frag tester, which was developed in Austria by Ludwig Ragossnig, is an instrument (see Figure 1) which subjects a flat paper specimen to repeated impacts by a mass of small steel balls until the paper specimen is ruptured. The tester was designed to simulate the type of impact fatigue stress which might be experienced by a sack in field service. Ragossnig (6) interprets the failure of a filled sack in field service in terms of the movement of the contents of the sack. A filled sack dropped from a given height has a given kinetic energy. When the sack with its contents hits the base on which it is dropped, the kinetic energy of the

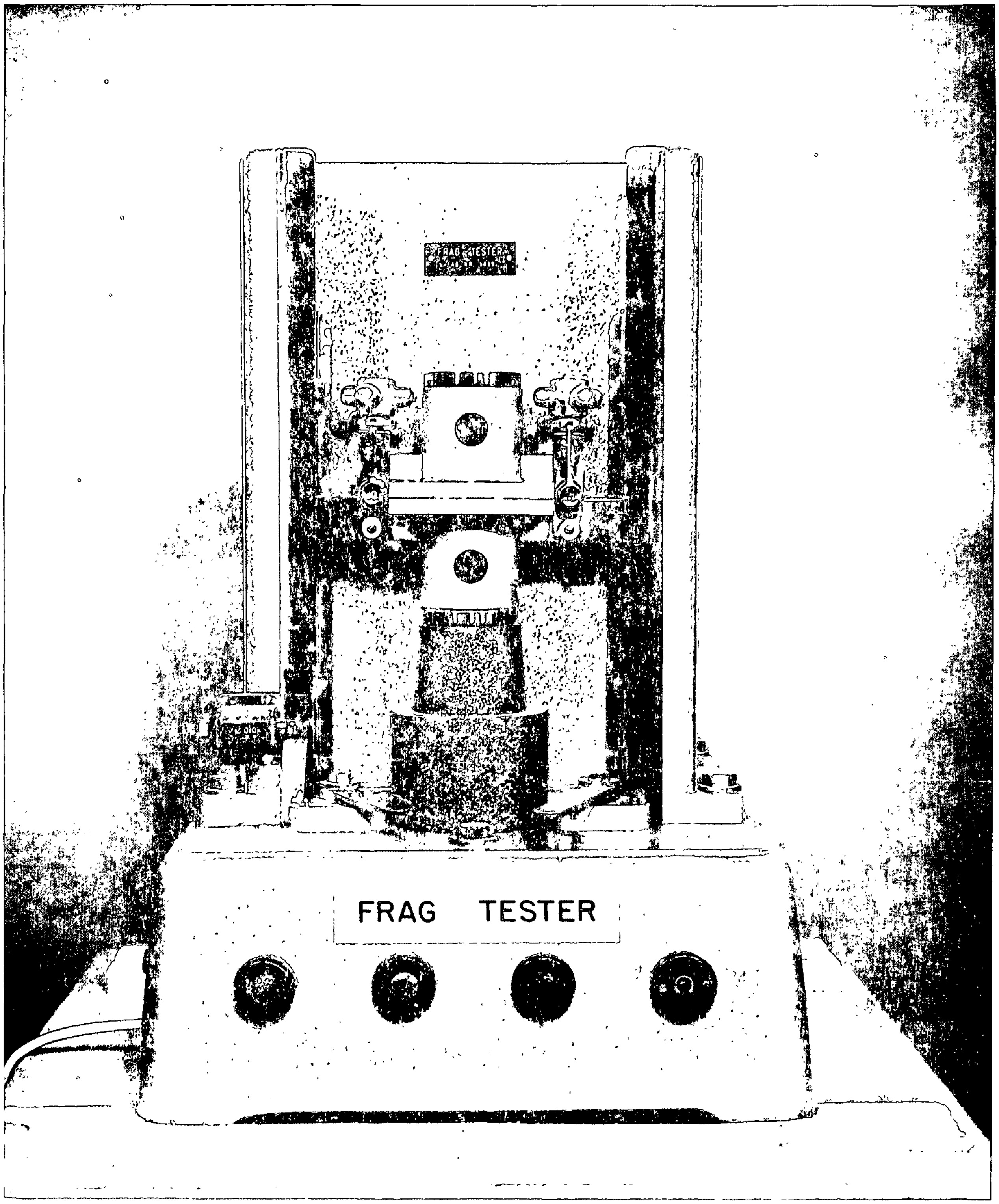


Figure 1. Photograph of Frag Tester

contents is transmitted not only to the base but also the sack walls. Ragossnig reasons that the movement of the contents stresses the sack in varying amounts, being greatest near the base on which the sack is dropped and less in proportion to the distance from the base until it approaches zero at the upper surface of the sack contents. Ragossnig also believes that the "adhesion between individual paper fibers" in the sheet of paper is partially destroyed each time a filled sack is dropped until after a series of drops the structure is ruptured.

The above hypothesis that a filled sack will undergo a fatigue type of failure when it is subjected to repeated drops may be represented mathematically by the Equation $\underline{F}/\underline{F}_o = 1 - (\underline{Z}/\underline{Z}_B)^3$ where $\underline{F}_o$ = original strength of paper, $\underline{F}$ = retained strength of paper, $\underline{Z}_B$ = number of drops to rupture the specimen, and $\underline{Z}$ = number of drops the specimen has undergone. This equation is illustrated graphically in Figure 2, where it may be seen that each additional drop to which a sack is subjected removes a proportionately larger fraction of the original total strength of the sack paper. It may be of interest to note in this respect that brief exploratory tests prior to this instrumentation study support the essential features of this hypothesis. After four samples, of 10 Frag specimens each, were subjected to 87% of the number of impacts required to rupture the sack paper, it was found that the tensile work values were reduced to 40 to 60% of their original values (in three of the four samples), emphasizing that the loss in strength was <u>not</u> proportional to the number of impacts. These results are in the neighborhood of the 50% value predicted by the hypothesis as illustrated in Figure 2.

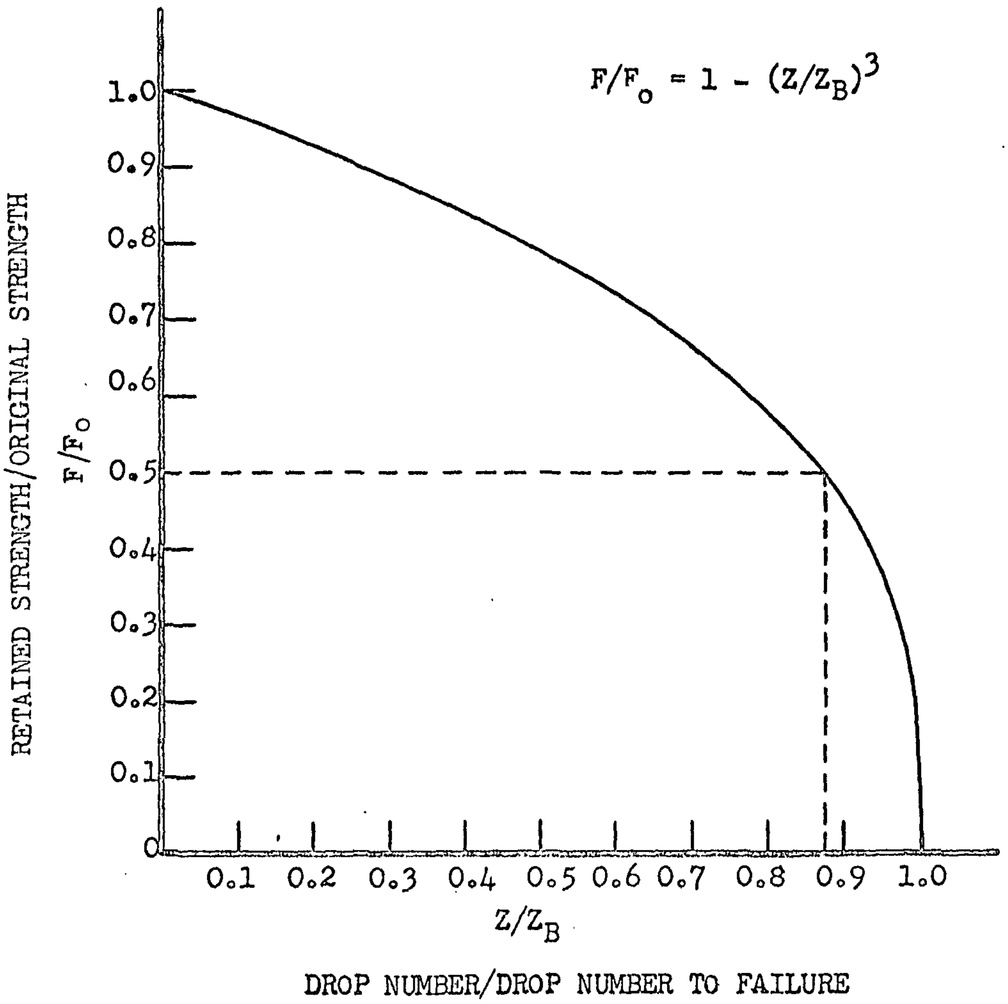


Figure 2. A Graphical Representation of Ragossnig's Hypothesis

To prove the hypothesis which this equation represents, Ragossnig built the prototype of the Frag tester. Other models were built between the prototype and the tester which was used in this study.

Figure 1 is a photograph of the Frag tester shown ready to test a specimen. The drop assembly is seen resting on the impact anvil from which, during a test, it is raised a specified distance and allowed to fall freely back to the anvil. The elevation of the drop assembly is achieved by an electric motor which simultaneously drives two roller lift chains, one located at the end of each lift arm of the assembly. Each lift chain is equipped with two arms for lifting the drop assembly; therefore, the assembly is raised and dropped twice for each revolution of the chain.

Figure 3 is a photograph of the drop assembly and shows the assembly open to give a view of the two cylindrical-shaped containers and the position of the Carborundum paper used for clamping purposes and closed to show the assembly ready for testing. To prepare a specimen for testing, it is first cut to a size of 3.3 by 4.0 inches, the fiber direction to be tested being parallel to the longer specimen dimension. A known weight of steel balls is placed in one of the two cylindrical containers and the specimen is then placed on the clamping platen of this same container. The clamping platen of the empty cylindrical container is then placed against the specimen and the two containers are securely held together by two locking thumbscrew clamps as shown in Figure 3. The assembly is rotated so that the mass of steel balls is resting on the paper specimen and it is placed in the tester in this fashion.

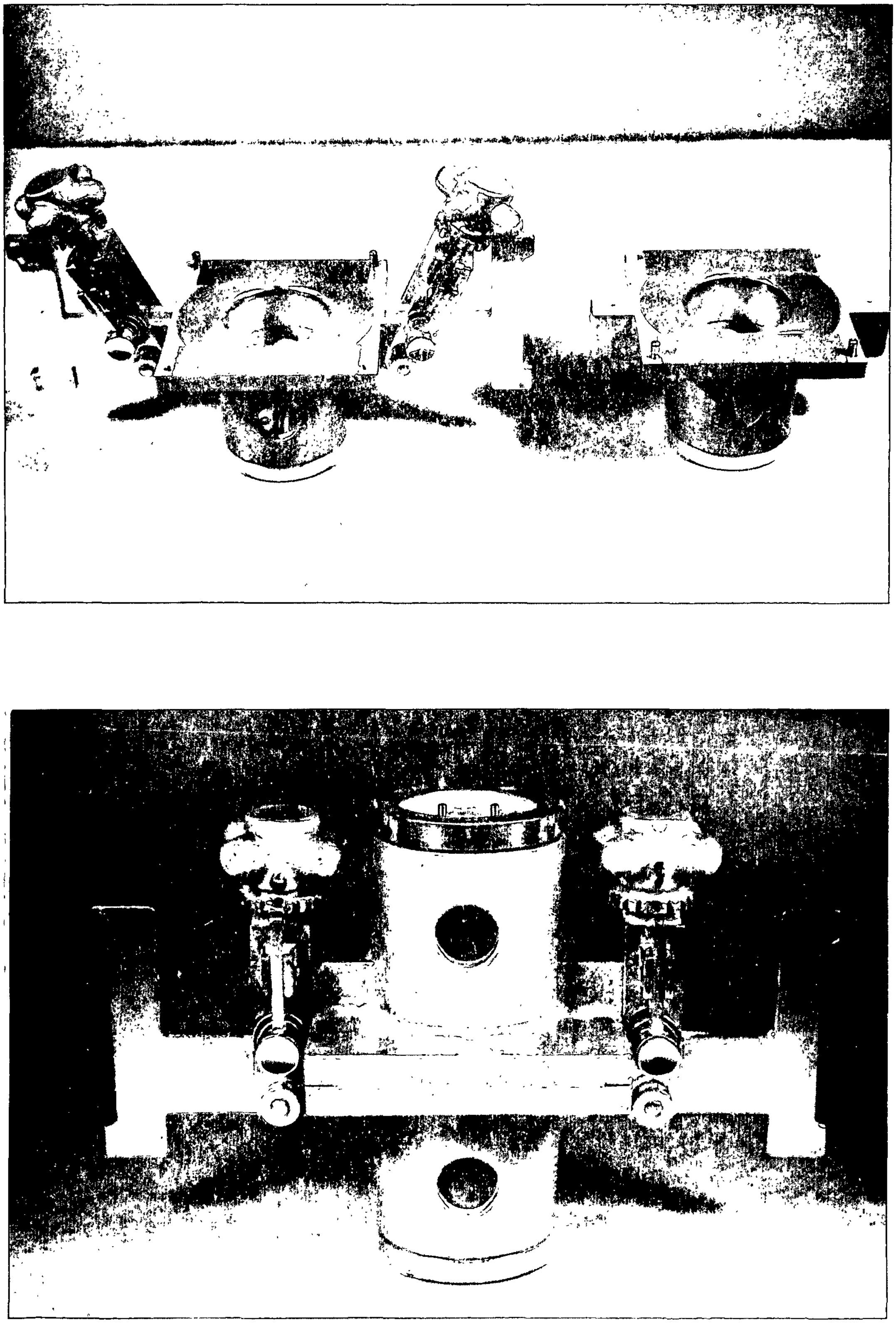

Figure 3. Photograph of Drop Assembly

When the drive switch is turned on, the motor rotates the lift chains which repeatedly carry the drop assembly a given height and allow it to fall back to the impact anvil. This repeated raising and dropping of the assembly subjects the specimen under test to constant impacts by the mass of steel balls. As the energy of the falling mass is imparted to the specimen under test, the specimen is weakened until it can no longer withstand the full energy imparted to it upon impact, at which time the specimen breaks and the steel balls fall into the empty container below the specimen. As the steel balls fill the lower container, an electric circuit is completed, thus stopping the driving motor. A mechanical counter is tripped each time the lifting arms of the drive chain complete a revolution; hence, the number of impacts which are required to break the specimen may be obtained. A table issued by the manufacturer can be used to convert the number of drops required to break the specimen to the absolute burst energy of the paper.

The time required to carry out a Frag test is a function of the time involved in preparing the specimen, aligning and clamping the specimen in the holder, and the number of drops required to rupture the specimen. For an individual specimen it is estimated that the preparation of the specimen requires approximately one-half minute, alignment and clamping approximately one minute, and impacting is carried out at the rate of 25 impacts per minute. On the basis of the average drop range encountered for the materials used in this study, the total lapsed time for <u>impacting</u> or testing a specimen varied from approximately one-half to twelve minutes. To this, of course, must be added the time required to prepare and align the specimen in the tester. Thus, for ten specimens of the character used in this study, from 20 to 135 minutes would be required to complete the test.

## GENERAL PROCEDURE

The purpose of this instrumentation study was to check the reliability of Ragossnig's hypothesis and to investigate instrumental, operational, and material variables which might influence the test results obtained with the Frag tester. The following variables were studied:

I. Instrumental Variables

A. Weight of drop assembly, size of cylinder and radius of its edge, maximum drop heights, size of steel balls constituting the impacting mass.

B. Flatness of drop

C. Distribution of steel balls on impact

II. Operational Variables

A. Effect of varying the level of input energy [a]

B. Effect of particle size in the impacting mass

C. Effect of drop height

D. Effect of clamping technique

III. Material Variables

A. Test results for various grades of kraft sack paper

B. The effect of fiber direction on the Frag test results

C. The effect of multiple plies

D. The effect of testing in 25 and 50% R.H. atmospheres

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[a] These results were also used to check Ragossnig's hypothesis

IV. Other Factors Studied

A. Comparison of Frag burst energy with Baldwin-Southwark tensile, stretch, and work data

B. Reproducibility of Frag test results

C. Observations on the construction and durability of the Frag tester

## MATERIALS

Two groups of materials were used in this study and are identified in Table I. Group One included the following weights of unbleached kraft sack paper: one sample of 30 lb., one sample of 35 lb., three samples of 50 lb., and one sample of 60 lb. Group Two included the following weights of unbleached kraft sack paper: one sample of 40 lb., four samples of 50 lb., and one sample of 60 lb. In each section of this instrumentation report, the materials used are identified as to group number and sample number or letter.

All materials used in this study (with one exception, which is described later) were preconditioned for at least 24 hours in an atmosphere at 73 ± 3.5°F. and less than 35% relative humidity and subsequently conditioned for at least 48 hours in an atmosphere at 73 ± 3.5°F. and 50 ± 2% relative humidity prior to being tested. The one exception involved the material used in studying the effect of relative humidity, for which, after being preconditioned in the manner described above, some of the material was conditioned for at least 48 hours in an atmosphere at 73 ± 3.5°F. and 25 ± 2% relative humidity.

During the instrumentation study, the original drop assembly failed and was replaced with a new drop assembly from Testing Machines, Inc. A difference in test results was noted for these two drop assemblies. The studies mentioned above under I-B (Flatness of Drop) and II-D (Effect of Clamping Technique) were concerned with finding reasons for these differences.

TABLE I

MATERIALS USED

| Sample Identification | Material | Nominal Basis Weight, lb. (24 x 36/500) | Stretch, % In | Stretch, % Across |
|---|---|---|---|---|
| | | Group One | | |
| A | Unbleached kraft | 30 | 1.6 | 2.6 |
| B | Unbleached kraft | 35 | 1.8 | 3.5 |
| C | Unbleached kraft | 50 | 1.9 | 4.5 |
| D | Unbleached kraft | 60 | 2.1 | 4.1 |
| E | Unbleached kraft | 50 | 1.9 | 3.6 |
| F | Unbleached kraft | 50 | 12.5 | 8.6 |
| | | Group Two | | |
| 100 | Unbleached kraft | 40 | 1.8 | 5.3 |
| 101 | Unbleached kraft | 50 | 2.1 | 4.5 |
| 102 | Unbleached kraft | 50 | 1.5 | 2.8 |
| 103 | Unbleached kraft | 50 | 1.9 | 3.6 |
| 104 | Unbleached kraft | 60 | 2.1 | 3.9 |
| 105 | Unbleached kraft | 50 | 15.9 | 7.6 |

The values of burst energy given in this report are based on the average number of drops required to rupture ten specimens. The data were obtained from a drop height of 14 cm. and with an impacting mass of steel balls which weighed 100 g. When these conditions were varied, a notation was made in the appropriate table or figure.

# DISCUSSION OF RESULTS

The objective of this study was to investigate variables associated with the evaluation of sack paper by means of the Frag tester. This involved variables associated with the instrument itself, variables associated with its operation, and variables associated with the materials it was designed to evaluate. Other factors were also studied, one of which was the relationship of Frag burst energy to work, tensile, and stretch data obtained on the Baldwin-Southwark tester and another the reproducibility of Frag test results. Observations on the durability and construction of the Frag tester are also summarized. An evaluation of the validity of Ragossnig's hypothesis is also included in the section which considers the effect of varying the level of input energy. In the discussions and presentations that follow, instrumental variables are considered first, operational variables second, material variables third, and other factors studied are considered last.

## INSTRUMENTAL VARIABLES

### Weight of Drop Assembly, Size of Cylinder and Radius of its Edge, Maximum Drop Heights and Size of Steel Balls Constituting the Impacting Mass

The fundamental constants of the instrument were measured to provide other users with comparative information. It was found that the complete drop assembly without specimen or steel shot weighed 5.03 pounds. The diameter of the cylinder in which the steel shot is placed measured 1.975 inches with an edge radius of 7/64 of an inch. This leaves an equivalent diameter of unrestrained specimen of about 2.084 inches. The maximum lift height of the drop assembly was measured and found to be 20.954 cm. for the 21-cm. drop height and 13.956 cm. for the 14-cm. drop height. These differences in drop height could introduce errors of about 1/4% in values taken from the table relating drop number to absolute burst energy. (See Table II).

The steel balls which came with the instrument and comprised the impacting mass were screened and found to lie within three ge neral classifications--namely, those approximately 1/16 inch or larger, those greater than 1/32 inch but less than 1/16 inch, and those 1/32 inch or smaller. On the basis of a sample of these steel balls weighing 400 grams, there were about 63.6% in the 1/16 inch category, 30.1% in the 1/32 to 1/16-inch range, and 6.3% of the balls were 1/32 inch in diameter. Figure 4 is a photograph of a mixture of the steel balls used as the impacting mass for the Frag test; also shown is a comparison of the sizes of these steel balls within such a mixture. It is noticeable when these balls are viewed under magnification that they are not always symmetrical but many variations of shape are present--spheres, flat, oblongs, and some with sharply pointed ends. This nonsymmetry may contribute to the variability of the data obtained from this instrument.

## Flatness of Drop

To study the flatness of drop, an impact pattern was obtained when the drop assembly hit the impact anvil by placing a sheet of carbon paper against a sheet of plain paper on the impact anvil and allowing the drop assembly to hit the anvil in the same manner as when testing. The patterns which were obtained with the original drop assembly and with the new drop assembly are shown in Figure 5. Some patterns show evidence that the drop

# TABLE II

## A PORTION OF THE CONVERSION TABLE SUPPLIED BY THE MANUFACTURER

zur Ermittlung der absoluten Berstenergie aus der Wurfzahl β nach der Beziehung
to determine the absolute burst energy out of the drop number β in relation to

abs. BE $= \sqrt[3]{\beta} \cdot h \cdot G$    h = Wurfhöhe   h = drop height
G = Füllgewicht   G = weight of steelballs

| β Mittelwert average | abs. BE kgm. 10 —4 h 14 cm G 100 g | 14 cm 200 g | 21 cm 200 g | β Mittelwert average | abs. BE kgm. 10 —4 h 14 cm G 100 g | 14 cm 200 g | 21 cm 200 g |
|---|---|---|---|---|---|---|---|
| 1,0 | 140 | 280 | 420 | 5,0 | 239 | 478 | 717 |
| ,1 | 144 | 289 | 433 | ,1 | 241 | 482 | 722 |
| ,2 | 149 | 297 | 446 | ,2 | 242 | 485 | 727 |
| ,3 | 153 | 306 | 458 | ,3 | 244 | 488 | 731 |
| ,4 | 157 | 313 | 470 | ,4 | 246 | 491 | 736 |
| ,5 | 160 | 320 | 481 | ,5 | 247 | 494 | 740 |
| ,6 | 164 | 327 | 491 | ,6 | 249 | 497 | 745 |
| ,7 | 167 | 334 | 501 | ,7 | 250 | 500 | 750 |
| ,8 | 170 | 340 | 510 | ,8 | 252 | 503 | 755 |
| ,9 | 173 | 346 | 520 | ,9 | 253 | 505 | 759 |
| 2,0 | 176 | 353 | 529 | 6,0 | 254 | 508 | 762 |
| ,1 | 179 | 358 | 537 | ,1 | 255 | 511 | 767 |
| ,2 | 182 | 364 | 546 | ,2 | 257 | 514 | 771 |
| ,3 | 185 | 369 | 554 | ,3 | 258 | 517 | 775 |
| ,4 | 187 | 374 | 562 | ,4 | 260 | 520 | 779 |
| ,5 | 190 | 380 | 570 | ,5 | 261 | 522 | 783 |
| ,6 | 192 | 385 | 577 | ,6 | 262 | 525 | 787 |
| ,7 | 195 | 390 | 585 | ,7 | 264 | 528 | 791 |
| ,8 | 197 | 394 | 592 | ,8 | 265 | 530 | 795 |
| ,9 | 199 | 399 | 598 | ,9 | 266 | 532 | 799 |
| 3,0 | 202 | 403 | 605 | 7,0 | 267 | 535 | 802 |
| ,1 | 204 | 408 | 612 | ,1 | 269 | 538 | 806 |
| ,2 | 206 | 412 | 618 | ,2 | 270 | 541 | 810 |
| ,3 | 208 | 417 | 625 | ,3 | 271 | 543 | 814 |
| ,4 | 210 | 421 | 631 | ,4 | 273 | 546 | 818 |
| ,5 | 212 | 425 | 637 | ,5 | 274 | 548 | 822 |
| ,6 | 214 | 429 | 643 | ,6 | 275 | 550 | 825 |
| ,7 | 216 | 432 | 649 | ,7 | 276 | 553 | 829 |
| ,8 | 218 | 436 | 655 | ,8 | 278 | 555 | 832 |
| ,9 | 220 | 440 | 660 | ,9 | 279 | 558 | 836 |
| 4,0 | 222 | 444 | 666 | 8,0 | 280 | 560 | 840 |
| ,1 | 224 | 447 | 671 | ,1 | 281 | 562 | 843 |
| ,2 | 226 | 451 | 677 | ,2 | 282 | 564 | 846 |
| ,3 | 227 | 455 | 682 | ,3 | 283 | 566 | 850 |
| ,4 | 229 | 458 | 687 | ,4 | 284 | 569 | 854 |
| ,5 | 231 | 462 | 693 | ,5 | 285 | 571 | 857 |
| ,6 | 233 | 465 | 698 | ,6 | 287 | 573 | 860 |
| ,7 | 234 | 469 | 703 | ,7 | 288 | 576 | 864 |
| ,8 | 236 | 472 | 708 | ,8 | 289 | 578 | 867 |
| ,9 | 237 | 475 | 712 | ,9 | 290 | 580 | 870 |

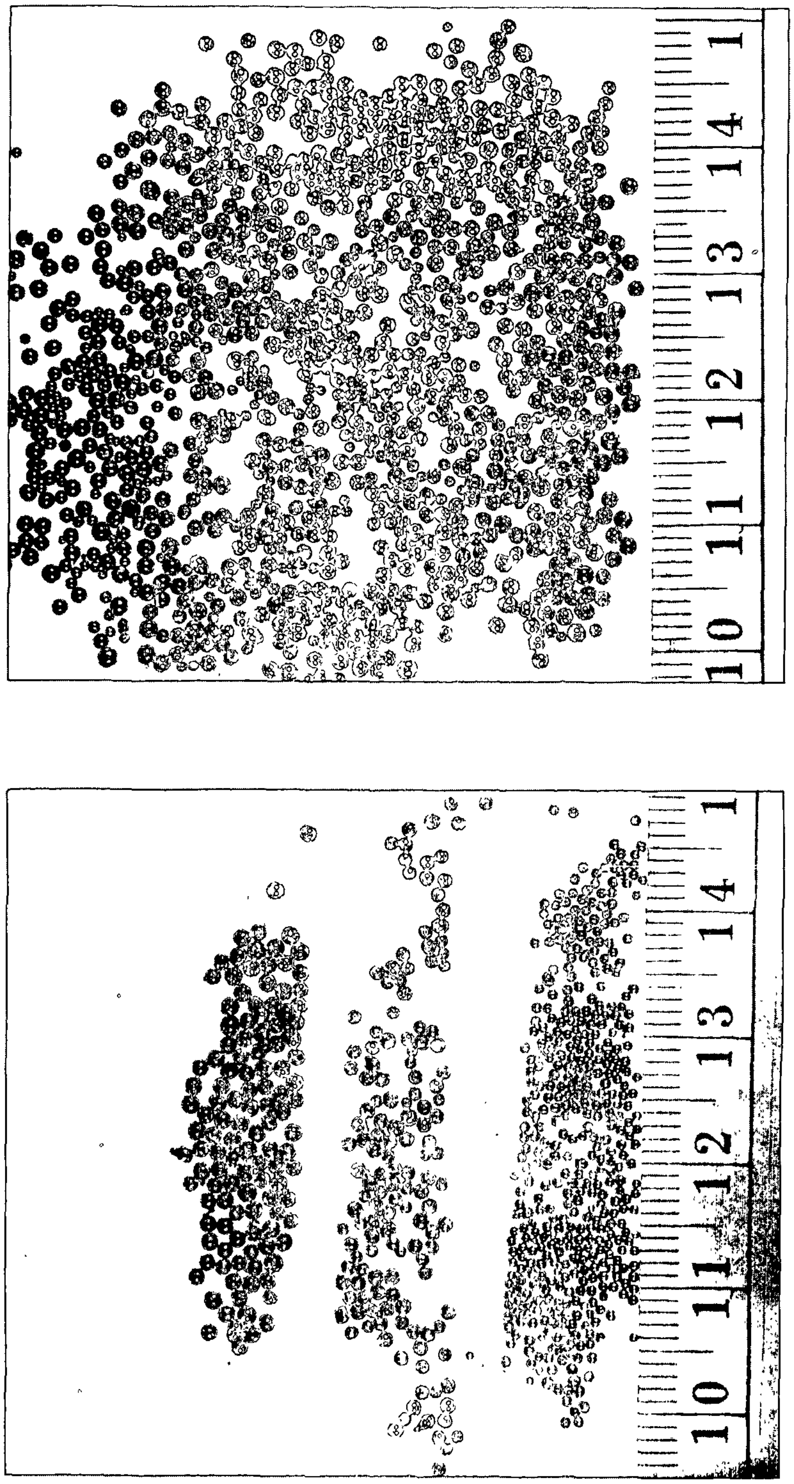


Figure 4. Steel Balls Supplied with the Frag Tester Showing Size Variation and Composite Mixture

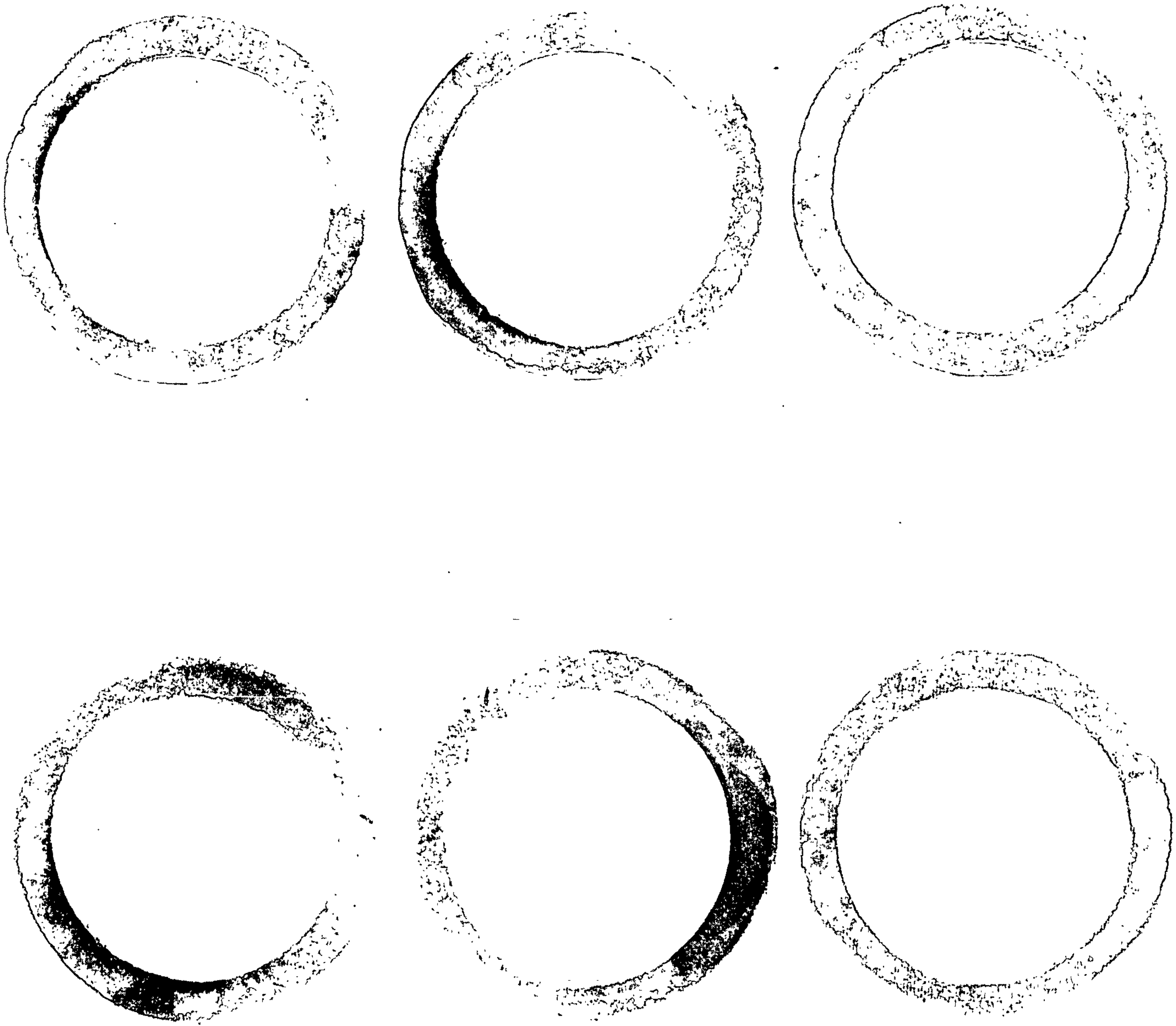


Figure 5

Impact Patterns of Drop Assembly Hitting Impact Anvil assemblies impacted the anvil with greater force on one side than on the other. A study conducted with the new drop assembly indicates that several factors may influence the flatness of the drop attained. One is a difference in tautness between the two lift chains; a second is the rigidity of the lift arms, and a third is the rigidity of the anvil. No provision is made on the Frag tester for adjusting any of these factors. However, through the use of shims and by means of trial and error adjustments, some improvement was obtained. As a first step toward studying the effect of the flatness of drop on the Frag test results, adjustments of the tautness between the lift chains and of the rigidity of the anvil were made to obtain as flat a drop as possible. The second and third steps were concerned with obtaining various drops that were not flat by the following adjustments: Step 2. The anvil was made less rigid by removal of the shims and other adjustments were not changed. Step 3. Same as Step 2 above and, in addition, the lift chains were adjusted to cause the drop assembly to hit the anvil at a slight angle--i.e., in a nonflat position. The fourth step was an effort to return the tester as nearly as possible to its first condition--i.e., so it would give as flat a drop as possible. Tests were made at these various conditions on two samples of bag paper (Samples 102 and 103). The test results obtained for these four conditions of flatness of drop are given in Table III. These results indicate that the flatness of drop influenced the variability and magnitude of the data obtained on the Frag tester. Variability tended to be greater when the tester was adjusted to give a nonflat drop (Conditions B and C in Table III) and burst energy results also tended to be larger. Condition A, which represented the tester adjusted to give as flat a drop as possible, agreed reasonably well with Condition D, which represented an effort to return the tester to Condition A after it had been purposely adjusted to give nonflat drops.

TABLE III

THE EFFECT OF ANVIL RIGIDITY AND FLATNESS OF DROP ON THE FRAG TEST RESULTS

| | | Condition of Test * | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | | | B | | | C | | | D | | |
| Sample Identification | Fiber Orientation | Falls to Failure, Average | Falls to Failure, Range | Burst Energy, $10^{-4}$kg.m. | Falls to Failure, Av. | Falls to Failure, Range | Burst Energy, $10^{-4}$kg.m. | Falls to Failure, Av. | Falls to Failure, Range | Burst Energy, $10^{-4}$kg.m. | Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$kg.m. |
| 102 | Machine | 11.1 | 6-17 | 313 | 13.1 | 5-20 | 330 | 17.8 | 12-28 | 366 | 10.7 | 5-21 | 309 |
| | Across machine | 29.3 | 12-60 | 432 | 43.9 | 20-107 | 494 | 63.4 | 40-105 | 557 | 41.1 | 22-95 | 483 |
| 103 | Machine | 30.3 | 13-41 | 435 | 38.3 | 14-54 | 471 | 40.6 | 15-59 | 483 | 20.5 | 11-31 | 383 |
| | Across machine | 40.7 | 20-64 | 483 | 52.4 | 17-94 | 523 | 65.9 | 14-137 | 566 | 28.0 | 7-45 | 425 |

*

A Represents the first case of tight anvil and flat drop.

B is the anvil again loosened with all else constant.

C is a loose anvil and nonflat drop.

D is an attempt to repeat A with the anvil again tight and with an average flat drop.

It had been noticed in this study of the flatness of the drop that the lift arms on the specimen holder became loose as testing progressed. To investigate what effect this looseness might have on the test results, impact patterns were made with the lift arms loose and with the lift arms tightened by means of shims. These impact patterns shown in Figure 6 indicate that a flatter drop can be obtained with tight lift arms. To check this effect further, the lift arms were tightened by the use of shims and with no further adjustment Samples 102 and 103 were evaluated on two successive days. The test results are shown in Table IV and reveal that tight arms generally reduced the range of the drop number by comparison with the ranges shown in Table III for the best flat drop conditions (A and D) previously achieved. It appears from these results that the tightness of the lift arms had an influence on the flatness of drop which, in turn, affected the variability and magnitude of the results.

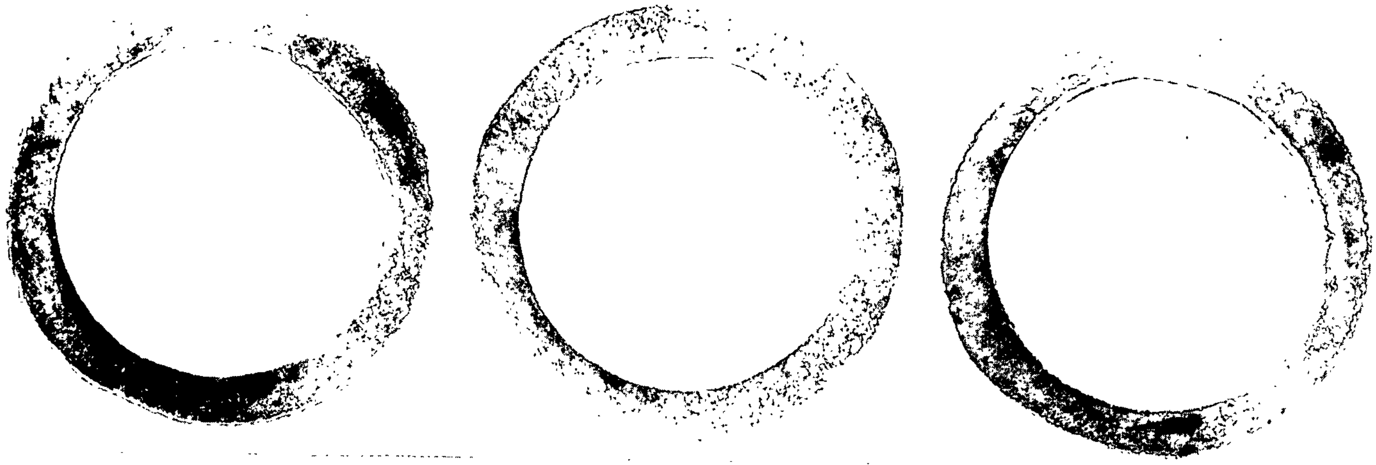
## Distribution of Steel Balls on Impact

To study the distribution of the steel balls on impact, patterns were made of the balls impacting the specimen by placing a sheet of carbon paper between the specimen and the impacting mass. Figure 7 shows the pressure patterns obtained when a specimen was subjected to one, two, and three contacts with the impacting mass. The number of impacts made by the steel balls were counted for each of the three cases. There were approximately 900 impact points after the first contact with the impacting mass. After two contacts, there were approximately 1450 points of impact. This latter figure indicate that there were approximately 560 new points of impact and 340 points of impact in areas previously hit. After the specimen was subjected to three contacts,

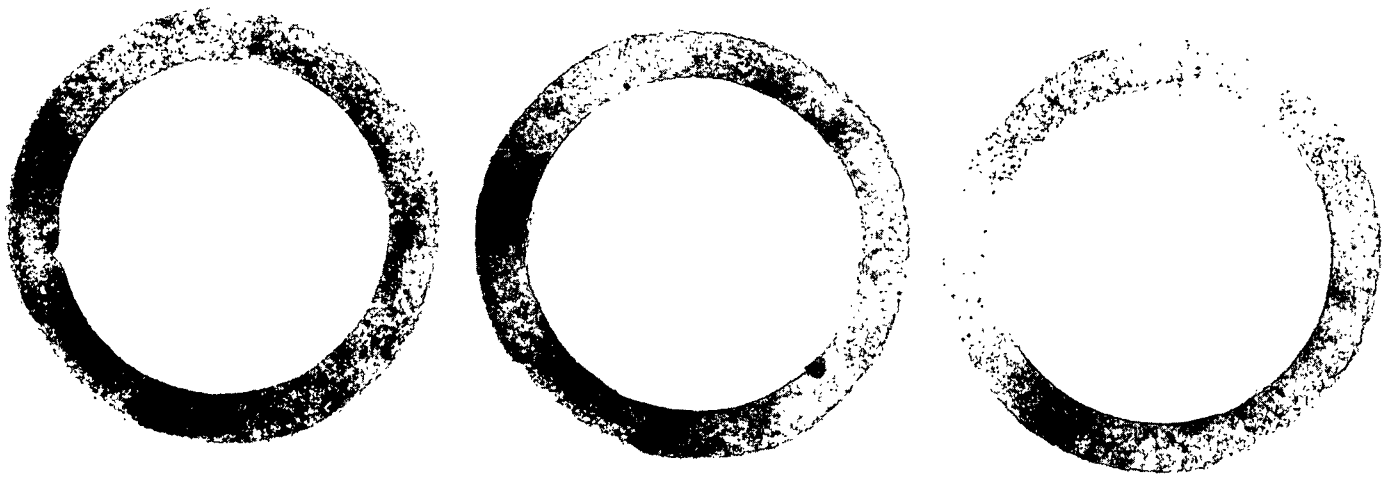
TABLE IV

THE EFFECT OF RIGID LIFT ARMS ON THE FRAG TEST RESULTS

| Sample Identification | Fiber Direction | Test Run 1: Falls to Failure Average | Test Run 1: Falls to Failure Range | Test Run 1: Burst Energy, $10^{-4}$kg.m. | Test Run 2: Falls to Failure Average | Test Run 2: Falls to Failure Range | Test Run 2: Burst Energy, $10^{-4}$kg.m. |
|---|---|---|---|---|---|---|---|
| 102 | Machine | 6.1 | 3-11 | 255 | 9.6 | 4-19 | 279 |
| | Across machine | 26.5 | 3-53 | 418 | 23.4 | 17-31 | 401 |
| 103 | Machine | 14.6 | 3-32 | 343 | 14.2 | 8-21 | 339 |
| | Across machine | 22.9 | 7-40 | 398 | 18.5 | 12-30 | 371 |



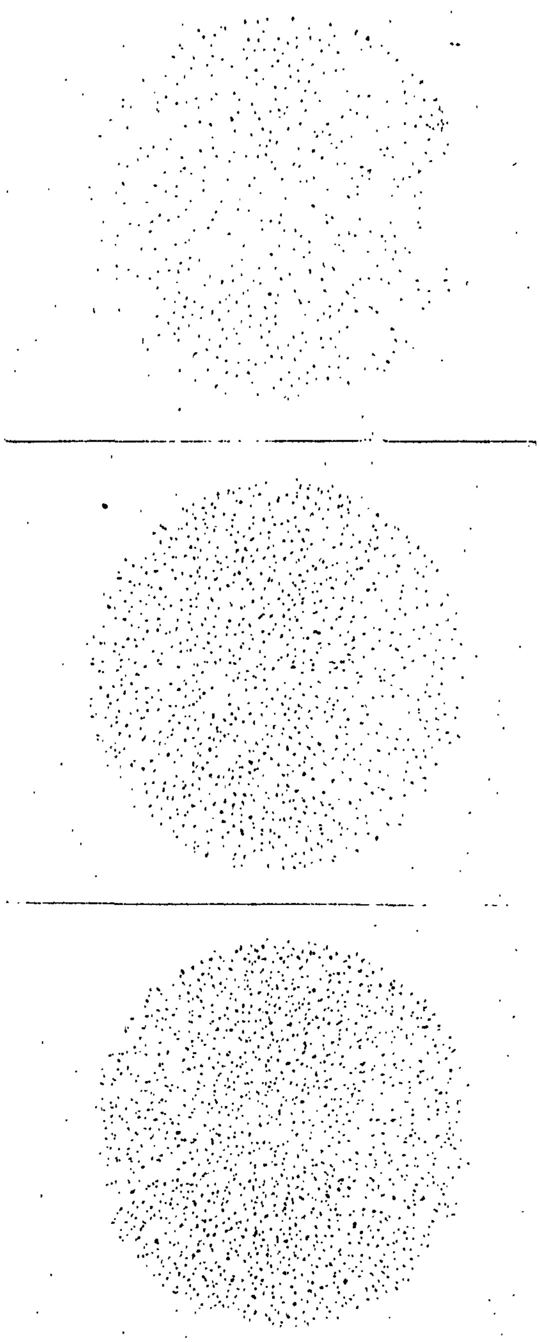
Impact Impressions Before Tightening Lift Arms



Impact Impressions After Tightening Lift Arms

Figure 6

Impact Patterns of Drop Assembly Hitting Impact Anvil with Lift Arms Loose and with Lift Arms Tightened by Means of Shims



| Number of Drops | Number of Impacts |
| --- | --- |
| 1 | 900 |
| 2 | 1450 |
| 3 | 1710 |

Figure 7

Impact Patterns Showing Distribution of Steel Balls approximately 1710 points of impact were noted. This means that there were about 250 new points of stress and about 650 points which were being stressed for either the second or third time. These impact patterns reveal that not all points of the specimen were equally stressed and that, as the number of drops or contacts increased, more points of the specimen underwent repeated stresses; however, the pattern of repeated stressing is more or less random. It may be possible that this random type of repeated stressing influences the variability associated with the number of drops required to rupture a specimen.

## OPERATIONAL VARIABLES

### Effect of Varying the Level of Input Energy to Check Ragossnig's Hypothesis

A study was conducted in which different levels of input energy were used to determine the validity of the empirical formula used by Ragossnig to relate drop number to burst energy. The energy levels were obtained by keeping the drop height constant (14 cm.), and varying the weight of the impacting mass as follows: 100, 150, 200, and 250 grams of steel balls. From the data obtained in this study, it was possible to check (1) Ragossnig's hypothesis that the cube root of the drop number is a function of the absolute burst energy (if the cube root of the drop number is a true function of absolute burst energy as Ragossnig's formula for converting drop number to burst energy indicates, then the data plotted on log-log paper should yield a straight line with a slope of 3.0), and (2) the ability of the Frag tester to yield the same absolute burst energy for a given sample of paper when different levels of input energy were used.

Six samples of sack paper from the materials in Group II (See Table I) were used in this study. Table V is a presentation of the data obtained for the machine direction tests on the Frag tester at different input energy levels. Table VI presents the data for the cross-machine direction tests.

The first objective of this portion of the study in which the level of input energy was varied was to check Ragossnig's hypothesis. Ragossnig's hypothesis, it may be recalled, states that the cube root of the number of drops required to rupture the paper (drop number) is a true function of the absolute burst energy and hence should yield a straight line with a slope of 3.0 when plotted on log-log paper. The formula used by Ragossnig to express this relationship is

$$\text{abs. B. E.} = \sqrt[3]{\underline{B}} \cdot \underline{h} \cdot \underline{g}$$

where abs. B. E. = absolute burst energy

$\underline{B}$ = number of drops to rupture the specimen

$\underline{h}$ = height of drop

$\underline{g}$ = weight of steel balls

In Figure 8 the relationship between the number of drops to rupture and input energy is plotted for each of six samples of bag paper at four different levels of input energy. These relationships, when plotted on log-log paper, are straight lines and the slopes of the lines are given in Figure 8 for tests made in the machine direction and in the cross-machine

## TABLE V

### MACHINE-DIRECTION FRAG TEST RESULTS OBTAINED AT FOUR DIFFERENT LEVELS OF IMPACT ENERGY

| | Levels of Input Energy, g.cm. | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 140 | | | 210 | | | 280 | | | 350 | | |
| Sample Identification | Falls to Failure Average | Falls to Failure Range | Burst Energy, $10^{-4}$kg.m. | Falls to Failure Average | Falls to Failure Range | Burst Energy, $10^{-4}$kg.m. | Falls to Failure Average | Falls to Failure Range | Burst Energy, $10^{-4}$kg.m. | Falls to Failure Average | Falls to Failure Range | Burst Energy, $10^{-4}$kg.m. |
| 100 | 7.5 | 3-16 | 274 | 3.4 | 2-4 | 316 | 1.9 | 1-3 | 346 | 2.0 | 1-3 | 441 |
| 101 | 35.4 | 27-45 | 458 | 11.4 | 8-17 | 473 | 4.3 | 3-6 | 455 | 1.8 | 1-3 | 426 |
| 102 | 6.8 | 4-10 | 265 | 4.3 | 3-5 | 341 | 2.3 | 2-3 | 369 | 2.1 | 2-3 | 448 |
| 103 | 8.7 | 5-14 | 288 | 6.0 | 4-8 | 382 | 3.0 | 2-4 | 403 | 2.2 | 2-3 | 455 |
| 104 | 69.6 | 38-104 | 577 | 17.0 | 11-24 | 540 | 7.0 | 6-8 | 535 | 4.8 | 4-6 | 590 |
| 105 | 280.8 | 249-311 | 917 | 40.0 | 30-57 | 718 | 18.7 | 12-26 | 743 | 13.9 | 10-19 | 842 |

## TABLE VI

### CROSS-MACHINE DIRECTION FRAG TEST RESULTS OBTAINED AT FOUR DIFFERENT LEVELS OF IMPACT ENERGY

Levels of Input Energy, g. cm.

| Sample Identification | 140 | | | 210 | | | 280 | | | 350 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Falls to Average | Failure Range | Burst Energy, $10^{-4}$ kg.m. | Falls to Average | Failure Range | Burst Energy, $10^{-4}$ kg.m. | Falls to Average | Failure Range | Burst Energy, $10^{-4}$ kg.m. | Falls to Average | Failure Range | Burst Energy, $10^{-4}$ kg.m. |
| 100 | 16.1 | 12-22 | 354 | 7.8 | 6-11 | 416 | 4.4 | 3-6 | 458 | 3.3 | 2-4 | 521 |
| 101 | 76.5 | 60-93 | 593 | 19.3 | 14-26 | 563 | 7.4 | 5-11 | 546 | 3.1 | 2-4 | 510 |
| 102 | 20.2 | 14-28 | 381 | 11.2 | 7-18 | 470 | 5.6 | 3-8 | 497 | 2.5 | 2-4 | 475 |
| 103 | 41.0 | 24-59 | 483 | 13.2 | 10-17 | 496 | 5.9 | 5-7 | 505 | 3.3 | 3-4 | 521 |
| 104 | 62.3 | 44-89 | 554 | 14.0 | 9-19 | 506 | 6.4 | 5-8 | 520 | 4.3 | 4-5 | 569 |
| 105 | 44.6 | 36-57 | 498 | 14.7 | 11-20 | 514 | 7.0 | 5-9 | 535 | 6.1 | 5-7 | 640 |

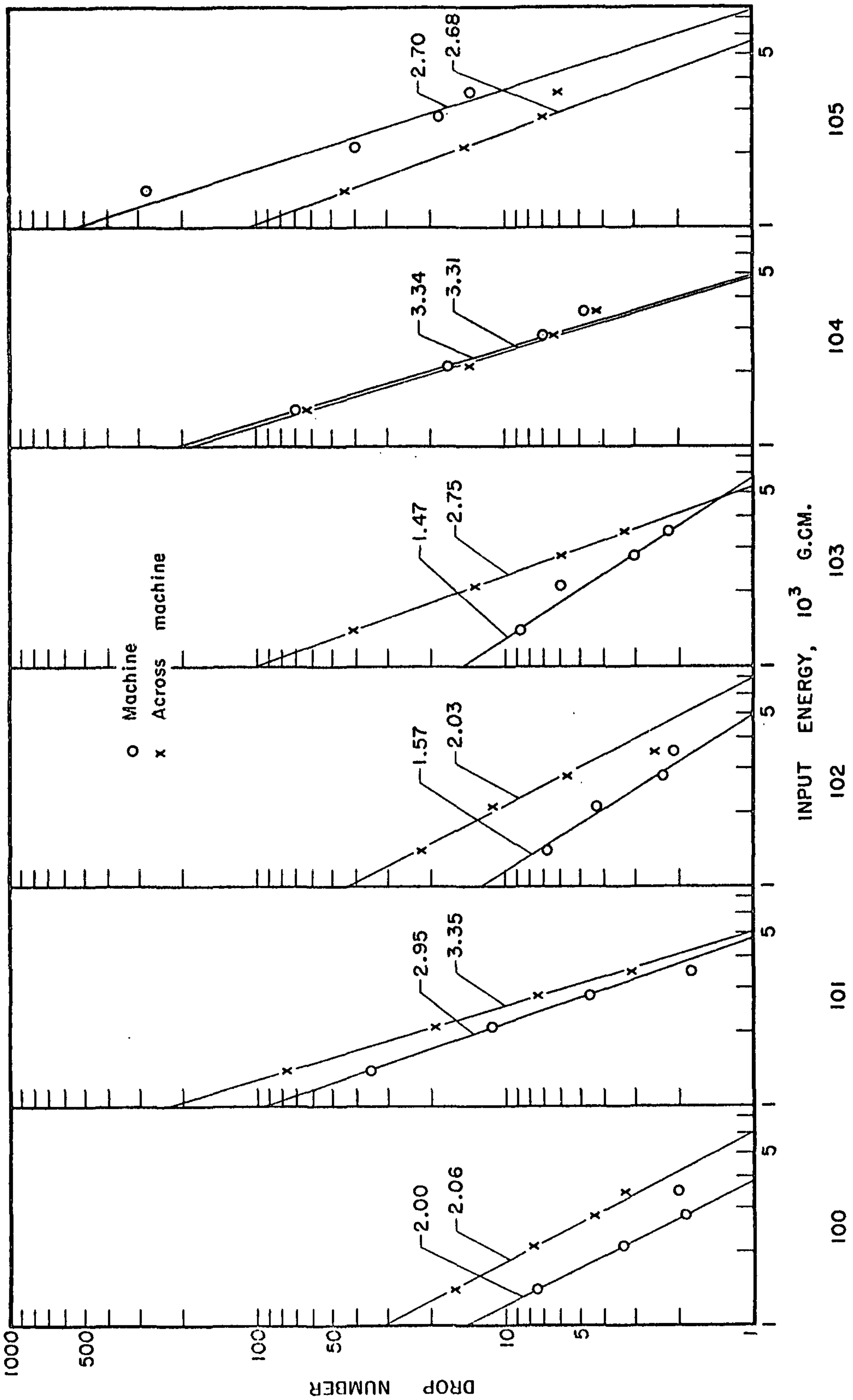



Figure 8. Relationship Between Number of Drops to Rupture and Impact Energy for Each of Six Samples of Sack Paper

direction. It may be noted in Figure 8 that these slopes are not <u>three</u> as Ragossnig suggested. Instead, each material appears to be associated with its own characteristic slope as indicated by the observation that, for a given sample, the slopes for machine direction and cross-machine direction tests are nearly the same. The guiding philosophy in determining how the various lines should be drawn was to place more emphasis on the points associated with low input energies. The reason for this is covered more fully later in this discussion.

Figure 9 is a composite plot for the six samples included in this study and shows the relationship between the number of drops to rupture and impact energy. From this graph it may be noted that the composite slope for the machine direction tests was 2.73 and for the cross-machine direction tests, 2.87. These composite results are based on the data for six different samples, only one of which was associated with slope data which approximate the composite slopes.

The results which are shown in Figures 7 and 8 indicate that the drop number is an exponential function of the input energy. They do not, however, indicate that for all grades of a material such as kraft sack paper there is one exponent which adequately describes the relationship between drop number and impact energy for that material undergoing an impact fatigue type of test. It suggests rather that each sample of paper has an individual exponent that characterizes the relationship between the drop number and impact energy. This observation appears to be substantiated by the fact that the results obtained in the two principal directions of the paper have slopes which are nearly the same.

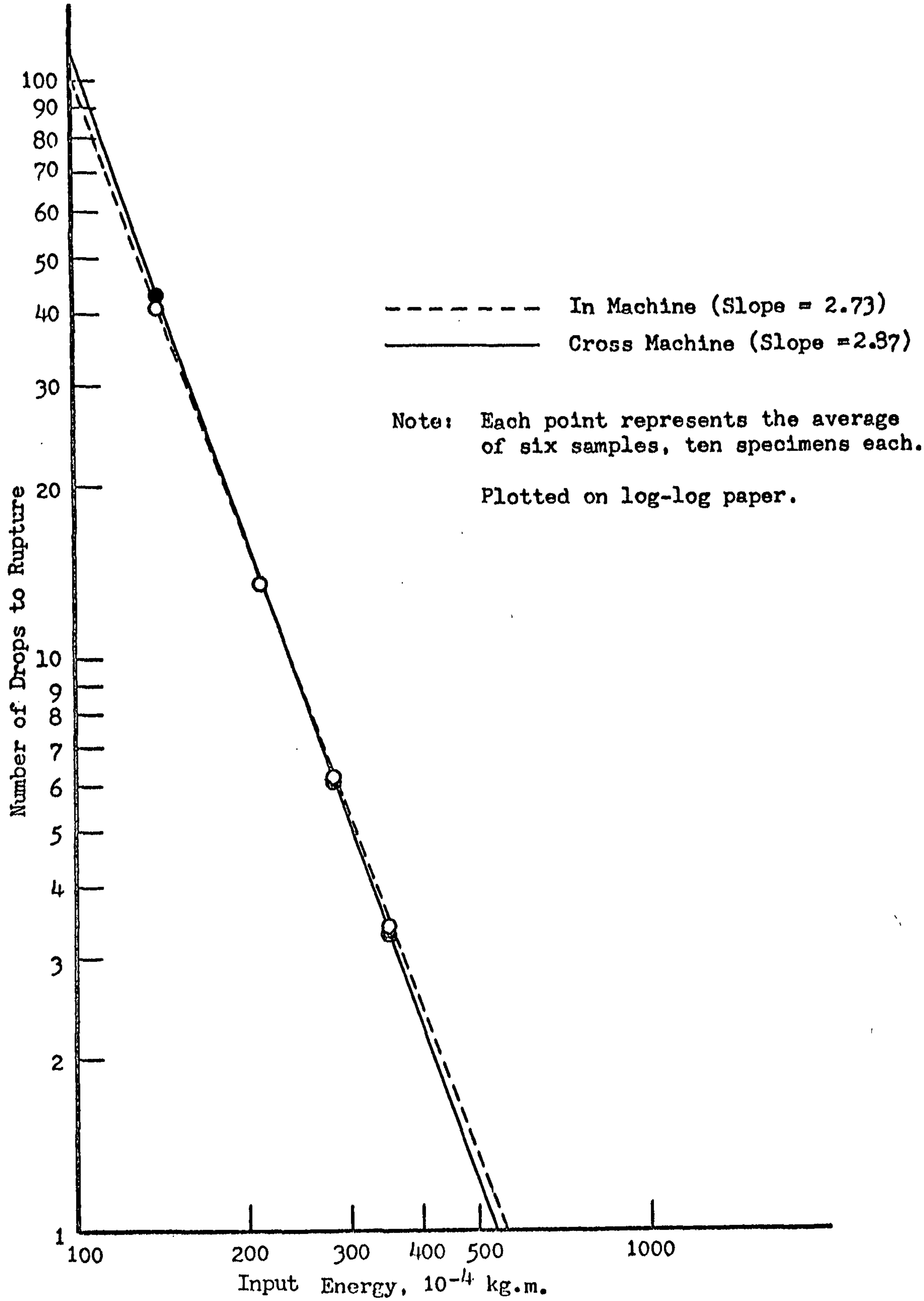



Figure 9. Composite Plot of the Relationship Between Number of Drops to Rupture and Input Energy

It has been noted that the exponents for different grades of sack paper are different. Therefore, if an improper exponent were used in calculating absolute burst energy, a certain error would be introduced for a given number of drops and would increase as the number of drops increased. If Ragossnig's slope of 3.0 were used to calculate absolute burst energy in place of the composite slopes for the six samples in this study (2.73 for the machine direction and 2.87 for the cross-machine direction), an error of approximately 12% would be introduced for the machine direction and an error of 5% would be introduced for the cross-machine direction (both of these errors being based on 31 drops). If Ragossnig's slope of 3.0 were used in place of the slope data for individual grades in Figure 8, larger errors would be introduced. Sample 102, for example, has slopes of 1.57 and 2.03 in the machine and cross-machine directions. Use of Ragossnig's 3.0 in place of these slopes would give an error of 184% in the absolute burst energy for the machine direction specimens and an error of 73% in the absolute burst energy for the cross-machine direction specimens (based again on 31 drops).

The different slopes obtained for different grades of sack paper indicate that use of a constant slope of 3.0, as Ragossnig has done, will involve a certain amount of error in calculating the absolute burst energy. The errors which might be introduced by the use of a constant slope could be different for different materials and make reliable comparisons difficult.

The second objective of this investigation was to check the ability of the Frag tester to yield the same absolute burst energy for a given sample of paper when different levels of input energy were used.

When the data in Tables V and VI are examined, it may be seen that the different levels of input energy ranked the samples almost the same way. The highest level of input energy, 250 grams dropped 14 cm., however, did result in a slightly different ranking of the samples than did the remaining three energy levels. Why should the data for the high energy level rank the samples somewhat differently? The answer may lie in the observation that only a few drops were required to break the specimen. Hence, a specimen breaking in two or three drops perhaps might have broken from only a portion of the input energy it was subjected to on the final drop; therefore, the burst energy may be fictitiously large. This observation might also hold true with regard to the final drop at any energy level where only a portion of the input energy on the last drop was required to break the specimen. However, because the burst energy obtained with the Frag tester is related by Ragossnig's formula to the cube root of the drop number, the influence of the drop number is more pronounced when it is small. This observation was kept in mind when the log-log plots (previously discussed in the first part of this section) were prepared. The data in Tables V and VI also show that even though the sample ranking is relatively uniform for all energy levels, the greater the energy level, the greater is the tendency to obtain a high burst energy of the paper. This tendency to obtain a high burst energy did not occur in every case; one-half of the data showed an upward trend, while one-twelfth showed a downward trend and the remainder of the data appeared to show no definite trend. This observation indicates that for most testing purposes the same levels of input energy should be used in order to avoid any effects which may be peculiar to one energy level.

Effect of Particle Size in the Impacting Mass

The steel balls which comprise the impacting mass used with the Frag tester ranged in diameter from 1/32 to 1/16 inch. There appears to be no information in the literature on the effect of particle size in the impacting mass. Therefore, it may be of interest to investigate what happens when the energy level at which the paper is being stressed is held constant, but the size of steel ball which applies the stress is varied. Figure 10 is a bar graph of data given in Table VII in which a comparison is made of the data obtained (1) with an impacting mass of the regular mixture of 1/32 to 1/16-inch steel balls, (2) with an impacting mass of 5/32-inch steel balls, and (3) with an impacting mass of 7/32-inch steel balls. In each case the impacting mass weighed 100 g. and was dropped from a height of 14 cm.

From the bar graph shown in Figure 10, it may be seen that in most cases the larger the steel ball size used, the lower was the apparent burst energy of the sample. The biggest decrease in burst energy was noted between the normal testing mixture and the 5/32-inch size of steel balls.

It may be noted in Figure 10 that only one of the six samples failed to show this decrease. A smaller decrease was noted between the burst energy obtained with the 5/32-inch steel balls and that obtained with the 7/32-inch steel balls. These decreases in burst energy when larger size balls were used might be anticipated inasmuch as fewer points of contact would be experienced; hence, higher localized stresses might result. With higher localized stresses, fewer applications of this stress might be required to rupture the specimen. This may explain why Sample 105, which had

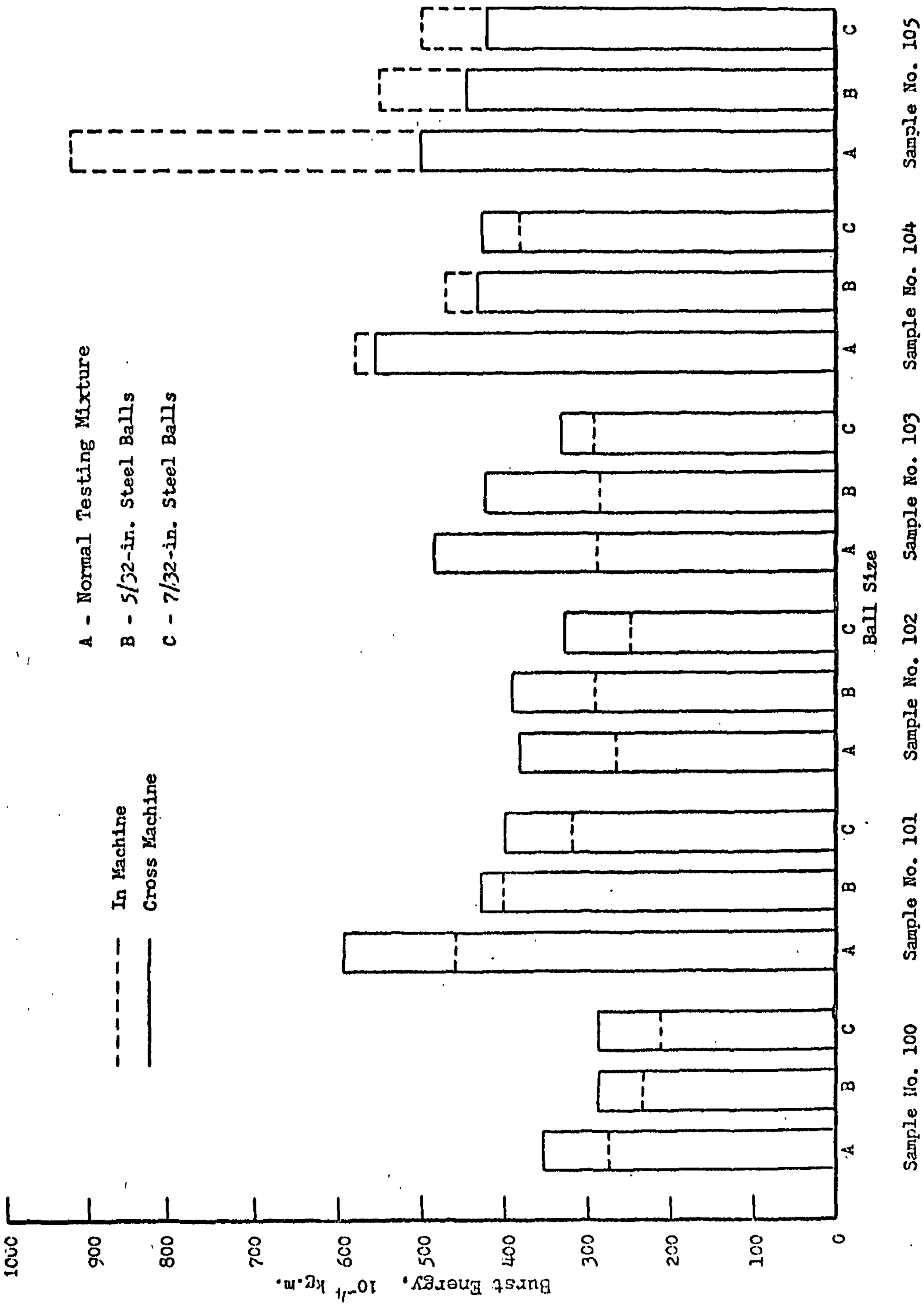



Figure 10

Relationship Between Burst Energy and the Size of Steel Balls in the Impacting Mass

TABLE VII

FRAG TEST RESULTS OBTAINED WITH IMPACTING MASSES

COMPRISED OF VARIOUS SIZES OF STEEL BALLS

| Sample No. | Fiber Direction | Regular Mixture, 1/32 to 1/16: Falls to Failure Av. | Regular Mixture: Falls to Failure Range | Regular Mixture: Burst Energy, $10^{-4}$ kg.m. | 5/32: Falls to Failure Av. | 5/32: Falls to Failure Range | 5/32: Burst Energy, $10^{-4}$ kg.m. | 7/32: Falls to Failure Av. | 7/32: Falls to Failure Range | 7/32: Burst Energy, $10^{-4}$ kg.m. |
|---|---|---|---|---|---|---|---|---|---|---|
| 100 | Machine | 7.5 | 3 to 16 | 274 | 4.6 | 4 to 5 | 233 | 3.5 | 2 to 4 | 212 |
| | Cross machine | 16.1 | 10 to 22 | 354 | 8.6 | 7 to 10 | 287 | 8.6 | 7 to 11 | 287 |
| 101 | Machine | 35.0 | 29 to 45 | 458 | 23.4 | 19 to 30 | 401 | 11.7 | 10 to 15 | 318 |
| | Cross machine | 76.5 | 60 to 93 | 593 | 28.5 | 24 to 36 | 428 | 23.2 | 18 to 28 | 399 |
| 102 | Machine | 6.8 | 4 to 10 | 265 | 8.9 | 5 to 13 | 290 | 5.5 | 4 to 9 | 247 |
| | Cross machine | 20.2 | 14 to 28 | 381 | 21.6 | 10 to 29 | 390 | 12.7 | 9 to 17 | 327 |
| 103 | Machine | 8.7 | 5 to 14 | 288 | 8.5 | 6 to 10 | 285 | 9.0 | 6 to 13 | 291 |
| | Cross machine | 41.0 | 24 to 62 | 483 | 27.3 | 22 to 33 | 422 | 13.2 | 10 to 17 | 331 |
| 104 | Machine | 69.6 | 38 to 104 | 577 | 37.1 | 31 to 47 | 469 | 19.9 | 11 to 32 | 380 |
| | Cross machine | 62.3 | 44 to 89 | 554 | 29.2 | 21 to 34 | 431 | 27.9 | 23 to 32 | 425 |
| 105 | Machine | 280.8 | 249 to 311 | 917 | 59.6 | 45 to 80 | 547 | 44.6 | 39 to 53 | 496 |
| | Cross machine | 44.6 | 36 to 57 | 498 | 31.4 | 20 to 43 | 442 | 26.6 | 20 to 33 | 418 |

a high machine-direction stretch, showed a large decrease in machine-direction results when the larger sizes of steel balls were used.

The initial work on the effect of varying the particle size in the impacting mass was completed with the original drop assembly. After the new assembly was received and adjustments had been made to obtain as flat a drop as possible, additional work was undertaken with regard to the effect of the composition of the impacting mass. Test specimens were taken from two sack paper samples used in the earlier study--namely, Samples 102 and 103. Four different impacting masses were used. The first was the regular testing mixture supplied with the tester; the second was limited to steel balls which were 1/32 inch in diameter, the third to steel balls 1/16 inch in diameter, and the fourth to steel balls 3/32 inch in diameter. As in the previous study, the impacting mass weighed 100 g. and was dropped from a height of 14 cm. The burst energy results obtained for each of these four different impacting masses are shown in Table VIII and presented graphically in Figure 11. It may be noted from an inspection of these results that no significant difference appeared to be evident. It may be recalled from the earlier study in which three impacting masses were used--(1) the regular testing mixture, (2) steel balls 5/32 inch in diameter, and (3) steel balls 7/32 inch in diameter--that lower burst energies were noted for the impacting mass of larger steel balls. The fact that this trend was not evident in this continuation of that study may be related to the rather narrow range of ball sizes used.

As a further check on the effect of particle size in the impacting mass, Samples 102 and 103 were tested with an impacting mass of No. 40 silicon carbide grit. High drop numbers were obtained, being in the approximate range

## TABLE VIII

### SUPPLEMENTARY FRAG TEST RESULTS OBTAINED WITH IMPACTING MASSES COMPRISED OF VARIOUS SIZES OF STEEL BALLS

Ball Diameter, inches

| Sample No. | Direction | Regular Mixture, 1/32 to 1/16: Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$ kg.m. | 1/32: Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$ kg.m. |
|---|---|---|---|---|---|---|---|
| 102 | Machine | 9.6 | 4 to 19 | 279 | 11.0 | 6 to 18 | 312 |
| | Cross machine | 23.4 | 17 to 31 | 401 | 19.6 | 8 to 29 | 378 |
| 103 | Machine | 14.2 | 8 to 21 | 339 | 27.1 | 18 to 38 | 421 |
| | Cross machine | 18.5 | 12 to 30 | 371 | 25.8 | 16 to 39 | 414 |

Ball Diameter, inches

| Sample No. | Direction | 1/16: Falls to Failure | | Burst Energy, | 3/32: Falls to Failure | | Burst Energy, |
|---|---|---|---|---|---|---|---|
| 102 | Machine | 16.4 | 8 to 23 | 356 | 8.6 | 4 to 17 | 287 |
| | Cross machine | 29.9 | 20 to 41 | 435 | 25.8 | 14 to 41 | 414 |
| 103 | Machine | 16.1 | 10 to 25 | 354 | 20.6 | 16 to 28 | 384 |
| | Cross machine | 24.2 | 15 to 34 | 405 | 24.7 | 6 to 39 | 408 |

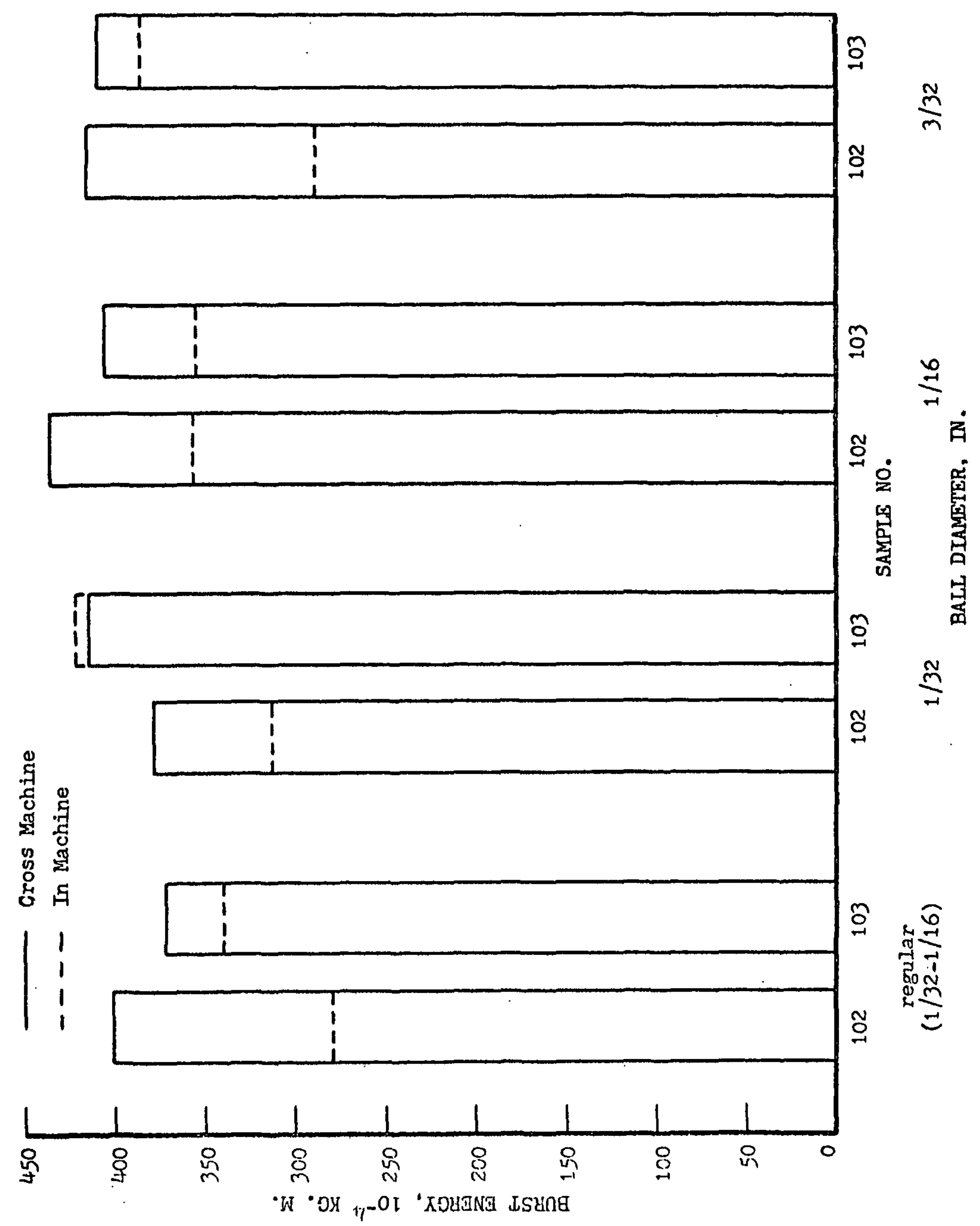



Figure 11

Relationship Between Burst Energy and the Size of Steel Balls in the Impacting Mass of three to twenty times those obtained with the regular testing mixture. This may be due to high energy absorption within the impacting mass as the particles rub against other particles. If this should be the reason, it would indicate that the type of materials packaged in sacks may exert a considerable influence on how much rough handling the sack will take before it fails. Tests were also made with an impacting mass of No. 600 silicon carbide powder and the drop numbers were even higher than were obtained for the No. 40 silicon carbide grit. Only a few tests were made because the powder could not be contained in the holder without some leakage. The test results indicated that the values obtained with the Frag tester appeared to be dependent upon the material used in the impacting mass. The type of failure noted for the silicon carbide powder and grit was generally an edge type shear as opposed to the central fatigue type rupture of fibers and fiber bonds associated with the regular impacting mass of steel balls. Only the machine direction of Sample 102 failed with silicon carbide in the same way it failed with steel balls. It might be conjectured that, if it were possible to obtain a fatigue type failure with silicon carbide powder in place of the observed shear type of failure, higher values of drop number might have been obtained.

Effect of Drop Height

Two methods can be used to attain different levels of input energy with the Frag tester. One of these, which has already been discussed, involves using impacting masses of different weights. The second method, which is the subject of this phase of the instrumentation study, involves using different heights of drop. Two drop heights are readily available on the Frag tester by simply changing the impact anvils upon which the specimen holder is dropped.

These heights are 14 and 21 cm. Six samples of sack paper (Group II of Table I) were evaluated at these two drop heights with a constant impacting mass. The results obtained are given in Table IX and presented in the form of a bar graph in Figure 12. It may be noted in Figure 12 that no clear-cut trend is evident. In some cases, burst energy increased with an increase in drop height; in other cases the opposite trend was noticed. On the basis of composite results for the six samples of sack paper included in this study, a 1-3/4% decrease was observed for the machine direction test results when the drop height was increased from 14 cm. to 21 cm. Similarly, a 3-3/4% increase was observed for the cross-machine direction test results when the drop height was increased this same amount. It appears that a change in drop height of the magnitude studied did not significantly change the burst energies of the samples used in this work. It should also be noted that the change in drop height between 14 and 21 cm. is only 7 cm. or 2.76 inches. This change in drop height has a relatively modest effect on the impact velocity. At a drop height of 14 cm. the impact velocity is approximately 5.5 ft. per sec., and at a drop height of 21 cm., the impact velocity is approximately 6.5 ft. per sec.

## Effect of Clamping Technique

As mentioned previously, it was necessary to replace the specimen holder after the instrumentation study was underway. It was found that the test results obtained with the new holder were different from those obtained with the original folder. A study was undertaken to determine if clamping technique might be responsible for these differences.

TABLE IX

FRAG TEST RESULTS AT DROP HEIGHTS OF 14 CM. AND 21 CM.

FOR SIX DIFFERENT SACK PAPERS

| Sample No. | Fiber Direction | 14 cm. Falls to Failure Av. | 14 cm. Falls to Failure Range | 14 cm. Burst Energy, $10^{-4}$ kg.m. | 21 cm. Falls to Failure Av. | 21 cm. Falls to Failure Range | 21 cm. Burst Energy, $10^{-4}$ kg.m. |
|---|---|---|---|---|---|---|---|
| 100 | Machine | 7.5 | 3 to 16 | 274 | 2.3 | 2 to 3 | 277 |
| | Cross machine | 16.1 | 10 to 22 | 354 | 8.0 | 6 to 10 | 420 |
| 101 | Machine | 35.0 | 29 to 45 | 458 | 9.3 | 5 to 14 | 442 |
| | Cross machine | 76.5 | 60 to 93 | 593 | 12.7 | 9 to 18 | 490 |
| 102 | Machine | 6.8 | 4 to 10 | 265 | 2.4 | 2 to 3 | 281 |
| | Cross machine | 20.2 | 14 to 28 | 381 | 8.1 | 6 to 12 | 422 |
| 103 | Machine | 8.7 | 5 to 14 | 288 | 4.5 | 3 to 6 | 347 |
| | Cross machine | 41.0 | 24 to 62 | 483 | 8.8 | 8 to 11 | 434 |
| 104 | Machine | 69.6 | 38 to 104 | 577 | 12.7 | 10 to 16 | 490 |
| | Cross machine | 62.3 | 44 to 89 | 554 | 9.2 | 7 to 13 | 440 |
| 105 | Machine | 280.8 | 249 to 311 | 917 | 44.0 | 33 to 56 | 741 |
| | Cross machine | 44.6 | 36 to 57 | 498 | 12.6 | 10 to 17 | 489 |

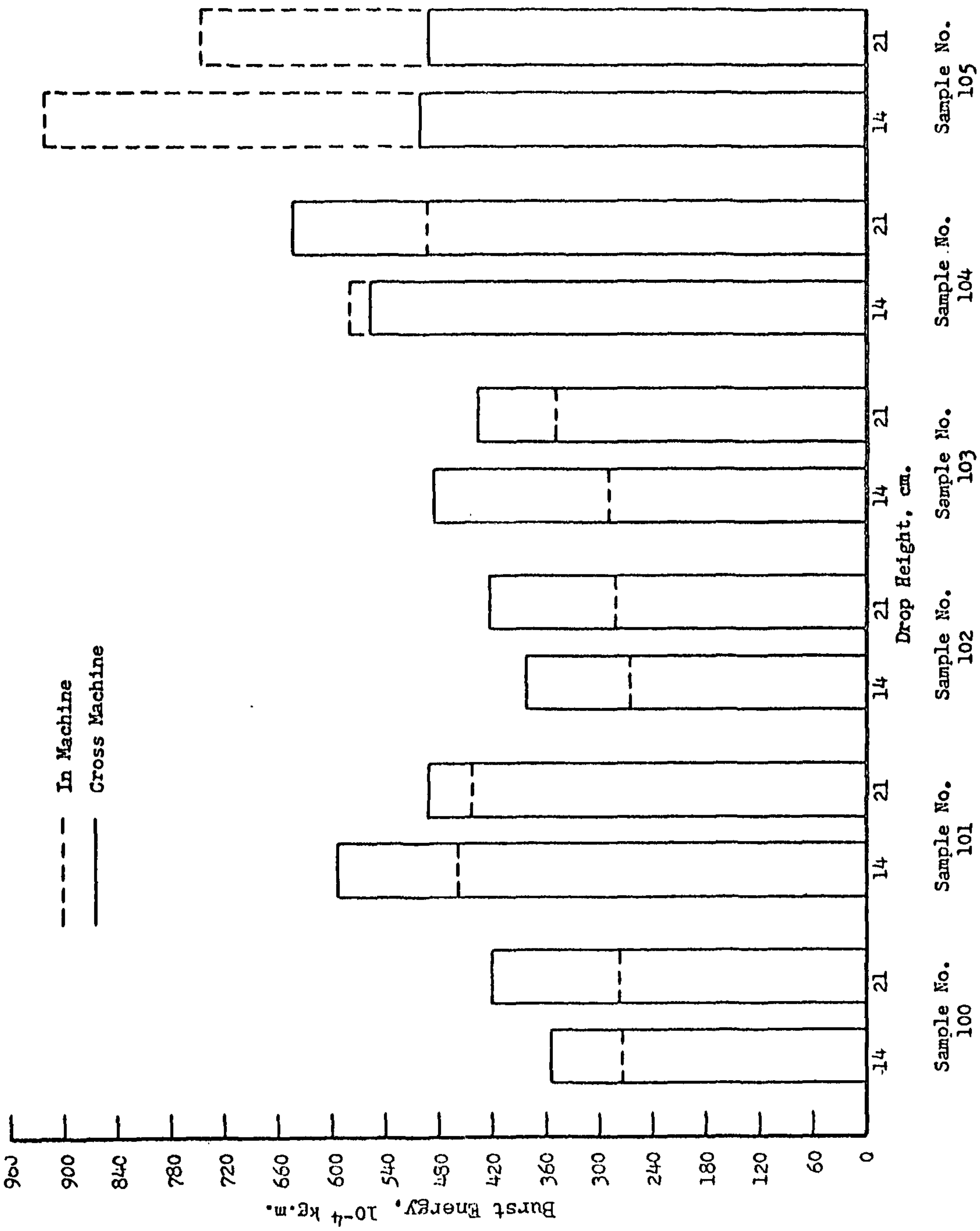



Figure 12

Comparison of Burst Energy at Drop Heights of 14 and 21 cm.
for Six Samples of Sack Paper

The new specimen holder differed from the original assembly in that a locking arrangement had been incorporated. The locking arrangement was an improvement because it permitted the two halves of the specimen holder to be held together throughout the test with a degree of tightness that did not change during the test. (See Figure 3.) Disadvantages of the improved replacement specimen holder were (1) the thumbscrews could not be tightened easily and (2) there was no easy way to maintain a predetermined torque because the clearance between platens is controlled by a limited number of settings on the locking device. This latter disadvantage did not seem too important in view of the fact that the original specimen holder, even when the thumbscrews were adjusted with the same torque, would not maintain the set torque under test conditions. Hence, clamping pressure changed during the test.

The introduction of the new drop assembly made it necessary to compare the test results obtained with it to those obtained with the original assembly. Six samples of sack paper from Group II in Table I, which had been evaluated with the original drop assembly, were re-evaluated with the new drop assembly, the test conditions being the same in each case--namely, a drop height of 14 cm. and an impacting mass of 100 g. (regular test mixture of steel balls). The test results for the original and new drop assemblies are shown in Table X. It appears from an inspection of these data that the burst energy results in most cases were higher for the new drop assembly than for the original. Sample 104 was an exception to this observation for both the machine and cross-machine direction comparisons; Sample 105 was an exception for the machine-direction comparison only, and Sample 103 was an exception for the cross-machine direction comparison only. When the results for the six samples were averaged, it was found that the burst energy results for

TABLE X

FRAG TEST RESULTS OBTAINED WITH THE ORIGINAL DROP ASSEMBLY AND WITH THE NEW DROP ASSEMBLY

| Sample Identi-fication | Original Drop Assembly | | | | | | New Drop Assembly | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | In Machine | | | Cross Machine | | | In Machine | | | Cross Machine | | |
| | Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$ kg.m. | Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$ kg.m. | Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$ kg.m. | Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$ kg.m. |
| 100 | 7.5 | 3 to 16 | 274 | 16.1 | 10 to 22 | 354 | 8.0 | 6 to 9 | 280 | 28.3 | 18 to 37 | 427 |
| 101 | 35.0 | 27 to 45 | 458 | 76.5 | 60 to 93 | 593 | 46.0 | 32 to 66 | 502 | 132.4 | 44 to 243 | 713 |
| 102 | 6.8 | 4 to 10 | 265 | 20.2 | 14 to 28 | 381 | 12.6 | 9 to 16 | 326 | 42.8 | 20 to 61 | 490 |
| 103 | 8.7 | 5 to 14 | 288 | 41.0 | 24 to 62 | 483 | 19.7 | 9 to 28 | 378 | 36.5 | 12 to 77 | 462 |
| 104 | 69.6 | 38 to 104 | 577 | 62.3 | 44 to 89 | 554 | 65.2 | 35 to 121 | 563 | 44.3 | 20 to 107 | 494 |
| 105 | 280.8 | 249 to 311 | 911 | 44.6 | 36 to 57 | 498 | 210.6 | 43 to 332 | 835 | 76.9 | 18 to 141 | 596 |

the new drop assembly were approximately 11% higher than those for the original. In addition to the trend to higher values of burst energy, it was noted that the range of drop numbers obtained with the new drop assembly was greater than that obtained with the original assembly. This was especially evident for the cross-machine direction results.

The observation noted above with regard to the higher burst energy values obtained with the new drop assembly prompted a number of investigations into factors that might be contributing to the increase. The first of these investigations concerned variables associated with the clamping of the specimen. The following variables were studied: (1) clamping pressure, (2) use of Carborundum paper attached to the platens with different types of bond, (3) use of Carborundum papers with different sizes of grit, and (4) the effect of varying the free specimen span. The first variable studied was clamping pressure. Four different pressures were achieved by adjusting the locking mechanism of the new drop assembly. Specifically, the thumbscrews provided on the locking mechanism were locked in four different positions. Each position permitted a given constant clearance to be maintained between the platens. This was the only means by which different clamping pressures could be attained. Under a system of this kind, the thickness of the specimen being tested would be expected to influence the pressure between the platens. Pressure patterns were made with a carbon paper for each of the four clearances that were used; these patterns are shown in Figure 13. Two samples of sack paper from Group II materials in Table I--Sample 102 and Sample 103--were tested on the Frag tester at each of the four clamping pressures. Clamping strips 0.95 inch in width of 280 A grit Carborundum paper were attached to the platens of the specimen holder with Duco cement. The test results obtained are shown

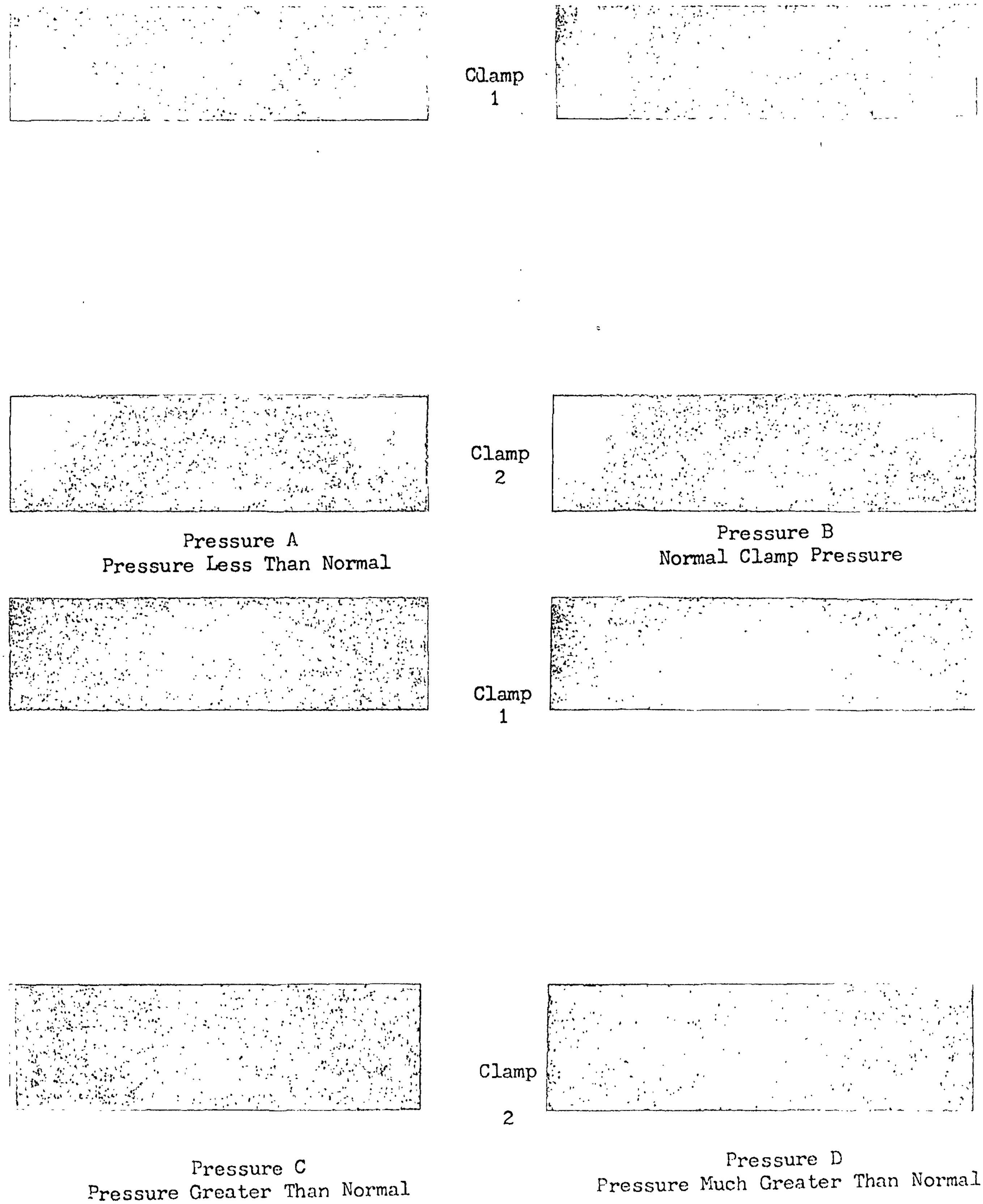



Figure 13

Clamping Pressure Patterns at Different Clearances Between Platens in Table XI where it may be noted that the test results did not exhibit a definite trend. It appears, however, that the lowest pressure (greatest clearance between platens) was associated with the highest values of burst energy and also with high values of range for the drop number for three of the four comparisons. This might be expected because the test specimen may have freedom to slip. At the highest clamping pressure (smallest clearance between platens) it was observed that both the drop number range and the burst energy results were high for the cross-machine direction. There was no apparent reason for this observed phenomenon. It may be noted in Table XI that the two intermediate clamping pressures designated by the letters B and C appeared to give the most uniform test results on the basis of drop number range and the magnitude of the burst energy results. Of clamping pressures B and C, pressure B had generally smaller drop number ranges than pressure C. For this reason, clamping pressure B was chosen to be used for future work.

The second variable to be studied in connection with the clamping of the specimen was the effect of the method of attaching strips of Carborundum paper to the platens of the specimen holder. For the present investigation, strips of 280 A grit Carborundum paper 0.95 inch in width were attached to the platens of the specimen holder with double-face tape. The test results obtained when the strips were attached in this way were compared with the test results obtained when corresponding strips were attached with Duco cement. Clamping pressure B of Table XI was used. The Frag test results for this study are given in Table XII. It may be observed in Table XII that there were four comparisons, two in the machine direction and two in the cross-machine direction. The machine-direction comparisons both were associated with lower burst energy results for the method of attachment which utilized

TABLE XI

FRAG TEST RESULTS OBTAINED AT FOUR DIFFERENT CLAMPING PRESSURES

| | | Clamping Pressures | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | | | B | | | C | | | D | | |
| Sample Identification | Fiber Orientation | Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$ kg.m. | Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$ kg.m. | Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$ kg.m. | Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$ kg.m. |
| 102 | Machine | 29.8 | 9 to 54 | 434 | 14.0 | 8 to 25 | 338 | 15.0 | 8 to 24 | 345 | 16.7 | 7 to 30 | 360 |
| | Cross machine | 46.5 | 6 to 92 | 502 | 34.3 | 14 to 51 | 454 | 39.7 | 5 to 81 | 479 | 59.8 | 9 to 120 | 548 |
| 103 | Machine | 64.9 | 9 to 129 | 563 | 23.4 | 18 to 36 | 401 | 21.9 | 11 to 45 | 392 | 25.6 | 19 to 32 | 413 |
| | Cross machine | 35.6 | 16 to 60 | 462 | 37.8 | 12 to 60 | 471 | 38.5 | 10 to 131 | 471 | 46.6 | 24 to 103 | 505 |

Clamping pressures are identified by pressure patterns in Figure 13.

A - The greatest clearance allowable between platens without letting the smallest steel balls roll out between the platens.
B - One locking cog tighter than A.
C - Two locking cogs tighter than A.
D - Three locking cogs tighter than A, and represents the smallest clearance which can be attained by turning the thumbscrews without the aid of a wrench.

TABLE XII

FRAG TEST RESULTS OBTAINED FOR TWO METHODS OF ATTACHING CLAMPING STRIPS TO THE PLATENS

| Sample Identification | Fiber Orientation | Carborundum Paper Adhered with Duco Cement | | | Carborundum Paper Adhered with Double-face Tape | | |
|---|---|---|---|---|---|---|---|
| | | Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$ kg.m. | Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$ kg.m. |
| 102 | Machine | 14.0 | 8 to 25 | 338 | 22.6 | 16 to 29 | 396 |
| | Cross machine | 34.3 | 14 to 51 | 454 | 40.1 | 25 to 50 | 479 |
| 103 | Machine | 23.4 | 18 to 36 | 401 | 44.9 | 27 to 97 | 498 |
| | Cross machine | 37.8 | 12 to 60 | 471 | 30.3 | 12 to 44 | 435 |

Duco cement. Of the two cross-machine direction comparisons, one was associated with lower burst energy for the method of attachment which utilized double-face tape. Of these four comparisons, three gave lower burst energy results for the method of attachment which utilized Duco cement. This tendency to obtain lower burst energy results for the method of attachment which utilized Duco cement may be explained by the observation that the double-face tape may have a greater tendency to creep than the Duco cement has. Creep might permit movement of the specimen in the clamp and in this way result in higher values of burst energy. On the basis of the results obtained in this study, preference would be given to the method of attachment which utilized Duco cement.

The third variable to be studied in connection with the clamping of the specimen was the effect of the size of the Carborundum grit associated with the clamping strips. To study this variable, tests were made with strips of Carborundum grit of two sizes: 280-A and 400-A. Clamping pressure B was used, the width of the strips was 0.95 inch, and the method of attachment utilized Duco cement. The test results for this study into the effect of the size of the Carborundum grit associated with the clamping strip are shown in Table XIII. These results indicate that there was not a great difference in burst energy between tests made with 280-A and 400-A grit Carborundum paper, 400-A being the finer grit. However, the drop number range appeared to be smaller in most cases for the results associated with the finer grit.

The fourth variable to be studied in connection with the clamping of the specimen was the effect of varying the free specimen span by changing the width of the clamping strips. The width of clamping strips supplied with the original

TABLE XIII

FRAG TEST RESULTS OBTAINED WITH CLAMPING STRIPS OF 280-A GRIT AND 400-A GRIT CARBORUNDUM PAPER

| Sample Identification | Fiber Orientation | Carborundum Grit Size: 280-A, Falls to Failure Av. | 280-A, Falls to Failure Range | 280-A, Burst Energy, $10^{-4}$ kg.m. | 400-A, Falls to Failure Av. | 400-A, Falls to Failure Range | 400-A, Burst Energy, $10^{-4}$ kg.m. |
|---|---|---|---|---|---|---|---|
| 102 | Machine | 14.0 | 8 to 25 | 338 | 11.7 | 8 to 16 | 318 |
| | Cross machine | 34.3 | 14 to 51 | 454 | 31.0 | 8 to 40 | 440 |
| 103 | Machine | 23.4 | 18 to 36 | 401 | 30.0 | 24 to 43 | 435 |
| | Cross machine | 37.8 | 12 to 60 | 471 | 38.1 | 30 to 54 | 471 |

holder was 0.75 inch, whereas the width of the clamping strips supplied with the new holder was 0.95 inch. The difference in width was small; but when the strips supplied with the new drop assembly were placed in the holder so that they were flush with the outer edge of the platen, the unclamped width of specimen was decreased 0.4 inch. To study what effect the width of the clamping strips might have on the test results, tests were made with strips that were 0.7, 0.8, and 0.95 inch in width. The strips were cut from 280-A grit Carborundum paper and were attached to the platen with Duco cement. The Frag test results obtained in this study are shown in Table XIV and illustrated by means of a bar chart in Figure 14. It appears from these data that the burst energy increased as the free specimen span increased--i.e., burst energy increased as the width of the clamping strip became smaller. This phenomenon might be explained in terms of the strain per unit area. With narrow clamping strips and the attendant increase in free specimen width, the strain per unit area would appear to be decreased and the specimen would be expected to withstand a larger number of drops. This explanation assumes that the stress from the impacting mass is transmitted uniformly to the free area of the specimen.

To summarize the results of this investigation into factors that might be contributing to higher burst energy results with the new drop assembly, the following conclusions were reached with regard to clamping variables that might have an effect on the test results: (1) Clamping pressure affected the magnitude of the burst energy results, low clamping pressure being associated with high burst energy results because of the possibility that the specimen may be free to slip; (2) it was found that the method of attaching the clamping strips to the platen of the specimen holder affected the magnitude

TABLE XIV

FRAG TEST RESULTS OBTAINED WITH CLAMPING STRIPS OF DIFFERENT WIDTHS

| | | Clamping Strip Width, inches | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.70 | | | 0.80 | | | 0.95 | | |
| Sample No. | Fiber Direction | Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$ kg.m. | Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$ kg.m. | Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$ kg.m. |
| 102 | Machine | 35.9 | 15 to 57 | 462 | 31.2 | 13 to 82 | 440 | 14.0 | 8 to 25 | 338 |
| | Cross machine | 66.9 | 7 to 185 | 568 | 54.5 | 23 to 88 | 529 | 34.3 | 14 to 51 | 454 |
| 103 | Machine | 48.0 | 20 to 70 | 509 | 41.4 | 12 to 113 | 483 | 23.4 | 18 to 36 | 401 |
| | Cross machine | 45.0 | 12 to 72 | 498 | 43.6 | 10 to 87 | 494 | 37.8 | 12 to 60 | 471 |

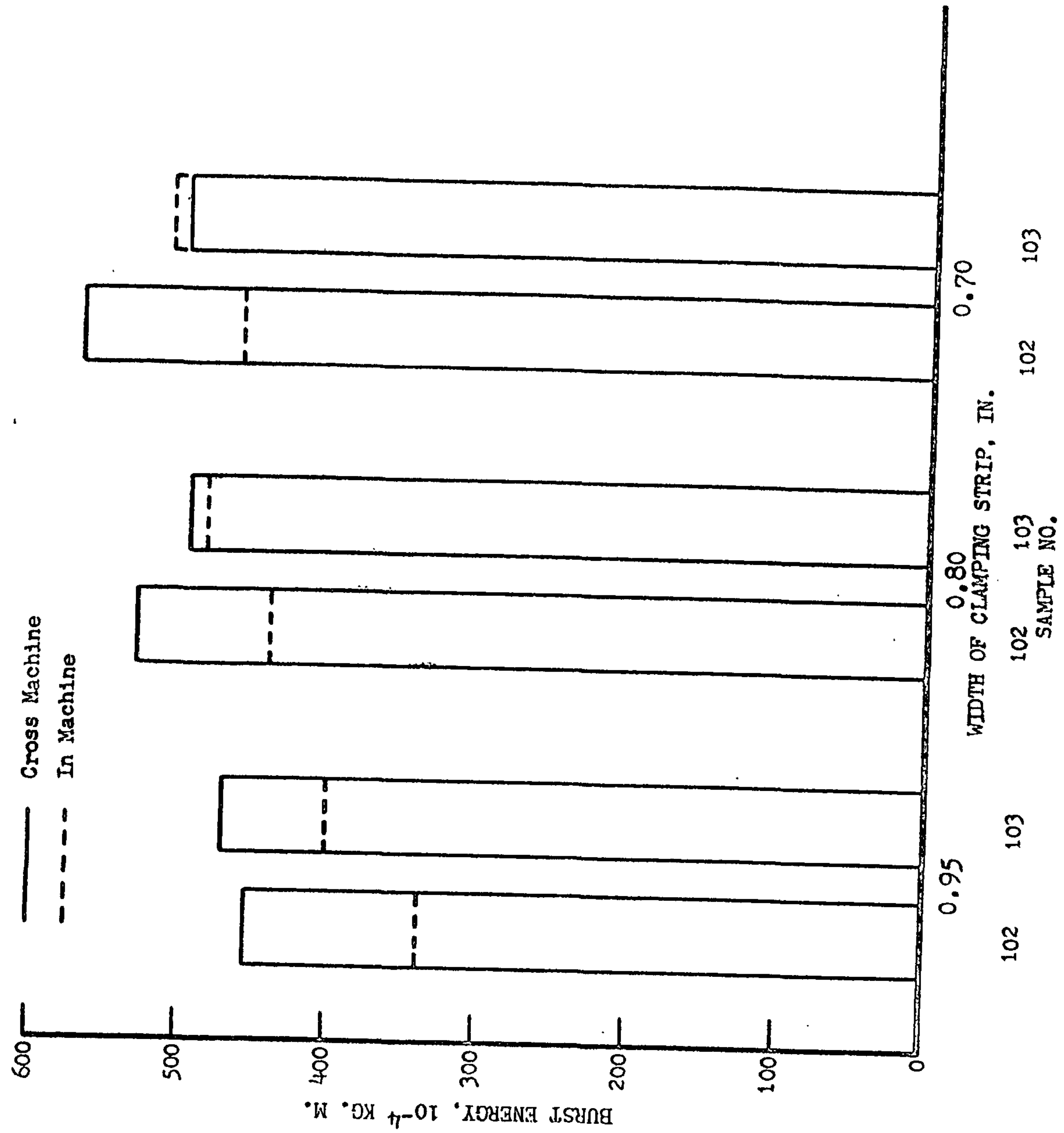



Figure 14

Comparison of Burst Energy for Clamping Strips of Three Different Widths of the burst energy results, Duco cement being associated with lower results than double-face tape, which might permit the specimen to move; (3) the size of the Carborundum grit on the clamping strips influenced the magnitude of the burst energy results only slightly; but the variability of the results, measured in terms of the range of the drop numbers, was less for the specimens evaluated with clamping strips made with the finer grit; and (4) width of the clamping strip was found to influence the magnitude of the burst energy results because of its influence on the width of specimen over which the stress was distributed; narrower strips permitted the stress of impact to be distributed over a larger area and reduced the stress per unit area. This permitted the specimen to sustain a greater number of drops.

A study was also made to compare the results obtained by clamping the specimen around its entire perimeter with those obtained by clamping the specimen in the usual directional way. It was thought that a biaxial test (perimeter clamping) on the Frag tester might simulate to some degree the type of stress to which a sack is subjected in use. Six samples of sack paper (Group II in Table I) were evaluated in this study. Although no directional effects should be observed in biaxial testing, five specimens were oriented in the machine-direction and five in the cross-machine direction to minimize any possible effects of nonuniform clamping pressure. For the directional tests, ten specimens were evaluated in each principal direction. The test results obtained for these two different clamping methods are given in Table XV. From a study of the data in Table XV, it may be noted that the burst energy values obtained for specimens clamped around their entire perimeter (simulated biaxial test) approximated the burst energy values obtained for the weaker direction of specimens clamped in the usual directional manner. If the assumption is made that biaxial testing simulates most closely

TABLE XV

FRAG TEST RESULTS FOR PERIMETER CLAMPING AND EDGE CLAMPING TECHNIQUES

| Sample Identification | Perimeter Clamping | | | Edge Clamping: Machine | | | Edge Clamping: Cross Machine | | |
|---|---|---|---|---|---|---|---|---|---|
| | Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$ kg.m. | Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$ kg.m. | Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$ kg.m. |
| 100 | 6.1 | 4 to 9 | 255 | 8.0 | 6 to 9 | 280 | 28.3 | 18 to 37 | 427 |
| 101 | 50.3 | 19 to 95 | 516 | 46.0 | 32 to 66 | 502 | 132.4 | 44 to 243 | 713 |
| 102 | 10.4 | 6 to 16 | 306 | 12.6 | 9 to 16 | 326 | 42.8 | 20 to 61 | 490 |
| 103 | 20.4 | 15 to 28 | 383 | 19.7 | 9 to 28 | 378 | 36.5 | 12 to 77 | 462 |
| 104 | 77.1 | 41 to 141 | 596 | 65.2 | 35 to 121 | 563 | 44.3 | 20 to 107 | 494 |
| 105 | 50.7 | 19 to 73 | 519 | 210.6 | 43 to 332 | 835 | 76.9 | 18 to 141 | 596 |

the type of stress to which a sack is subjected in actual use, then, from the results just cited, it appears that the Frag results for the weaker fiber direction would be best suited for predicting sack performance.

MATERIAL VARIABLES

Test Results for Various Grades of Kraft Sack Paper

Various grades of kraft sack paper were evaluated to determine how the Frag tester ranks sack papers with different characteristics. The materials shown in Group One of Table I were used and included one sample of 30 lb., one sample of 35 lb., three samples of 50 lb., and one sample of 60 lb. The Frag test data obtained for these materials are shown in Table XVI. It appears from an inspection of these results that the Frag tester rated the burst energies of the normal-stretch samples in direct proportion to the weight--that is, the lowest weight of paper had the lowest burst energy and the highest weight of paper had the hhghest burst energy for both the machine and cross-machine directions. With regard to the 50-lb. papers with low and high stretch properties (Samples E and F, respectively), it was found that the 50-lb. sample with low stretch also had low burst energy and the 50-lb. sample with high stretch also had high burst energy for the machine direction test. It should be pointed out here that the machine-direction stretch of the high stretch sample was approximately six times that of the low stretch sample, whereas the cross-machine direction stretch of the high stretch sample was approximately twice that of the low stretch sample. It may be noted in Table XVI that burst energy data for the low and high stretch samples were not vastly different in the cross-machine direction. On the basis of the results for the low stretch and high stretch papers, it appears that burst energy increases as stretch increases, as would be expected.

## TABLE XVI

### FRAG TEST RESULTS FOR DIFFERENT GRADES OF KRAFT SACK PAPER

| Sample Identification | Nominal Basis Weight, lb. (24x36/500) | Stretch, % | | Machine | | | Cross Machine | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Machine | Cross Machine | Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$ kg.m. | Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$ kg.m. |
| A | 30 | 1.6 | 2.6 | 4.4 | 3 to 7 | 229 | 6.8 | 3 to 12 | 265 |
| B | 35 | 1.8 | 3.5 | 16.9 | 9 to 28 | 360 | 30.4 | 22 to 46 | 435 |
| C | 50 | 1.9 | 4.5 | 75.7 | 53 to 121 | 593 | 133.2 | 82 to 176 | 715 |
| D | 60 | 2.1 | 4.1 | 284.0 | 253 to 321 | 922 | 535.0 | 391 to 765 | 1137 |
| E | 50 | 1.9 | 3.6 | 20.5 | 5 to 37 | 383 | 48.8 | 17 to 110 | 512 |
| F | 50 | 12.5 | 8.6 | 385.9 | 265 to 557 | 1019 | 71.6 | 41 to 101 | 583 |

## The Effect of Fiber Direction on the Frag Test Results

Frag test data were given in Table XVI of the previous section for various grades of kraft sack paper. The data presented in Table XVI may also be used to determine what effect fiber orientation has on the absolute burst energy of paper as measured by the Frag tester. Burst energy results are presented in bar chart form in Figure 15 for the machine direction and cross-machine direction of each of the six samples of sack paper for which data are given in Table XVI. It may be seen in Figure 15 that burst energy for the cross-machine direction was generally higher than burst energy for the machine direction. The exception to this observation was Sample F which had unusually high machine-direction stretch. It appears, therefore, that the fiber direction which has higher stretch will also have higher burst energy as measured by the Frag tester. This might be expected because a specimen clamped with the higher stretch direction in a fixed position and with the lower stretch direction free will perhaps recover from the strain to which it is subjected with each repeated impact and, thus, have a higher burst energy.

## The Effect of Multiple Plies

The objective of this part of the instrumentation study was to compare the magnitude of the Frag test results for one, two, and three plies of sack paper. This is of interest because rough handling tests indicate that multi-ply sacks outperform single-ply sacks of a given weight of substance, and consequently a component test to be reliable in evaluating or predicting

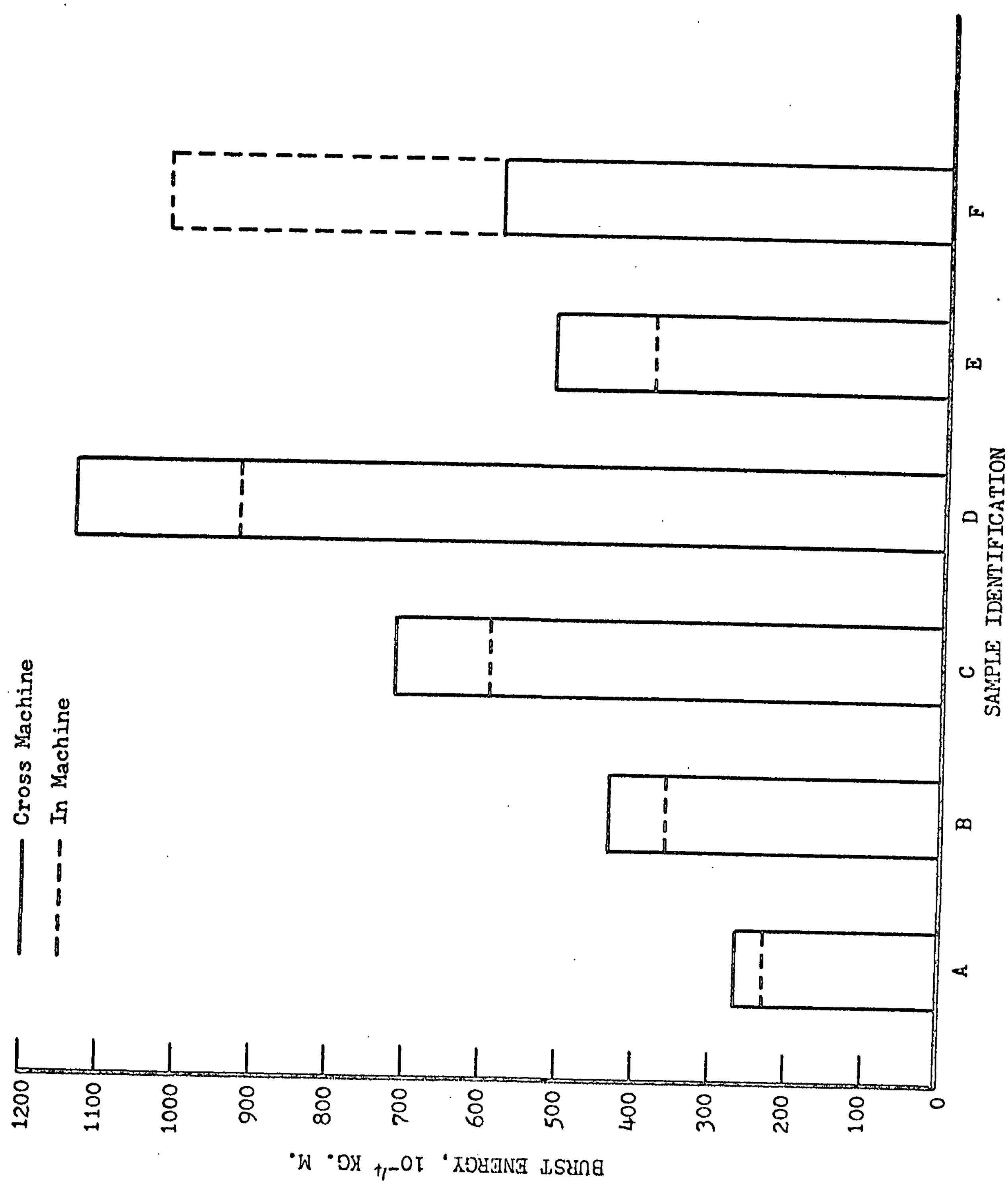



Figure 15

Effect of Fiber Direction on Burst Energy for Six Different Sack Papers a rough-handling potential of sack paper should give a substantially higher result as the number of plies is increased. This should not be construed as the sole criterion of a good test by any means as many other criteria would have to be met before a component test could be considered to be reliable in predicting field performance. However, it might be taken as an indication that the test possessed some of the needed characteristics.

In Table XVII, where the Frag test results on one, two, and three plies are given for six samples of sack paper (Group II of Table I) and in Figure 16 where these results are presented as a bar chart, it may be observed that both machine direction and cross-machine direction test results increased as the number of plies increased. The increase appears to be synergistic in nature for the three-ply tests; that is, the burst energy of three plies is more than three times that of one ply. The increase in burst energy when two plies were tested in place of one was large (generally about double that of one ply) but the really large increase occurred when three plies were tested in place of one. In the latter case the increase was much more than three times the burst energy for a single ply in most instances. Specifically, it was found when composite data for the six samples were used that, for the machine-direction tests, the average burst energy of two plies was 1.95 times that of a single ply and the average burst energy of three plies was 4.29 times that of a single ply; for the cross-machine direction tests, the average burst energy of two plies was 2.17 times that of a single ply and the average burst energy of three plies was 5.08 times that of a single ply.

TABLE XVII

FRAG TEST RESULTS FOR ONE, TWO, AND THREE PLIES

OF SIX DIFFERENT SACK PAPERS

| | | Number of Plies | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | | | 2 | | | 3 | | |
| Sample No. | Fiber Direction | Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$ kg.m. | Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$ kg.m. | Falls to Failure Av. | Falls to Failure Range | Burst Energy, $10^{-4}$ kg.m. |
| 100 | Machine | 1.0 | 0 | 420 | 4.2 | 4 to 5 | 677 | 63.4 | 47 to 80 | 1674 |
| | Cross machine | 1.3 | 1 to 2 | 458 | 6.6 | 4 to 9 | 787 | 205.8 | 176 to 232 | 2480 |
| 101 | Machine | 2.1 | 2 to 3 | 538 | 15.9 | 11 to 23 | 1057 | 279.2 | 242 to 309 | 2745 |
| | Cross machine | 2.4 | 2 to 3 | 562 | 37.7 | 24 to 56 | 1407 | 694.3 | 669 to 731 | 3719 |
| 102 | Machine | 1.8 | 1 to 2 | 511 | 9.9 | 8 to 13 | 902 | 45.4 | 43 to 51 | 1498 |
| | Cross machine | 2.1 | 1 to 3 | 538 | 26.2 | 19 to 37 | 1247 | 181.4 | 174 to 193 | 2378 |
| 103 | Machine | 1.3 | 1 to 2 | 458 | 10.9 | 8 to 13 | 931 | 91.4 | 73 to 109 | 1892 |
| | Cross machine | 2.1 | 2 to 3 | 538 | 24.8 | 17 to 34 | 1226 | 443.0 | 396 to 499 | 3202 |
| 104 | Machine | 2.9 | 2 to 4 | 598 | 25.8 | 18 to 36 | 1241 | 302.0 | 227 to 351 | 2818 |
| | Cross machine | 3.9 | 3 to 5 | 660 | 37.7 | 31 to 44 | 1408 | 363.0 | 351 to 388 | 2996 |
| 105 | Machine | 6.9 | 6 to 8 | 799 | 64.9 | 53 to 79 | 1688 | 643.0 | 582 to 704 | 3625 |
| | Cross machine | 4.8 | 4 to 5 | 708 | 40.2 | 25 to 51 | 1438 | 305.2 | 267 to 339 | 2827 |

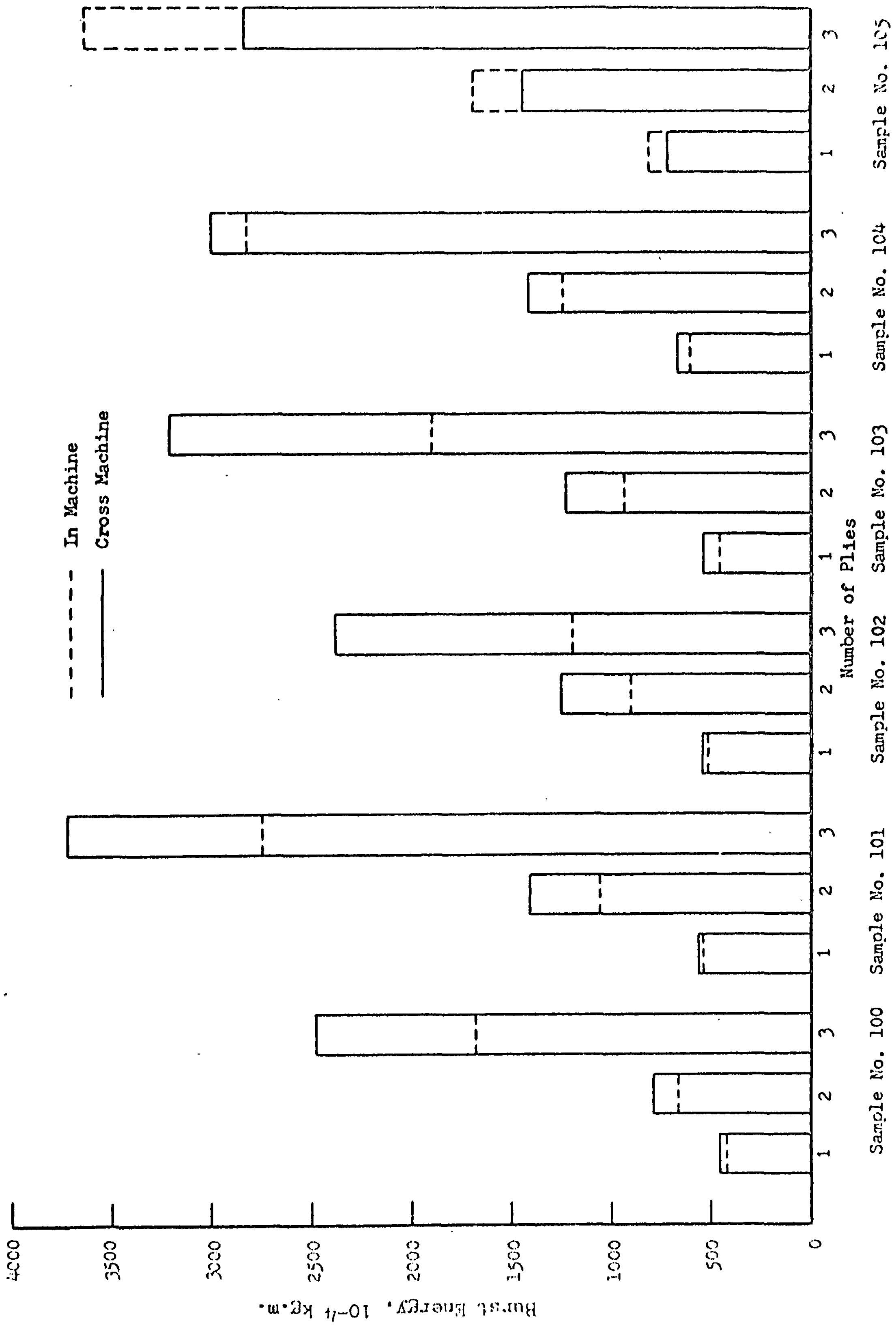



Figure 16

Comparison of Burst Energy for One, Two, and Three Plies

of Six Different Sack Papers

These data might lead to the conclusion that several plies of light paper would produce a sack of superior field performance, if burst energy were used as the sole criterion of performance. Experience indicates that it is not the sole criterion but that other factors must be considered--such as ability to resist scuffs, punctures, etc.--and to fulfill these latter requirements, heavier paper might be preferred (5).

### The Effect of Testing in 25 and 50% Relative Humidity Atmospheres

To study the effect on the Frag results of testing in atmospheres maintained at different relative humidity levels, six samples of sack paper (identified in Table I as Group II materials) were evaluated in two different testing atmospheres--namely, 25 and 50% relative humidity, both at a temperature of 73°F. The test results obtained are shown in Table XVIII and presented by means of a bar chart in Figure 17. It may be seen in Figure 17 that the burst energy was lower for the samples tested at the lower relative humidity. In most cases the decrease was small, the one exception being Sample 105, the high machine-direction stretch sample, for which the burst energy at 25% R.H. was appreciably lower than it was at 50% R.H.

## OTHER FACTORS STUDIED

### Comparison of Frag Burst Energy with Baldwin-Southwark Tensile, Stretch, and Work Data

The six samples of sack paper identified as Group II materials in Table I were evaluated on the Frag tester and on the Baldwin-Southwark tester,

TABLE XVIII

FRAG TEST RESULTS FOR SIX DIFFERENT SACK PAPERS CONDITIONED AND TESTED

IN ATMOSPHERES OF 25% AND 50% RELATIVE HUMIDITY

| Sample No. | Fiber Direction | Testing Atmosphere, % R.H. 25: Falls to Failure Av. | 25: Falls to Failure Range | 25: Burst Energy, $10^{-4}$ kg.m. | 50: Falls to Failure Av. | 50: Falls to Failure Range | 50: Burst Energy, $10^{-4}$ kg.m. |
|---|---|---|---|---|---|---|---|
| 100 | Machine | 6.5 | 4 to 9 | 261 | 7.5 | 3 to 16 | 274 |
| | Cross machine | 11.4 | 5 to 20 | 315 | 16.1 | 10 to 22 | 354 |
| 101 | Machine | 31.6 | 21 to 42 | 445 | 35.0 | 29 to 45 | 458 |
| | Cross machine | 67.7 | 54 to 89 | 571 | 76.5 | 60 to 93 | 593 |
| 102 | Machine | 5.3 | 3 to 9 | 244 | 6.8 | 4 to 10 | 265 |
| | Cross machine | 17.6 | 8 to 26 | 364 | 20.2 | 14 to 28 | 381 |
| 103 | Machine | 6.9 | 4 to 10 | 266 | 8.7 | 5 to 14 | 288 |
| | Cross machine | 36.5 | 24 to 50 | 464 | 41.0 | 24 to 62 | 483 |
| 104 | Machine | 58.5 | 44 to 78 | 544 | 69.6 | 38 to 104 | 577 |
| | Cross machine | 54.5 | 38 to 78 | 530 | 62.3 | 44 to 89 | 554 |
| 105 | Machine | 100.4 | 73 to 134 | 651 | 280.8 | 249 to 311 | 917 |
| | Cross machine | 36.7 | 28 to 47 | 465 | 44.6 | 36 to 57 | 498 |

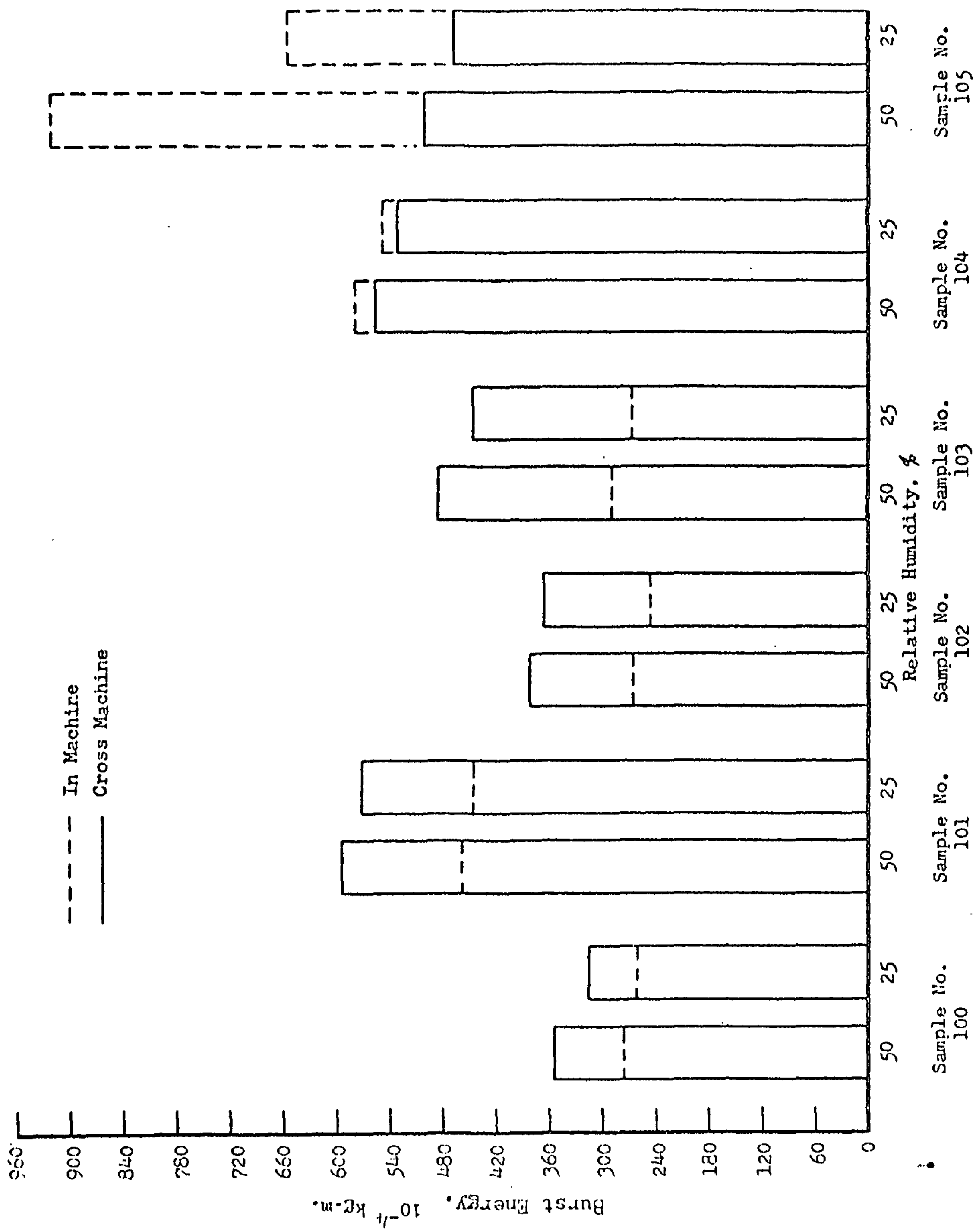



Figure 17

Effect of Relative Humidity on Burst Energy absolute burst energy being determined on the former and tensile, stretch, and work on the latter. These data are given in Table XIX. Baldwin-Southwark tensile load versus Frag absolute burst energy is plotted in Figure 18, Baldwin-Southwark stretch versus Frag absolute burst energy is plotted in Figure 19; and Baldwin-Southwark work data versus Frag absolute burst energy is plotted in Figure 20. These plots represent rather limited data but some general trends may be cited. It appears, for instance, that high tensile, stretch, and work values exhibit a tendency to be associated with high absolute burst energy values. An inspection of Figures 18, 19, and 20 indicates that Frag absolute burst energy might correlate somewhat better with work than with tensile or stretch. This might be explained by the fact that work takes into consideration both tensile load and elongation. It should also be mentioned that the correlation between these various factors may be influenced by the nature of the tests themselves--that is, the Frag tester applies a series of impact stresses whereas the Baldwin-Southwark results were obtained by applying stress to the specimen at a uniform rate.

Reproducibility of Test Results

An important consideration when any instrument is to be used for quality control purposes is the reproducibility of test results. If the results obtained cannot be reproduced from day to day for one given sample, they will not be very useful. Throughout this instrumentation study, it was noticed many times that the results were difficult to reproduce because of the sensitivity of these results to various instrumental adjustments, some of which

## TABLE XIX

### BALDWIN-SOUTHWARK TENSILE, STRETCH, AND WORK DATA AND FRAG BURST ENERGY DATA

| Sample Identification | Machine | | | | Cross Machine | | | |
|---|---|---|---|---|---|---|---|---|
| | Burst Energy, $10^{-4}$ kg.m. | Tensile, lb. | Stretch, % | Work, in. lb. | Burst Energy, $10^{-4}$ kg.m. | Tensile, lb. | Stretch, % | Work, in. lb. |
| 100 | 274 | 26.4 | 1.8 | 1.22 | 354 | 12.9 | 5.3 | 2.05 |
| 101 | 458 | 37.8 | 2.1 | 2.07 | 593 | 23.2 | 4.5 | 2.98 |
| 102 | 265 | 28.7 | 1.5 | 1.08 | 381 | 23.4 | 2.8 | 1.86 |
| 103 | 288 | 33.6 | 1.9 | 1.67 | 483 | 19.0 | 3.6 | 1.87 |
| 104 | 577 | 43.4 | 2.1 | 2.39 | 554 | 20.0 | 3.9 | 2.19 |
| 105 | 917 | 22.6 | 15.9 | 8.08 | 498 | 14.8 | 7.6 | 3.23 |

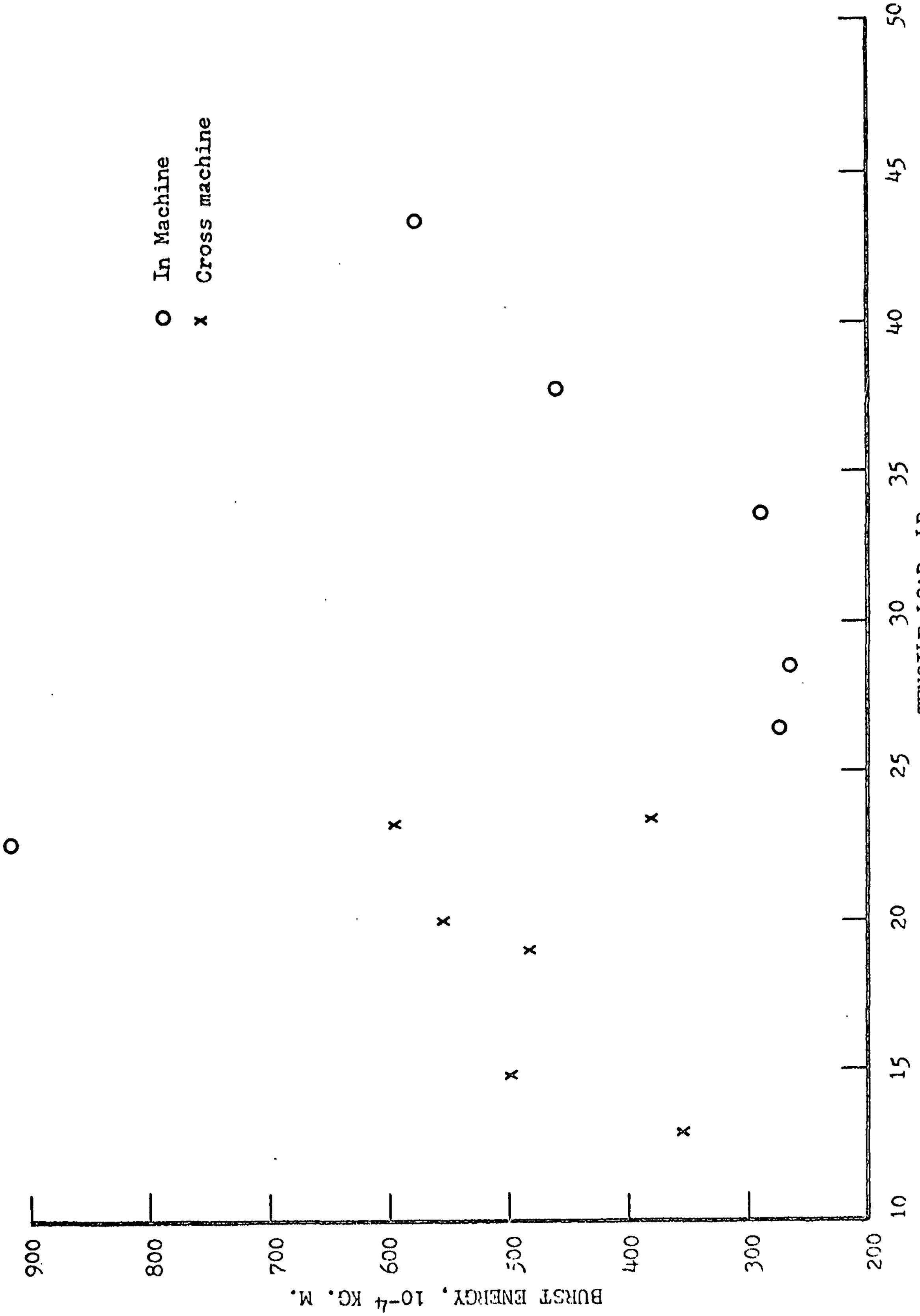



Figure 18

Comparison of Baldwin-Southwark Tensile with Frag Burst Energy

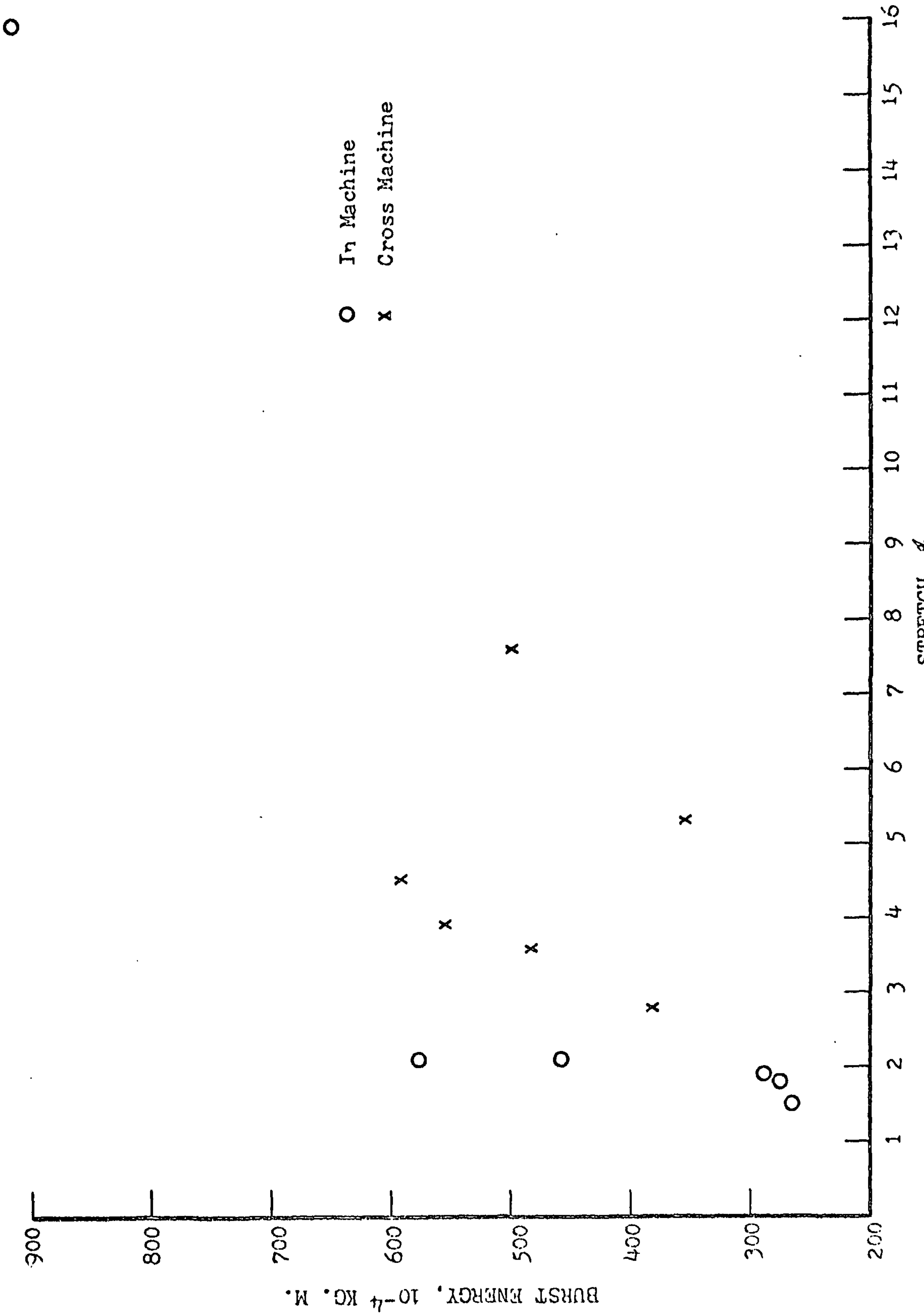



Figure 19

Comparison of Baldwin-Southwark Stretch with Frag Burst Energy

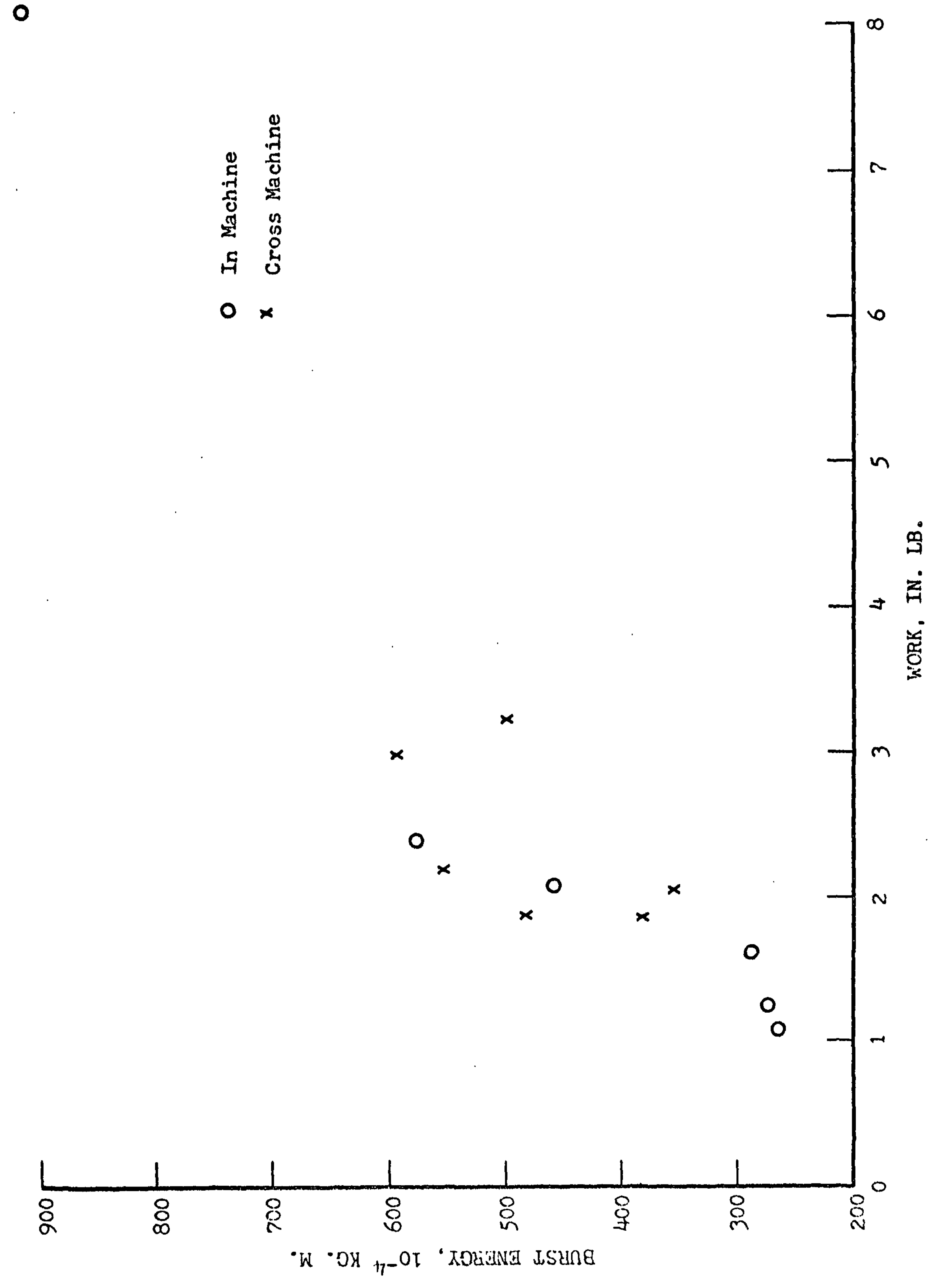
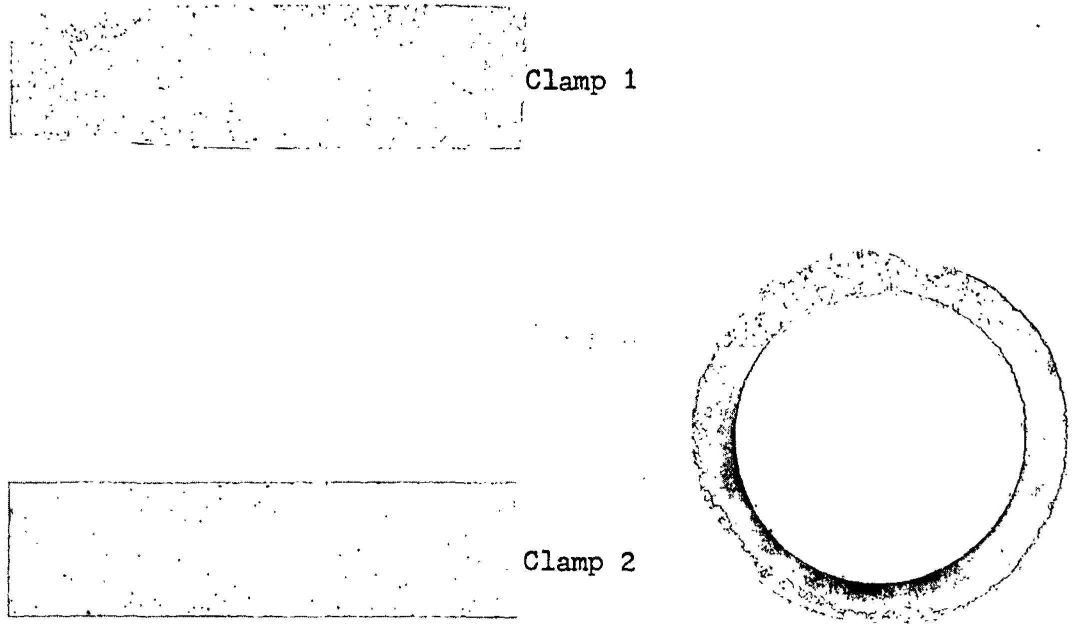



Figure 20

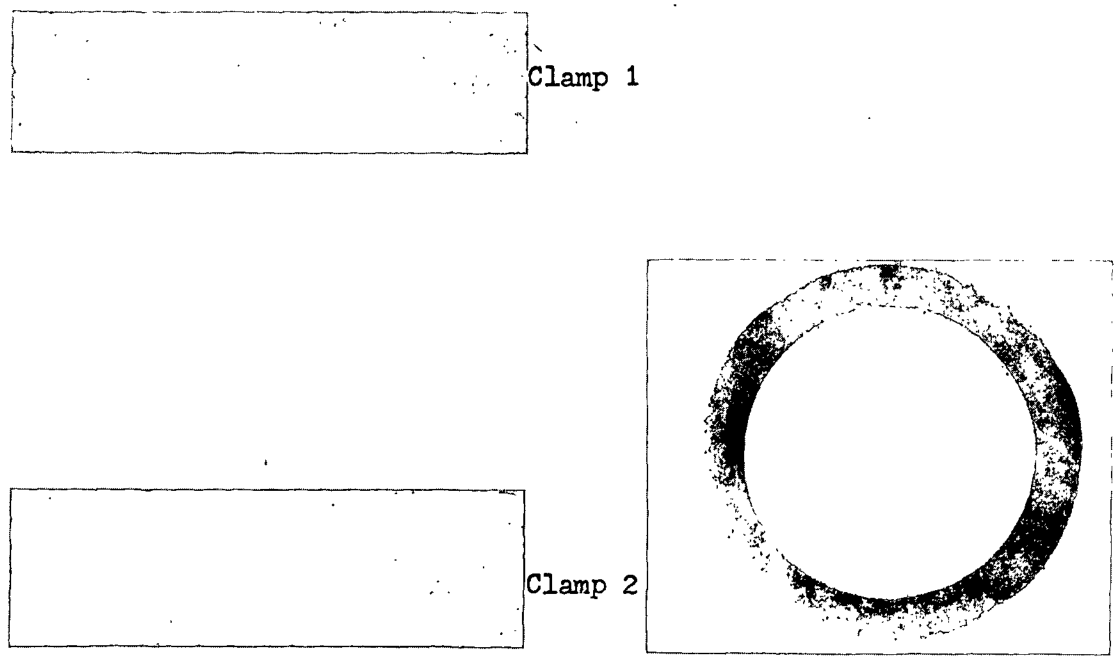
Comparison of Baldwin-Southwark Work Data with Frag Burst Energy could not be controlled with a high level of confidence. For this reason, it was considered to be an indispensable part of this instrumentation program to study the reproducibility of the test results obtained with a Frag tester. The knowledge gained from the instrumentation work was used to control the factors that were subject to adjustment.

A sample of 51-lb. sack paper (No. 102), randomized by shuffling the specimens, was used for this reproducibility study which was designed to cover a period of ten days, on each of which ten specimens were tested in the two principal fiber directions. The Frag tester was adjusted to have a firm anvil, solid lift arms, and as flat a drop as possible. The same operator was used throughout the test period of ten days. No instrumental adjustments were made during the ten-day period. Pressure patterns were made each day to check the flatness of drop and the uniformity of the clamping pressure. The pressure patterns made on the first and last days of testing are shown in Figure 21. It may be noted in Figure 21 that the pressure pattern for the clamping pressure appeared to be somewhat lighter for the last day of testing than for the first day. This might indicate that the strips of Carborundum paper used for holding the specimens firmly between the clamping platens exhibited wear and, as a result, the clearance between the platens increased as testing proceeded. The pressure patterns for the drop assembly hitting the anvil also appeared to be different for the first and last day of testing, the latter pattern being somewhat darker on one side and indicating that the drop was not as flat on the last day as it was on the first.




Clamping Pressure Impact

Patterns from First Day of Testing




Clamping Pressure Impact

Patterns from Tenth Day of Testing

Figure 21

Clamping Pressure and Impact Patterns Made on the First and Last Days of the Reproducibility Trial

The data obtained were statistically analyzed to determine if significantly different results were obtained during the test period using the analysis of variance technique. Separate analyses were performed for the machine and cross-machine data expressed in terms of both drop number and burst energy. If significant day-to-day differences were encountered (this was true in each of the four analyses), a statistical gap test was used to segregate the data into groups (7).

With the above in mind, the machine-direction results are summarized in Table XX in order of increasing test value. In Table XX, it may be noted that the test values varied from a low of 6.7 falls to a high of 20.5 falls (261.2 to 377.5 in terms of burst energy). Thus, the results varied over a considerable range during the test period. When the results were plotted in chronological order as in Figure 22, it may be noted that there appeared to be a marked tendency for the results to increase during the ten-day test period. Other phases of this study have suggested that the flatness of drop, anvil tightness, and clamping pressure may affect the instrumental readings. As mentioned previously, some changes in the drop and pressure patterns appeared to occur during the test period. This may indicate that the increasing trend in results was due to changes in these factors. In any event, the data suggest that use of the instrument in production control or in the comparative evaluation of various samples should be accompanied by frequent checking of the instrument and careful experimental design to minimize the effect of any changes in the instrument.

## TABLE XX

### MACHINE DIRECTION FRAG TEST RESULTS OBTAINED DURING THE TEN-DAY REPRODUCIBILITY TRIAL

| Date of Test | Test Day | Average Falls to Failure | Statistical Population Group |
|---|---|---|---|
| 9-25 | 3 | 6.7 | 1 |
| 9-23 | 1 | 7.6 | |
| 10- 1 | 7 | 8.4 | |
| 9-24 | 2 | 9.3 | |
| 9-26 | 4 | 11.3 | |
| 9-29 | 5 | 11.8 | |
| 9-30 | 6 | 14.2 | 2 |
| 10- 2 | 8 | 15.1 | |
| 10- 3 | 9 | 18.1 | |
| 10- 6 | 10 | 20.5 | 3 |

| Date of Test | Test Day | Average Burst Energy, $10^{-4}$ kg.m. | Statistical Population Group |
|---|---|---|---|
| 9-25 | 3 | 261.2 | 1 |
| 9-23 | 1 | 271.2 | |
| 10- 1 | 7 | 280.6 | |
| 9-24 | 2 | 287.6 | |
| 9-26 | 4 | 306.6 | |
| 9-29 | 5 | 318.2 | 2 |
| 9-30 | 6 | 337.4 | |
| 10- 2 | 8 | 343.3 | |
| 10- 3 | 9 | 362.5 | |
| 10- 6 | 10 | 377.5 | 3 |

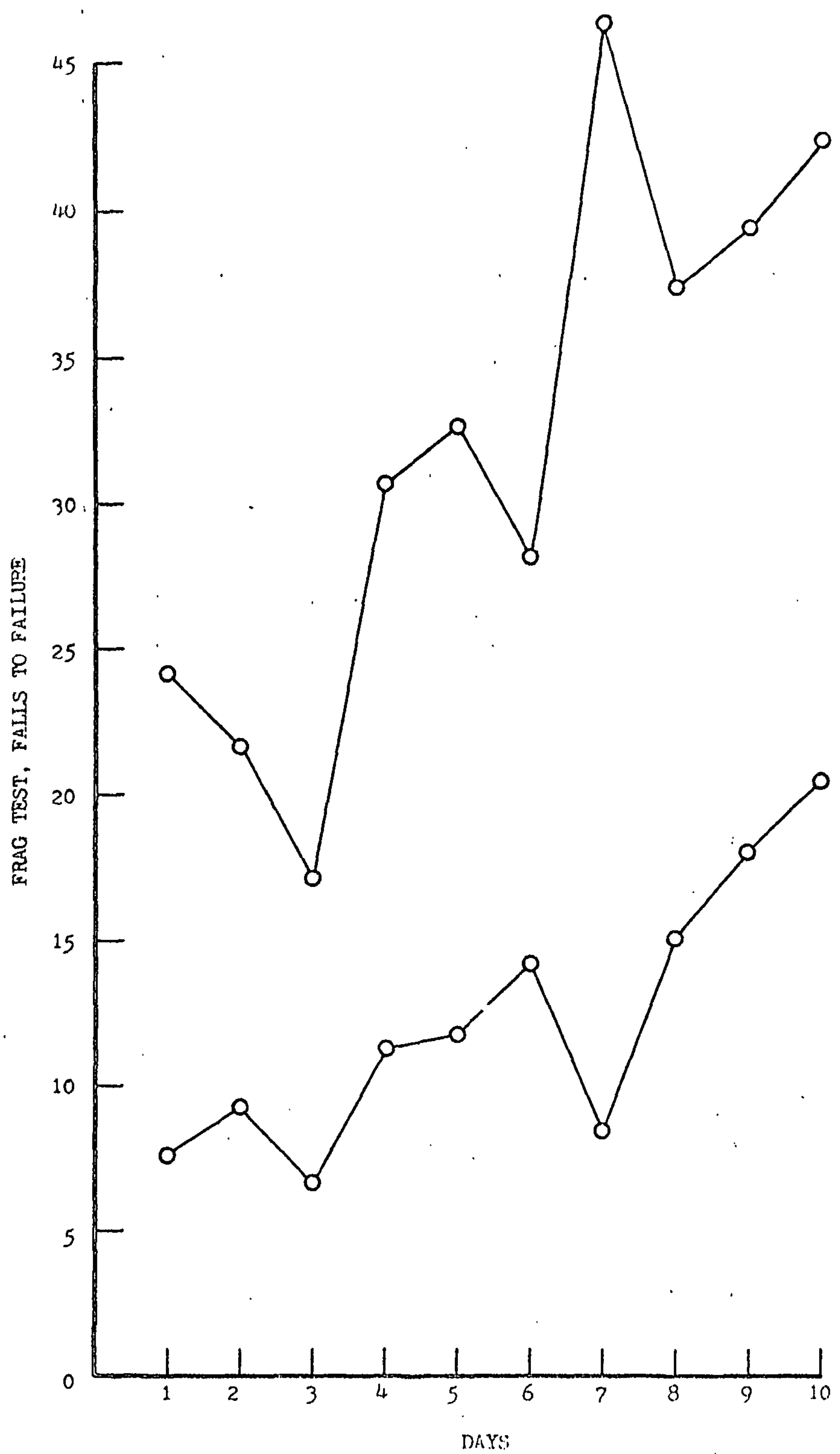



Figure 22

Machine and Cross-machine Direction Frag Test Results

for the Ten-Day Reproducibility Trial

When the machine direction data were subjected to an analysis of variance, the following results were obtained:

| Source of Variance | Degrees of Freedom | Mean Square | F |
|---|---|---|---|
| | Drop Number | | |
| Between days | 9 | 212.4 | 10.07* |
| Within days | 90 | 21.1 | |
| | Burst Energy | | |
| Between days | 9 | 15,879 | 10.86* |
| Within days | 90 | 1,462 | |

* Significant at the 1% level.

As may be noted, the results indicated that the differences in test level between days were significant at the 1% level. In other words, the odds were only 1 in 100 that the differences could have occurred by chance.

After completing the above analysis, a statistical gap test was used to segregate the data into statistically alike groups, As indicated in Table XX, in terms of falls to failure, the data for days 1 through 5 and 7 formed one population; days 6, 8, and 9 formed a second population, and the test value for the tenth day fell in neither of the other two groups. Basically similar results were obtained when the test data were converted to burst energy.

The cross-machine direction test results are tabulated in Table XXI in order of increasing test value and a graph of the data in chronological order may be found in Figure 22. As may be noted in Table XXI, the results

TABLE XXI

CROSS-MACHINE DIRECTION FRAG TEST RESULTS OBTAINED DURING

THE TEN-DAY REPRODUCIBILITY TRIAL

| Date of Test | Test Day | Average Falls to Failure | Statistical Population Group |
|---|---|---|---|
| 9-25 | 3 | 17.2 | 1 |
| 9-24 | 2 | 21.7 | |
| 9-23 | 1 | 24.2 | |
| 9-30 | 6 | 28.2 | |
| 9-26 | 4 | 30.7 | |
| 9-29 | 5 | 32.7 | 2 |
| 10- 2 | 8 | 37.4 | |
| 10- 3 | 9 | 39.5 | |
| 10- 6 | 10 | 42.5 | |
| 10- 1 | 7 | 46.4 | |

| Date of Test | Test Day | Average Burst Energy, $10^{-4}$ kg.m. | Statistical Population Group |
|---|---|---|---|
| 9-25 | 3 | 344.7 | 1 |
| 9-24 | 2 | 361.5 | |
| 9-23 | 1 | 389.1 | |
| 9-30 | 6 | 420.5 | |
| 9-26 | 4 | 429.0 | |
| 9-29 | 5 | 439.6 | |
| 10- 2 | 8 | 465.9 | 2 |
| 10- 3 | 9 | 470.2 | |
| 10- 6 | 10 | 478.2 | |
| 10- 1 | 7 | 484.3 | |

varied from a low of 17.2 to a high of 46.4 falls to failure (344.7 to 484.3 in terms of burst energy). Figure 22 indicates that the test values tended to increase during the test period in much the same manner as the machine-direction results previously discussed.

When the analysis of variance technique was used to analyze the data, the following results were obtained:

| Source of Variance | Degrees of Freedom | Mean Square | F |
|---|---|---|---|
| | Drop Number | | |
| Between days | 9 | 895.1 | 3.490 * |
| Within days | 90 | 256.5 | |
| | Burst Energy | | |
| Between days | 9 | 24,414 | 4.156 * |
| Within days | 90 | 5,874 | |

* Significant at the 1% level.

As in the case of the machine-direction results, the above analysis indicated that significant changes in test level occurred during the 10-day test period.

Use of the gap test on the cross-machine data yielded little additional information. Apparently because of the relatively large standard deviation or variance associated with the cross-machine tests, the gap test was not sensitive enough to effectively separate the data into more than two populations although significant differences still existed in the large population group.

Some caution should be exercised in interpreting the statistical results reported herein. In general, the basic assumption is made that the data are distributed in accordance with the normal distributiom function. Fatigue data, however, are usually characterized by a large variance and frequency distributions of such data are usually skewed to a greater or lesser extent. This is true of other materials as well as paper (8,9). Other workers in the field such as Freudenthal have suggested that a closer approximation to the usual normal distribution function may be obtained when fatigue data are converted to logarithms (8). It may also be remarked that Bergstrom arrived at a similar conclusion in his analysis of the behavior of bags in the drop test (10). Conversion of the drop number to burst energy by taking the cube root of the drop number would be expected to be somewhat similar to taking logarithms.

To illustrate the above, frequency distributions were determined using the total number of specimens (100) evaluated in each direction during the ten days. The results obtained are tabulated in Table XXII and graphically illustrated in Figures 23 and 24. As may be noted in the figures, the data in Table XXII were also transformed into logarithms and the cube root of the drop number in order to illustrate the effect of these transformations on the frequency distribution curve.

Aside from the limited nature of the data, one further factor should be considered in interpreting the data--that is, the tendency for the test level to increase during the 10-day test period. Changes in test level, if present, would be expected to modify the shape of the distribution curve.

TABLE XXII

FREQUENCY DISTRIBUTION OF FRAG TEST RESULTS

| Class Interval, drop number | Midpoint | Frequency Machine Direction | Frequency Cross Direction |
|---|---|---|---|
| 1- 5 | 3 | 10 | 3 |
| 6-10 | 8 | 35 | 8 |
| 11-15 | 13 | 31 | 4 |
| 16-20 | 18 | 14 | 11 |
| 21-25 | 23 | 6 | 10 |
| 26-30 | 28 | 3 | 13 |
| 31-35 | 33 | 1 | 16 |
| 36-40 | 38 | | 8 |
| 41-45 | 43 | | 8 |
| 46-50 | 48 | | 8 |
| 51-55 | 53 | | 2 |
| 56-60 | 58 | | 2 |
| 61-65 | 63 | | 3 |
| 66-70 | 68 | | 1 |
| 71-75 | 73 | | 0 |
| 76-80 | 78 | | 0 |
| 81-85 | 83 | | 2 |
| 86-90 | 88 | | 0 |
| 91-95 | 93 | | 0 |
| 96-100 | 98 | | 1 |
| Total | | 100 | 100 |

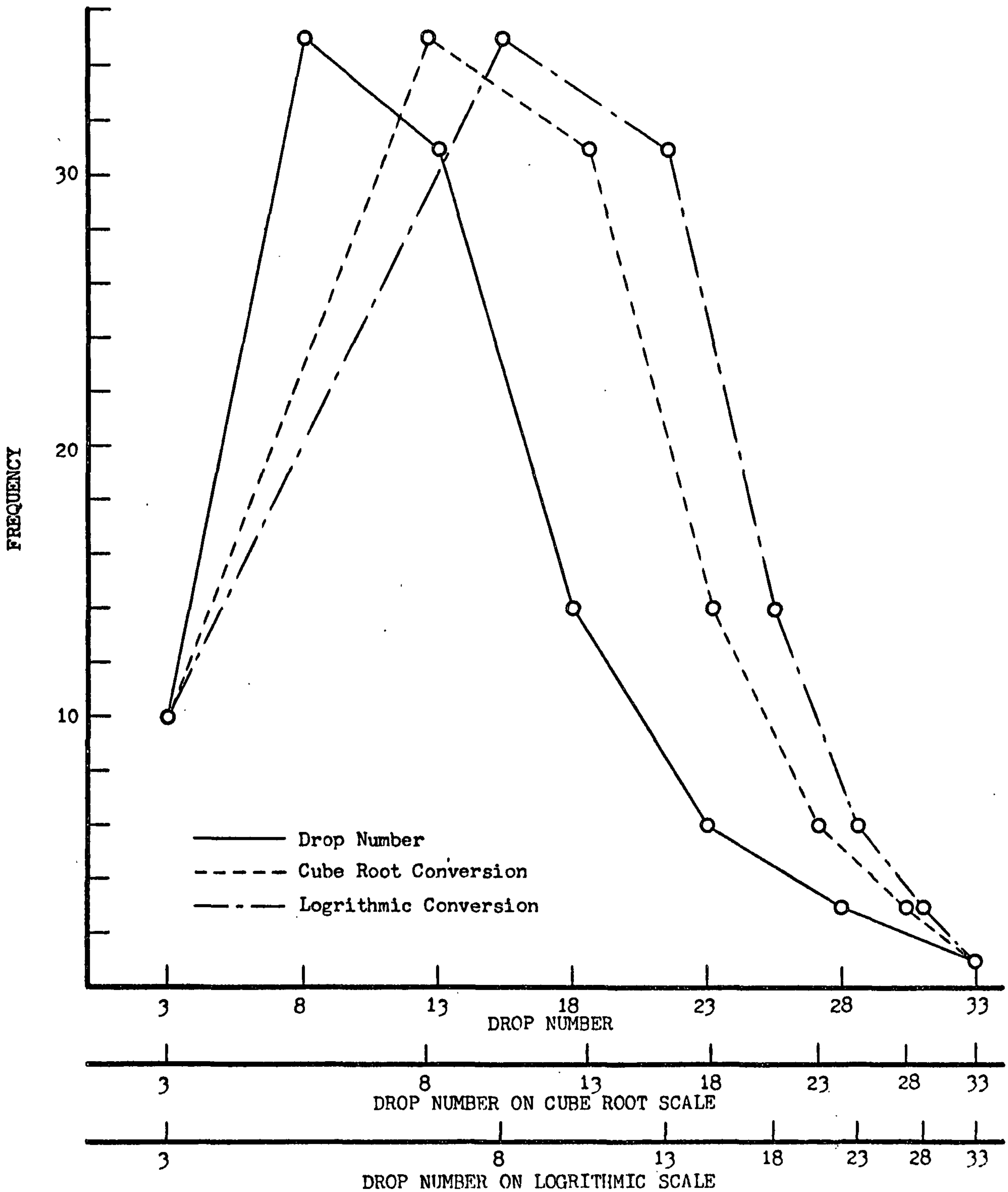



Figure 23

Frequency Distribution Curves for the Machine-Direction

Frag Test Results

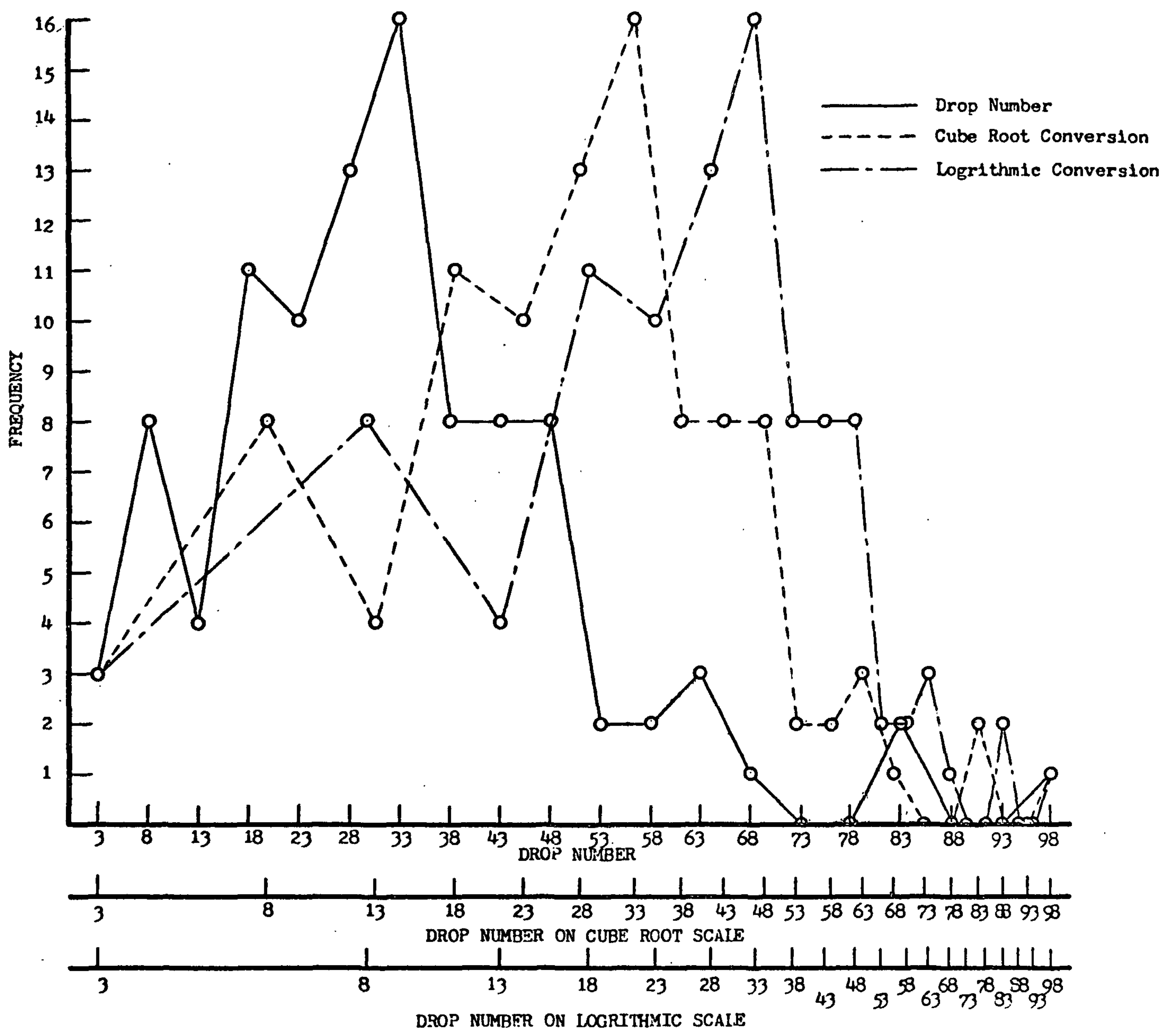



Figure 24

Frequency Distribution Curves for the Cross-Machine

Direction Frag Test Results

For a steadily increasing test level, it might be anticipated that the distribution curve would be flat-topped--approaching a rectangular shape in the extreme case. However, such generalizations may be dangerous for fatigue-type data.

From one standpoint, the problem poses a dilemma. On the one hand, to study the frequency distribution curves requires some assurance that the data are part of a homogeneous population. On the other hand, most common statistical techniques assume a normal distribution curve. Some caution should be exercised, therefore, where major deviations from normality occur. For the above reasons, among others, the exploratory nature of the analysis is emphasized.

With the above in mind, it may be noted in Table XXII or Figures 23 and 24 that the individual test values encompass a wide range--particularly in the cross-machine direction where extreme values were found in both the 1 through 5 and 96 through 100 class intervals. In Figure 23 it may be noted that the frequency distribution curve in terms of drop number appear to be relatively unsymmetrical and skewed to the right--in part, perhaps, because drop numbers less than 1 cannot be obtained. Both the logarithmic and cube root transformations seemed to yield a more symmetrically shaped curve. The frequency distribution curve in terms of drop number for the cross-machine data also appears to be skewed to the right; however, the two transformed curves appear to introduce an opposite skewness.

The limitations inherent in the data make difficult any positive conclusions regarding the merits of the transformation. If, in the future, means can be found to stabilize the instrumental readings, further consideration may be given this aspect of the problem. For the present, it is believed that the above discussion may be helpful in alerting the reader to the statistical problems involved.

With the above in mind, the estimates of residual variance obtained in the analysis of variance were used to estimate the sample standard deviation in both directions and to compute confidence intervals at the 95% level for various sample sizes. It may be recalled that the standard deviation is a measure of the dispersion of the individual values about the population average. In a normally distributed population, about 95% of the individual values may be expected to be within ± 2 standard deviations of the average. Despite the possible departures from normality of Frag test data, it was believed that the conventional statistical measures would be helpful in depicting the variance in individual readings--particularly if too great reliance is not placed on the theoretical probabilities. It may also be recalled that the standard deviation is a characteristic of a given sample and may vary within wide limits depending on the uniformity of the sample and the precision of the test machine. The estimates given below pertain strictly to the sample used herein; however, it was felt that the values could assist in establishing an order of magnitude.

The values of standard deviation obtained were as follows:

| | Machine Direction | Cross-Machine Direction |
|---|---|---|
| Standard deviation, | | |
| Drop number | 4.6 | 16.0 |
| Burst energy | 38.2 | 76.6 |
| Percent standard deviation * | | |
| Drop number | 37.4 | 50.0 |
| Burst energy | 12.1 | 17.9 |

* Based on grand average of 100 tests in each direction as reference.

The standard deviations in terms of drop number are relatively high and reflect the inherently great scatter in the Frag test results (see frequency distribution curves in Figures 23 and 24). It may also be of interest to note that conversion of test results to Burst Energy materially decreases the standard deviation on a percentage basis because of the effect of taking the cube root of the drop number.

In order to assist the reader in assessing the effect of sample size (number of specimens tested) on the precision of the resulting average, the values of standard deviation were used to compute confidence intervals for averages at the 95% level. The computations were made using the following equation:

$$\text{Confidence interval} = \pm \frac{t_{05}\,\sigma}{\sqrt{N}}$$

where $\sigma$ = standard deviation

$N$ = number of specimens tested

$t_{05}$ = from "$t$" distribution tables

For a normally distributed population, it may be stated that the odds are only 5% that a sample average will deviate more than $\pm\, t_{05}\,\sigma \sqrt{N}$ from the population average.

The calculated values are tabulated in Table XXIII and graphically illustrated in Figures 25 and 26. As may be seen in the table or figures, little gain in the precision of the test averages can be attained by testing more than 10 to 20 specimens in the machine direction or 20 to 40 specimens in the cross-machine direction. Beyond this point, the gains in precision are accomplished only through inordinately large increases in sample size.

TABLE XXIII

CONFIDENCE LIMITS FOR DROP NUMBER AND BURST ENERGY AVERAGES OBTAINED

BY TESTING VARIOUS NUMBERS OF SPECIMENS
(Based on test results from ten-day reproducibility trial)

$$\pm \frac{t_{05}\,\sigma}{\sqrt{N}}$$

| No. of Specimens | Drop Number | | Burst Energy | |
|---|---|---|---|---|
| | Machine Direction | Cross Direction | Machine Direction | Cross Direction |
| 3 | 11.4 | 39.8 | 94.9 | 190.3 |
| 5 | 5.7 | 19.9 | 47.5 | 95.3 |
| 10 | 3.3 | 11.4 | 27.3 | 54.8 |
| 20 | 2.1 | 7.5 | 17.9 | 35.8 |
| 30 | 1.7 | 6.0 | 14.2 | 28.5 |
| 40 | 1.5 | 5.1 | 12.2 | 24.5 |
| 60 | 1.2 | 4.1 | 9.9 | 19.8 |
| 80 | 1.0 | 3.6 | 8.5 | 17.1 |
| 100 | 0.9 | 3.2 | 7.6 | 15.2 |
| 120 | | 2.9 | 6.9 | 13.9 |
| 150 | | 2.6 | 6.2 | 12.4 |
| 200 | | 2.2 | | 10.7 |
| 300 | | 1.8 | | 8.7 |
| 400 | | 1.6 | | 7.6 |
| 500 | | 1.4 | | 6.7 |

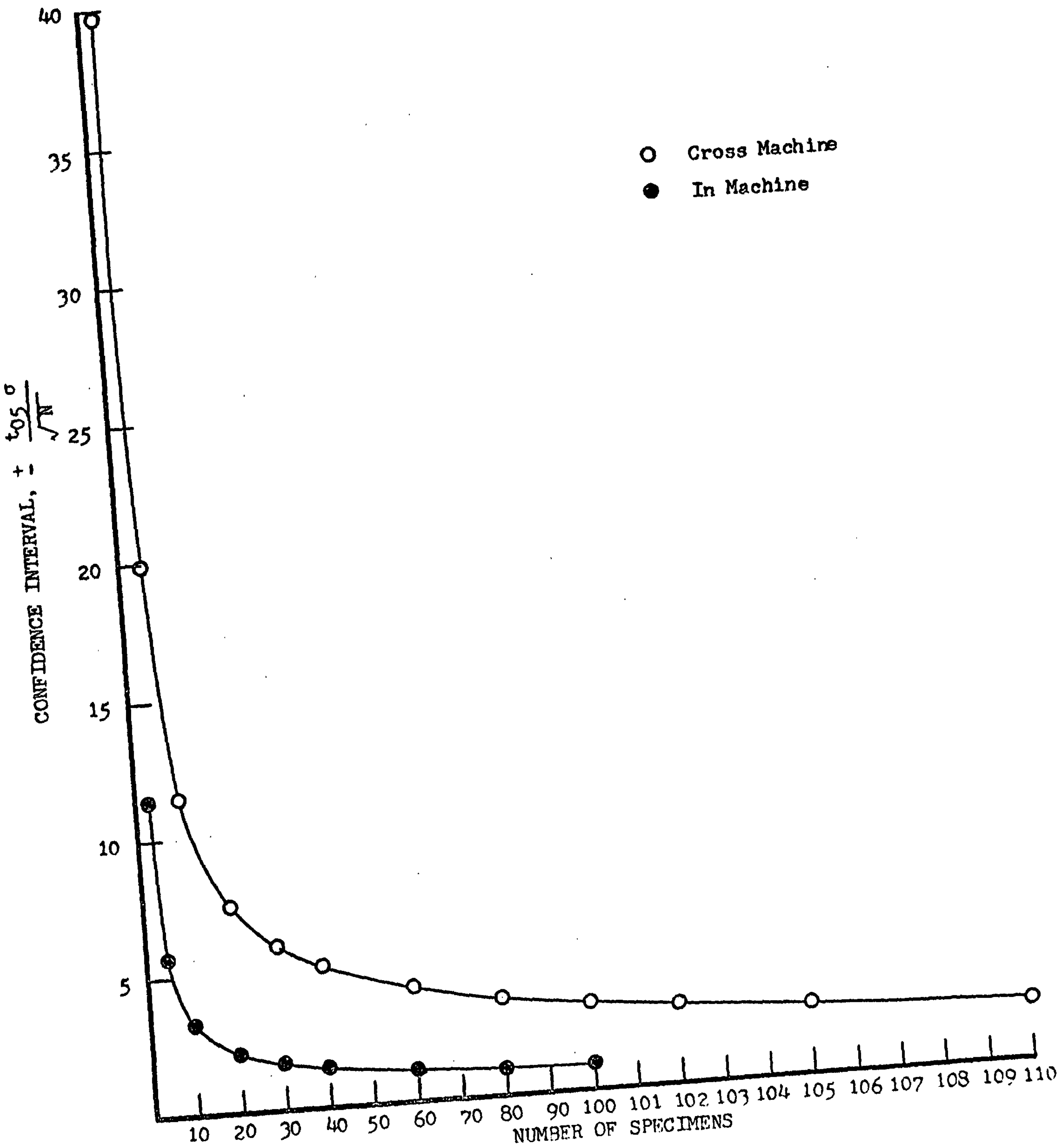



Figure 25

Confidence Curve for Frag Test Results
(Based on drop number)

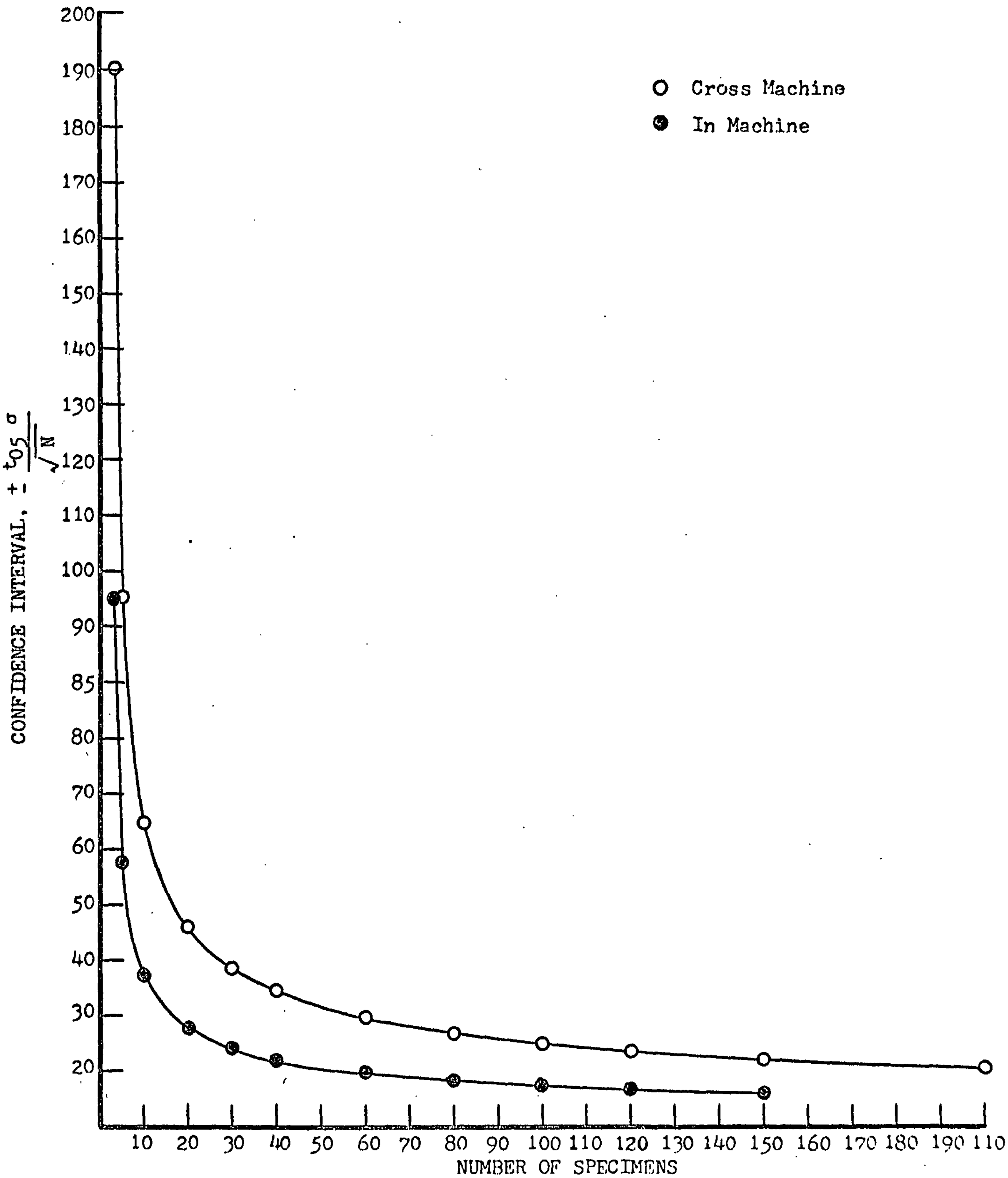



Figure 26

Confidence Curve for Frag Test Results
(Based on burst energy)

To briefly summarize the results obtained in this phase of the study the following conclusions might be drawn:

1. During the 10-day test trial, the Frag results appeared to steadily increase.

2. Using conventional statistical techniques, the difference in test results between days appeared to be highly significant.

3. Causes for the changes in test results were not clearly evident; however, changes in type of drop or clamping pressure may have been responsible. It is believed that the above emphasizes the difficulties which may be encountered in keeping the instrument in calibration.

4. The individual test values obtained were subjected to an exploratory evaluation to define the type of frequency distribution curve obtained in the Frag test. A skewed distribution seemed to be obtained; however, the limitations in the data made it difficult to evaluate the merits of various transformations in correcting the skewness.

5. Estimates of standard deviation and error were also made to assist in depicting the variance to be expected in Frag test results.

## Observations on the Construction and Durability of the Frag Tester

In carrying out this instrumentation program, some instrumental failures associated with the Frag tester were pointed out. This section of the report summarizes the failures that were encountered. These are not cited for the purpose of placing the Frag tester in unfavorable light but instead for the purpose of pointing out those things which were troublesome to the operation of the tester used in this investigation so that present and future users of the same model of the Frag tester may be aware of its limitations.

The following points were noted before any testing was undertaken:

(1) The balls which constituted the impacting mass were not strictly spherical but varied in shape, some being oblong, some flat, some pointed. This may or may not affect the results obtained with the Frag tester, but it seems that such a variety of shapes might add to the variability of test results.

(2) The drop attained when the drop assembly hit the impact anvil was never consistently flat. There is no measurable adjustment for achieving and maintaining a flat drop.

(3) The two impact anvils which are used for the 14 cm. and 21 cm. drop heights could not be rigidly held in position.

(4) With the original drop assembly, when the two containers were held together by securing the thumbscrews with hand pressure, the screws would become loose after repeated impacts. This looseness permitted the small steel balls to work between the platens and score the platen surface.

(5) The maximum lifts of the drop assembly were found to be somewhat less than the heights designated by the manufacturer. For a drop height of 14 cm., the drop assembly was lifted 13.956 cm. and, for a drop height of 21 cm., the assembly was raised 20.954 cm. These differences in drop height could give an error of about 1/4% in calculated values of burst energy.

The following weaknesses in the Frag tester were noted after tests were made:

(1) The light which indicates a specimen has ruptured was inoperative after only a few impacts.

(2) The light within the instrument cabinet to indicate the electrical power button is on and allow visual observation of the steel balls as they fall into the lower chamber was inoperative after the first month's use and was replaced by a 50-watt, 250-volt standard-type light bulb which it has been necessary to replace on at least one other occasion. It appears that the constant impacting is hard on the filaments of light bulbs in the instrument.

(3) The counter which records the number of drops required to rupture a specimen broke after approximately one month.

(4) The electrical leads which connect the anvil cut-out leads with the cut-out circuit became loose from vibration.

(5) Inside of the 14-cm. anvil one of the rods which completes the cut-out circuit with the plates within the specimen holder was found broken after two months' use and had to be replaced.

(6) After a period of use, the toggle switch that completes the electrical circuit with the main power supply developed enough play to break contact momentarily when the drop assembly impacted the anvil. This resulted in premature stopping of the test before the specimen failed. This was remedied by replacing the switch.

(7) After a period of use, the clamping arms of the original specimen holder showed signs of fatigue failure. The drop assembly was replaced with a new one from Testing Machines, Inc. The new drop assembly had a cog-locking arrangement to keep the thumbscrews (used for clamping pressure adjustment) from backing off from repeated impacting. During the time the replacement drop assembly was on order, it was noticed that one of the anvil clamp arms had also failed and a new one was constructed for a replacement.

(8) On the new specimen holder one of the clamping brackets through which the thumbscrews pass broke open at a seam. This breakage necessitated brazing the seam closed before testing could be resumed.

In general, much difficulty was encountered in keeping various nuts and bolts from working loose with repeated impacting of the drop assembly on the impact anvil. The lighting and electrical system in general tended to deteriorate from repeated impacts. It was almost impossible to achieve a drop in which the assembly hit the impact anvil flatly and squarely each time. The tightness of the anvil, the tautness between lift chains, and the tightness of the lift arms of the drop assembly seemed to have a substantial influence on the flatness of drop attained, but the degree of tightness achieved with shims or other means seemed to deteriorate as testing proceeded. The clamping of the specimen between the platens of the drop assembly could not be accomplished so that each specimen necessarily was held by a constant pressure. The first assembly used free thumbscrews which tended to loosen as testing proceeded. Therefore, clamping pressure varied throughout a test. The new drop assembly locked the thumbscrews so loosening could not occur, but no provision was made for finer adjustments between locking cogs. This meant that an equal clearance between platens might be attained for two different specimens, but the clamping pressure might still not be identical because the clamping paper used on the platens wears and consequently the clearance between platens may increase, resulting in lower clamping pressure. In conclusion, the instrument itself was found to be a noisy device. Although it may serve some purpose as an experimental tool, its usefulness judged from the standpoint of quiet, troublefree operation for quality control purposes is subject to question.

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