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Friability of Spray-Applied Fireproofing and Thermal Insulations: Laboratory Evaluation of Prototype Test Devices

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National Bureau of Standards became the National Institute of Standards and Technology on August 23, 1988, when the Omnibus Trade and Competitiveness Act was signed. NIST retains all NBS functions. Its new programs will encourage improved use of technology by U.S. industry.

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C. William Verity, Secretary

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Ernest Ambler, Director

ABSTRACT

This report describes the results of the second phase of a study to develop a field test method for assessing the friability of spray-applied fireproofing and thermal insulating materials. Phase 2 is the laboratory evaluation of the prototype devices for conducting surface and bulk compression/shear, indentation, abrasion, and impact tests. These tests were performed on specially prepared fireproofing materials, produced to have a range of friabilities. Differences in response of the test samples to dislodgment or indentation were observed in the tests.

In the surface and bulk compression/shear tests, it was found that, for a given type of material, as the density increased, the torque level at which dislodging occurred increased. In the indentation tests of the fibrous materials, the indentation depth increased as their density decreased. However, little indentation of the cementitious samples occurred regardless of their density. In tests using the abrasion device, all samples left a residue over the range of bearing forces examined. The amount of residue, as determined by image analysis, was extremely variable, and did not relate to the type or density of the material. With regard to the impact tests, all samples underwent some amount of indentation. The lower density fibrous materials experienced the greatest depths of indentation.

The results indicated that the surface and bulk compression/shear, indentation, and impact devices provided some measure of discrimination between samples subjectively judged as having "high" and "moderate" friability. In contrast, the abrasion device was non-discriminating in that, for all tests, a residue was produced. It was concluded that all devices be included in the field phase of the study using in-place spray-applied fireproofings having different levels of friability.

Key words: abrasion; asbestos-containing materials; compression; fireproofing; friability; impact; indentation; mechanical tests; shear; spray-applied; test devices; test methods; thermal insulations

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1. INTRODUCTION

1.1 Background

The Public Building Service (PBS) of the General Services Administration (GSA) has responsibility for the construction, maintenance, and operation of many of the Nation's public buildings. Some were constructed in the era when spray-on asbestos-containing materials were extensively used in building construction. At present, GSA owns approximately 1700 buildings. In some of these buildings, GSA has assessed the conditions of the asbestos-containing materials in the GSA-controlled buildings, monitors changes in its condition over time, and recommends appropriate abatement actions.

GSA prepared an algorithm-based procedure for use in the assessments of its buildings that have asbestos-containing materials [1]. The GSA algorithm was developed on the basis of modifications and additions to an earlier Environmental Protection Agency (EPA) algorithm [2]. The GSA assessment procedure was intended to "provide a relative index that indicates an overall risk potential" [1]. The use of the algorithm allowed GSA to identify the relative potential risk in the buildings with asbestos-containing materials. It also allowed GSA to rank the results of the condition assessments in a priority order for those buildings needing abatement actions.

For purposes of asbestos control, a friable asbestos-containing material is "any material containing more than 1 percent asbestos by weight that hand pressure can crumble, pulverize, or reduce to powder when dry" [3]. The GSA algorithm, as well as others [4], assess the friability of the asbestos-containing material from a subjective and non-defined test using the hand [5]. In the algorithm-based procedures, friability is normally ranked in one of four levels: high friability, moderate friability, low friability, and not friable. Because of the importance of having an objective ranking of the condition of the asbestos-containing materials in its buildings, GSA proposed that the friability test procedure using the hand should be replaced with a more objective, quantitative procedure. Thus, GSA requested the National Institute of Standards and Technology[1] (NIST) to develop a field test procedure for assessing and monitoring the friability of spray-applied or troweled-on asbestos-containing materials.

This report describes the second phase of the GSA-sponsored study for the test method development. The development of a quantitativ friability test method will assist GSA to:

- improve condition assessments of asbestos-containing materials,
- establish priorities for abatement programs,
- select appropriate abatement options, and
- monitor the change in friability of asbestos-containing materials.

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[1] formerly the National Bureau of Standards (NBS).

The results of the first phase of the study have been reported [5]. Phase 1 was limited to the development of the technical bases for the field test method for assessing friability. Included in the scope of Phase 1 was the development of a conceptual model for determining the level of friability using mechanical tests. The conceptual model considered hand actions possibly used by field inspectors in friability determinations, and the descriptors of levels of friability of spray-applied asbestos-containing material given in algorithms.

A key task carried out in Phase 1 was the development of prototype test devices (see Section 2 of the present report) for conducting friability tests in the field [5]. Preliminary laboratory tests using the devices were performed on specially prepared spray-on mineral fibrous and cementitious fireproofings, which did not contain asbestos but which were produced to have a range of friabilities. The results suggested that the devices could distinguish between degrees of friability of the test samples. For example, for the fibrous materials included in the tests, the force required to damage the samples increased as the sample density increased.

The approach suggested in Phase 1 for development of a field test method for assessing the friability of a spray-applied fireproofing or thermal insulation is empirical. It was undertaken in response to an urgent need for GSA to have available a field test method that is not subjective. Ultimately, what is needed is to relate the results of the measurements using the prototype devices to the probability of releasing fibers or particles from the sample into the air. Also, as previously proposed [5], it may be useful to consider whether an indicator other than friability would be useful for characterizing the potential of the spray-on material to release fibers. Such properties might include cohesive/adhesive strength of the material and fracture mechanics properties such as the energy involved in fracturing or deforming the material.

1.1.1 Use of Algorithms to Assess Friability

Algorithm procedures for assessing the condition of spray-applied asbestos-containing materials were developed to provide a method for predicting the potential for fiber release and subsequent contamination of the building space [2,6,7]. The use of algorithms for assessing the condition of in-place asbestos-containing materials was reviewed in the Phase 1 report [5]. Eight factors, of which one is friability, are addressed in the algorithm-based assessments. The review of algorithm procedures in Phase 1 provided, in part, the basis for the prototype devices for evaluating friability. As indicated earlier in the present report, GSA originally developed the algorithm procedure as a means for obtaining a relative index of the risk potential for the buildings under its responsibility. At present, GSA makes less use of the algorithm, because most of the buildings under its responsibility have undergone assessments of sprayed-on fireproofings and insulations using algorithm-based procedures[2]. Consequently, GSA now has placed emphasis on a need to have available a non-subjective field method for assessing friability for use in abatement programs and in monitoring changes in friability over time.

1.2 Objective

The overall objective of the study is to develop a field test method to measure the friability of spray-applied fireproofing and thermal insulation materials. The level of friability has been associated with the potential of various types of spray-applied fireproofing and thermal insulations containing asbestos fibers to release materials into the building environment [8]. The objective of Phase 2 is to evaluate, in laboratory tests, the performance of the prototype devices in distinguishing different levels of friability of spray-applied fireproofing and thermal insulation materials. The present report presents a summary of the second phase. In Phase 3, field evaluation of the prototype devices will be conducted by NIST and recommendations for the field test method will be developed.

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[2]. Personal communication of W. Chan, GSA, to the authors of the report.

1.3 Scope of the Study

The scope of Phase 2 was limited to laboratory testing of the prototype devices. No field tests were conducted. The laboratory tests were performed using the same non-asbestos-containing materials obtained during the development of the prototype devices. The major tasks performed in Phase 2 of the study were:

- Modification of the compression/shear test device to provide for a uniform reproducible bearing force at which the device is set in contact with the surface of the specimen during testing.
- Modification of the flow diagram proposed in Phase 1 to reflect the need for GSA to have a field test method which may be used in abatement programs and also programs monitoring changes in friability over time.
- Development of a test protocol with the assistance of a statistician in the NIST Center for Applied Mathematics who provided advice on experimental design.
- Performance of the laboratory tests using the prototype devices.
- Analysis of the results with the assistance of the statisticia who participated in the experimental design.

2. PROTOTYPE TEST DEVICES FOR ASSESSMENT OF FRIABILITY

Figure 1 presents the modified flow diagram. The modifications were based on discussions with GSA regarding a sequence for conducting friability tests of spray-applied fireproofing and thermal insulation. It is based on the flow diagram proposed in Phase 1 for use with the GSA algorithm for assessing friability. As is evident, five tests are included in the sequence: surface compression/shear, bulk compression/shear, indentation, abrasion, and impact. The development of prototype devices for conducting the tests has been reported [5]. Appendix A provides photographs of the prototype test devices including the modified torque screwdrivers for performing surface and bulk compression/shear tests.

Appendix B describes the modified torque-screwdriver devices and their operation in conducting the surface and bulk compression/shear tests. The torque-screwdriver devices, as originally described in the Phase 1 report [5], were modified after the report's publication, and prior to conducting the Phase 2 laboratory tests described herein. The device for the surface compression/shear test was modified by the addition of a bearing plate and spring-loaded disk and fins (Figure A1). This was to provide uniform reproducible bearing force when the disk and fins are brought in contact with the surface of the test specimen during application of torque. The device for the bulk compression/shear test was modified by providing the disk with the same number and configuration of fins (Figure A2) as the surface compression/shear device. However, the bulk compression/shear device has longer fins than the surface compression/shear device.

The use of the flow diagram (Figure 1) is very similar to that proposed in Phase 1 for assessing friability according to an algorithm procedure. The key difference between the current and previous flow diagrams is that, in following the revised diagram to conduct tests, the results are not used to assign a classificati of the level of friability to the material. The intent of the revised diagram is to provide a sequence for conducting the friability tests and recording the data which may be used by GSA in ways such as comparing results for a series of buildings (e.g., establishing abatement priorities), or monitoring changes in a material for a given installation over time.

In using the flow diagram (Figure 1) for conducting field assessments of friability of a spray-applied fireproofing or thermal insulation, it is anticipated that tests would be conducted in turn until a positive result was obtained (i.e., a "yes" is produced). However, in the Phase 2 laboratory study, all five tests were conducted on each of the available samples.

3. EXPERIMENTAL

3.1 <u>Test Samples</u>

The spray-applied fireproofings, obtained during Phase 1 of the study in the development of the prototype devices, were also used in the laboratory program. These test samples included both mineral fibrous and cementitious spray-applied materials (Table 1). These materials were specially prepared by the suppliers in an attempt to simulate the range of friability levels given in the algorithms for the condition assessment of asbestos-containing materials. This was to provide a basis for the range of friabilities over which the test devices may be used. The densities [5] of the test materials are given in Table 1. The dimensions of both types of samples were 24 by 24 in. (600 by 600 mm) with a nominal 1 in. (25 mm) thickness of the fireproofing. The mineral fibrous material was prepared on 1/2 in. (13 mm) drywall board. The cementitious samples were spray-applied on 3/4 in. (19 mm) plywood. The samples were placed on a rigid laboratory bench during testing.

The spray-applied samples were examined manually according to the algorithm-based directives for judging the friability of asbestos-containing materials (Tables 2 & 3). The friability levels assigned to the samples, as based on the authors' judgment using the descriptions defined in Tables 2 & 3, are given in Table 4. Since the judgment was made using a subjective procedure, it was possible that other investigators might have assigned other friability levels. Three of the fibrous samples (F1, F2, & F3) were ranked in the "high friability" category; whereas the remaining four samples (F4, C1, C2, & C3) were categorized as having "moderate friability." None were considered as having "low friability" or being "not friable."

3.2 Test Protocol

The laboratory tests were conducted using the following protocol:

- The series of tests with each device was performed by two individuals so that the possibility of an operator effect could be examined.

- Three replicate specimens of each of the seven samples (F1 - F4 & C1 - C3) were used in each series of tests.

- The locations on the specimens for conducting the friability tests were selected by dividing the 24 by 24 in. (600 by 600 mm) specimen surface area into a grid of small squares, each 3 by 3 in. (75 by 75 mm). In the following sections of the present report, the term "square" is used to denote the small area of a specimen where a test was conducted. The grid of squares was marked on the specimen surface using a chalk line. The outer grid squares at the perimeter of the specimen were not used in the tests to eliminate specimen edge effects. The result was 36 usable squares per 24 by 24 in. (600 by 600 mm) specimen. A random pattern of selecting individual squares for each given test was not used. The same type of test (e.g., impact) was not conducted on two adjacent test squares.

- The operation of the devices was as previously described [5]. A summary of the variables examined for each of the test devices is given in Table 5. (The test procedure used with each device is given below in Section 3.2.1.)

- The cohesive strength of the test samples was measured according to the procedure given in ASTM E 736, Standard Test Method for "Cohesion/Adhesion of Sprayed Fire-Resistive Materials Applied to Structural Members" [10].

- Data were recorded in a computer file and analyzed using a statistical graphics program called "DATAPLOT" [11].

3.2.1 Test Procedures Using the Prototype Devices.

The test procedures for the devices were as follows:

a) Surface Compression/Shear Test. In conducting this test, the bearing force level (i.e., the force maintained normal to the surface of the specimen while the torque is applied) at which the fins of the device (Figure A1) were placed in contact with the specimen surface was first set. Two bearing force levels, 1 and 2 lbf (5 and 10 N), were chosen for this test program, and a series of surface compression/shear tests was conducted at each bearing force level. At the beginning of a series of tests, a torque level for the screwdriver was arbitrarily selected. The torque device was set on a specimen square, and the handle of the screwdriver was manually rotated. For the pre-set torque level, the specimen for a given square was designated as having "passed" the test if it resisted the level of applied torque without pieces dislodging (i.e., rotation of the handle occurred). Conversely, for the pre-set torque level, the specimen for a square was designated as having "failed" the test if pieces were dislodged at a torque less than or equal to the setting (without rotation of the screwdriver handle).

The torque setting on the screwdriver was increased or decreased in successive tests until a "pass/fail point" was experimentally determined for the specimen. The pass/fail point was associated with the band of data within which the test results represented a switch in the specimen's resistance to the level of applied torque from primarily passing to essentially failing. It was estimated as the "50 percent point," that is, the torque level at which 50 percent of the specimens tested passed the test. The pass/fail point was determined in one of two ways. First, it was taken as the torque setting of the screwdriver at which replicate determinations on test squares for a given specimen produced a number of both passes and failures. Second, in cases where no such torque setting was found, the pass/fail point was indicated by the torque setting at which essentially all tested squares passed, while at an incrementally higher setting, essentially all the tested squares failed. In general, for each replicate test specimen, the surface compression/shear test was conducted repeatedly on different squares at varying torque settings of the screwdriver until at least three failures and three passes were recorded at the same or at incrementally consecutive settings. (Three was considered the minimum necessary to have a measure of reproducibility of the results.)

b) <u>Bulk Compression/Shear Test</u>. This test was conducted in a manner similar to that for the surface compression/shear test in that a pass/fail point was determined for each specimen. Thus, an initial torque level on the screwdriver (Figure A2) was arbitrarily set. The bulk compression/shear test device was set on a test square such that the disk was flush with the specimen surface with the fins penetrating the specimen. If the fins did not totally penetrate the specimen, the test was not conducted. The screwdriver handle was manually rotated. The pass/fail point was again determined by increasing or decreasing the pre-set torque level set on the screwdriver and observing whether the specimen resisted the torque (i.e., continuous rotation of the screwdriver handle was possible) or whether pieces of the specimen were dislodged for each selected torque level.

c) Indentation Test. In this test, the extent of indentation of the foot of the device (Figure A3) into the specimen was recorded as a function of the bearing force level applied on the specimen surface. Four force levels, 4.5, 9, 13.5, and 18 lbf (20, 40, 60, and 80 N), were used for the fibrous samples. The third level, 13.5 lbf (80 N), was not used for the cementitious samples because of the limited number of samples. Three determinations of indentation were made for each replicate specimen at each bearing force level used.

d) Abrasion Test. This was conducted as a pass/fail test in that the felt disc on the foot of the abrasion device (Figure A4) was examined for the presence of a residue after its rotation on the specimen surface. Before conducting the tests, all felts were cleaned by hand-wiping to be seen visually free from fibers, lint, particles and similar material. If a residue was observed, then the specimen for a given test square was considered to have failed. This criterion was selected consistent with descriptors of friability concerning manual rubbing actions leaving powder or granules on the hand (Table 2). The variable investigated was the bearing force level applied when the felt face of the abrasion test device was set flush on the specimen surface. As for the indentation tests, four bearing force levels, 4.5, 9, 13.5, and 18 lbf (20, 40, 60,and 80 N), were used for the fibrous samples. The third level, 13.5 lbf (60 N), was omitted for the cementitious samples.

In addition to indicating that the specimen for a given square passed or failed based on the presence of a residue on the felt, the percent area of the felt covered by residue was determined using an image analysis technique [9]. This technique was a laboratory procedure to quantify the area of residue and was not intended for field use. Nevertheless, it could be applied to field testing by analyzing, in the laboratory, felts removed from the device or pictures taken of the felts.

e) Impact Test. The impact tests were conducted on the surface of the specimens using three rubber tips of varying size and hardness (Table 5). For all specimens, the impact tests were performed in duplicate. The depth of the indentation produced in the specimen by the impact device (Figure A5) was determined. This measurement was made using a depth gage which could be read to 0.1 mm. The depth measurement was made at the approximate center of the indentation.

4. RESULTS AND DISCUSSION

4.1 Comparison for Forces Applied by the Prototype Test Devices With Forces Likely From Hand Actions

Appendix C provides a comparison of the forces which could be exerted by the prototype test devices to the maximum forces which may be exerted by some hand actions expected to be used by field inspectors in assessing friability of spray-applied fire-proofings. As discussed in Appendix C, the forces which could be applied by the prototype devices were within the range of forces generated by the selected hand actions, and in most cases, comparable to the maximum forces of the hand actions. The maximum hand forces used in this comparison were exerted by 12 shop personnel considered to have relatively strong hands (see Appendix C).

4.2 Operator Effects

All tests using the prototype devices were conducted by two of the authors. This was to provide information on operator effects. For all devices, examination of the plotted data (not shown) clearly indicated no differences in results attributable to operators. The authors conducting the tests were associated with the development of the devices and thus considered to be skilled in their operation. Further tests with a larger group are required for a range of partially skilled (i.e., only briefed on use of the devices) to determine whether an operator effect exists for such individuals.

4.3 Effects of Replicate Specimens

As mentioned previously, all five tests were conducted in triplicate using three 24 by 24 in. (600 by 600 mm) specimens for each of the seven samples (F1 - F4 and C1 - C3). For each of the five tests, no substantial differences in results among the replicate specimens were found. Thus, in the discussion of the results which follows for each type of test, no reference is made to replicate specimens. Data for each of the five tests are grouped together for each of the seven samples.

4.4 Surface Compression/Shear Test

The surface compression/shear tests were first conducted on the fibrous samples using the torque-screwdriver device set flush on the specimen surface at one of the two bearing force levels. These levels, 1 and 2 lbf (5 and 10 N), were considered to be low, yet sufficient to allow the test to be conducted at a reproducible bearing force. Based on the results for the fibrous samples, the test was then conducted on the cementitious samples at the bearing force level of 2 lbf (10 N). (Sufficient cementiti sample was not available to allow the surface compression/shear tests to be performed at both bearing force levels.)

The results of the surface compression/shear tests at the bearing force levels of 1 and 2 lbf (5 and 10 N) are given in Figures 2 and 3, respectively. "Pass" indicates the specimen resisted the torque applied, while "fail" indicates specimen material was dislodged at a torque less than or equal to the set level (Section 3.2). A comparison of the results in these figures for the fibrous samples (F1 - F4) shows that, as the bearing force was raised from 1 to 2 lbf (5 to 10 N), the torque required to dislodge sample material (i.e. cause failure) increased. In general, for each sample, the pass/fail point at the greater bearing force (Figure 3) was about 1 unit of torque more than the pass/fail point at the lower bearing force (Figure 2). For example, in the case of sample F1, when the bearing force was 1 lbf (5 N), all tests resulted in failure at a pre-set torque level of 2 lbf in. (0.2 N m). However, when the bearing force was 2 lbf (10 N), about half the F1 samples passed and half failed at the 2 lbf in. (0.2 N m) torque level. The slight upward shift in resistance to dislodging as the bearing force increased was attributed to the increased compression of the samples. However, the slight shift was not considered significant, and it was decided that further testing (including field tests) be conducted at the greater bearing force level of 2 lbf in. (0.2 N m). A general benefit of the upward shift in the specimen resistance to dislodging is that, for samples having low resistance, the device would less likely be operated near its lower limit of torque when using the greater bearing force.

From the results presented in Figures 2 and 3, it is evident that, for a given type of sample (fibrous or cementitious), as the density of the samples (see Table 1) increased, the pass/fail point tended to increase. This was attributed to the presence of more binder in the samples of higher density. Having more binder, the samples probably had higher cohesive and shear strengths. The correlation between pass/fail point and density was not perfect as shown by the observation that samples F4 and C1 had comparable pass/fail points (Figure 3), although the density of sample C1 was about 23 percent less than that of sample F4. This indicated that, for the different types of materials in the study, density was not a correlation factor.

Figures 2 and 3 also show that the range of torque settings used in the tests to establish a pass/fail point for any individual sample was rather small. In most cases, only three or four consecutive settings of torque were used. The maximum number was five in the case of two cementitious samples, C2 and C3 (Figure 3

The finding that, for a given type of material, the sample resistance to dislodging in the surface compression/shear test increased with an increase in sample density was comparable to the subjective observations regarding dislodging using the hand. As summarized in Table 4, the samples appeared to increase in resistance to dislodging by pinching with the finger tips as density increased. This observation supports the premise that the mechanical surface compression/shear device may be used in lieu of the hand for determining a friability level for the spray-applied fireproofing.

In conducting the series of laboratory tests, the torque level was changed from one setting to another in determining the pass/fail point for each of the specimens. An important question was whether the surface compression/shear test device could be used at a single torque level to distinguish between samples considered of "high" and of "moderate" friability as subjectively assigned (Table 4) to the samples in this study.

Figure 4 shows, for each of the seven samples, plots of the percent of tests that passed at each pre-set torque level for the series of tests conducted using a bearing force of 2 lbf (10 N). The estimated pass/fail points are marked on these plots. Note that, in each plot with the exception of C2, the percent passed decreased with an increase in torque level. In addition, it can be seen that the torque levels used in the tests to establish the pass/fail points of the samples increased in the series F1 through F4 and C1 through C3. In Figure 4, the top row of plots is for those samples subjectively assigned (Table 4) a level of "high friability," whereas the middle and bottom rows are for samples designated as having "moderate friability." It is evident in Figure 4 that all test squares of specimens of "moderate friability" tested at a torque level of 5 lbf·in. (0.6 N·m) passed the test. Only at torque levels above 5 lbf·in. (0.6 N·m) did failure of the "moderate friability" specimens occur. Conversely, the majority of all test squares of specimens of "high friability" tested at the 5 lbf·in. (0.6 N·m) torque level failed the test. This finding suggested that a torque level of 5 lbf·in. (0.6 N·m) could be used to distinguish between the two categories of samples in the laboratory study.

4.5 Bulk Compression/Shear Test

The bulk compression/shear test was only conducted on the fibrous samples. The fins of the bulk compression/shear test device could not penetrate the cementitious samples. In using the flow diagram (Figure 1) to assess friability, it is considered that if a sample could not be tested using the bulk compression/shear device (and it passed the surface compression/shear test), then it should be evaluated using the indentation, abrasion, or impact devices, in turn as necessary, to provide a friability level.

Unlike the surface compression/shear test device, the bulk compression/shear device was not designed to have a collar for setting the bearing force at which the fins and disk are placed in contact with the sample surface. Based on considerations that the device contained a relatively large bearing disk, it was sufficient that the fins on the disk of the bulk compression/shear device be able to penetrate the test sample as the face of the disk is brought flush with the sample surface using the necessary amount of manual force [5].

The results of the bulk compression/shear tests of the fibrous samples are given in Figure 5. The trend in the data was comparable to that for the surface compression/shear tests on the fibrous samples in that, as the density of the samples increased, the torque level at which dislodging occurred increased. Also, the range of torque settings over which testing was performed to determine the pass/fail point was again found to be rather small, generally 3 or 4 settings of torque, suggesting that the laboratory samples had somewhat uniform compression/shear resistance.

The range of torque settings over which the bulk compression/shear tests were conducted on the four fibrous samples was from 2 to 30 lbf·in. (0.2 to 3.4 N·m) which reached the upper limit of the device. This range was greater than that used to conduct the surface compression/shear tests. As indicated in Appendix B, the fin area for the bulk device is four times larger than that for the surface device. Thus, an increase in torque range for the bulk compression/shear tests was expected. For a given pre-set torque setting, the force per unit fin area applied to the sample through the fins of the test device is less in the bulk compression/shear test than in the surface compression/shear test.

Table 6 provides a comparison of the pass/fail points determined on the fibrous samples in the surface and bulk compression/shear tests. As given in Table 6, a greater spread between the pass/fail points of each of the four fibrous samples was found in the series of bulk compression/shear tests as compared to the surface compression/shear tests. For example, in the bulk compression/shear tests, the pass/fail points for samples F3 and F4 were about 15 lbf·in. and 29 lbf·in. (1.7 and 3.3 N·m), respectively, which is a difference of 14 lbf·in. (1.5 N·m), or about a factor of 2. In contrast, for the surface compression/shea test, the pass/fail points for samples F3 and F4 were 5 and 6 lbf·in. (0.6 and 0.7 N·m), respectively, or a difference of only 1 lbf·in. (0.1 N·m), or a factor of 1.2. An advantage in having wider spreads between pass/fail points of different samples, as observed for the bulk tests, is greater potential for distinguishin between samples because of less possibility of overlap.

A key question to consider again is whether the bulk compression/sh test may be used at a single torque setting to distinguish between spray-applied materials of "high" and "moderate" friability Figure 6 gives, for each of the fibrous samples, plots of the percent of the specimen squares passing the test versus the pre-set torque setting. Note in Figure 6 that, for the limited data in the study, a torque setting of about 20 lbf·in. (2.3 N·m) provided a complete discrimination between samples assigned to categories of "high" and "moderate" friability. In all tests of the "high friability" fibrous specimens, a torque level below 20 lbf·in. (2.3 N·m) was found which produced 100 percent failure, whereas for "moderate friability" specimens, some torque levels slightly above 20 lbf·in. (2.3 N·m) were found that gave 100 percent passing.

4.6 Indentation Test

In using the indentation test device, the foot of the penetrometer was placed on the surface of the test specimen [5]. Then, a bearing force was manually applied until the collar of the device was flush with the test specimen surface. The maximum bearing force applied during testing was reached when the collar face became flush with the test specimen surface. Adjustment of the collar position along the length of the device housing resulted in different test forces. In the present study, four bearing forces were used as given in Table 5.

In conducting the indentation tests, the foot of the test device indented the test specimen or caused retraction of the rod supporting the device into the housing, making the indicator rod extend [5]. The extension was an indication of the specimen's resistance to indentation). For example, if the indicator rod extended fully, then indentation of the test specimen did not occur.

For each specimen at the bearing force levels used, the indentation test was generally conducted in triplicate. Bearing force level three, 13.5 lbf (60 N) (Table 5), was not included in the tests of the cementitious samples in order to conserve specimens. The results of the indentation tests are given in Figure 7. The indentation depth is given in "units," because the scale of the indicator rod of the indentation device is not marked in increments of length such as inches or millimetres[1] [5]. Use of the indentation device with the amount of indentation given in "units" was acceptable for this investigation. However, if the device is to be used in common practice, then the scale should be changed and marked in increments of length.

The results in Figure 7 indicated different behavior for the fibrous and cementitious samples. In general, for the fibrous materials, the higher applied bearing forces produced greater depth of penetration. For these samples, the greatest indentation was 2.25 units. This was achieved for the least dense sample, F1, at a bearing force of 18 lbf (80 N).

The cementitious samples were found to be resistant to indentation (Figure 7). For all cementitious samples, the majority of the measured indentations was 0.25 units. Little effect due to the bearing force level was observed, although samples C1 and C2 experienced indentation of 0.50 units at the greater bearing force levels (3 and 4). Conversely, the lower bearing force levels (1 and 2) produced no measurable indentation for some measurements of all samples. The slight indentation (0.25 units) found for the cementitious samples was primarily due to compaction of the rough-texture material at the surface. The foot of the

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[1]. For the information of the reader, each unit of the scale is about 0.3 in. (8 mm).

indentation device essentially underwent no penetration into the bulk of the specimens.

The results of the indentation tests of the cementitious samples may be considered with regard to the descriptor of a material that is of "moderate friability" (Table 2). This descriptor states such materials are "easily indented by hand pressure." A measured indentation of about 0.25 units was not considered indicative of a sample that is "easily indented." It appeared that the portion of the descriptor for "moderate friability" regarding indentation by hand pressure was more appropriate to the fibrous materials than the cementitious ones.

A consideration was whether the indentation test provided discrimination between samples considered to be of "high" and "moderate" friability. This is addressed in Figure 8 which is a plot of indentation depth versus sample for the tests conducted at bearing force level 4, and includes the average indentations for each sample (the bold lines). In addition, the upper portion of the plot notes the assigned friability levels (Table 4) of the samples. The average indentation of the samples assigned a "high friability" level was greater than 1 unit, whereas those ranked in the "moderate friability" level had an average indentation of about 0.5 units or less.

However, it was concluded that the indentation findings regarding discrimination of the test samples had no relation to the descriptors of levels of friability. As mentioned above, some "moderately friable" materials are described as being "easily indented by hand" (Table 2). The selection of an indentation depth of 0.5 units or less as the benchmark for "moderate friability" would be illogical. The consequence of such a selection would mean that a sample, assigned as having "moderate friability" on the basis of being "easily indented by hand" would, at the same time, have to exhibit little or no measurable penetration in the indentation test.

The observation that samples in the study considered as having "moderate friability" experienced little or no penetration using the indentation device raises two questions. First, it may be asked whether the indentation test is needed, and second, whether the compression/shear or abrasion tests can provide the same information. The data from the laboratory phase were too limited to answer the questions. Specifically, no samples were available in the study that were assigned the designation of "moderately friable" on the basis of their resistance to indentation by hand. It is considered that field testing will provide further data on indentation of materials having a range of friability, as assigned according to the descriptors in Tables 2 and 3.

4.7 Abrasion Test

The abrasion test was conducted at four levels of bearing force in the case of the fibrous materials and three levels in the case of the cementitious samples. Two replicate tests per sample were conducted at each bearing force level. It was originally intended to conducted triplicate tests, but the initial observations of abrasion resistance indicated that failure was likely to occur in all tests. Thus, the number of replicate tests was reduced to two.

The abrasion test is a pass/fail procedure in that any amount of sample residue, found on the black felt covering the foot of the test device through visual examination, is considered a "failure" of the sample. The results of the series of abrasion tests conducted on the study samples indicated that all failed. Every test left some amount of residue on the felt. Because of the light color of the samples, the residue could be clearly seen on the black felt. The perception from the visual observations was that the amount of residue left on the felts varied from slight to considerable, but a pattern relating the residue amount to either the type of material or the bearing force level could not be discerned when examined by eye.

Image analysis was performed on the felts removed from the abrasion test device to estimate the surface area covered by residue. A minor amount of residue was lost from most felts in detaching them from the foot of the test device. This was not believed to have a major effect on the image analysis results of percent area covered by residue. The results of the image analysis are given in Figure 9 which consists of four plots of the percent area of felt covered by residue in relation to the type of test material. Each plot represents a bearing force level at which the test device was set in contact with the sample surface. As is evident in Figure 9, the area covered by residue was found to vary from a little more than zero to over 90 percent. The variation in percent residue for many individual samples was found to be wide, in some cases having an absolute range greater than 50 percent (e.g., sample F1 at load level 4). The scatter was attributed to surface roughness effects in that the foot of the abrasion device was not always in uniform contact with the sample. Raised portions of the sample surface visually appeared to be more susceptible to abrasion damage than those sections having slight valleys or dips.

In general, the percent area of felt covered by residue was not found to relate to the variables of either bearing force level or type of material (Figure 9). This finding was consistent with the visible observations made during the testing. At best, the percent area of residue may have increased slightly for the cementitious materials at the higher bearing forces. The general conclusion for the abrasion procedure was that the test was non-discriminating between the samples in the study. This finding was comparable to hand testing of the samples whereby each was found to leave a residue when rubbed with the palm of the hand (Table 4). Although the method was non-discriminating, it may still be important for showing ease of loss of fibers or particles from the surface of a sample.

4.8 Impact Test

The results of the tests using the impact device are given in Figure 10. The specimens under all test conditions underwent some amount of indentation. Three different tips were used in the test. Tip no. 1 was empirically selected when designing the device such that the impact imparted would be somewhat comparable to "forceful impact" (Table 2) using the hand [5]. In conducting the series of tests described in the present report, the effect of different tips on the resultant impact damage to the test specimens was examined. Consistent with the descriptor of "low friability," (Table 2), impact damage was measured as the depth of indentation (impact depth) found in the tests.

Tip no. 2 was made of a rubber having the same hardness as tip no. 1, but the size was smaller (Table 5). Thus, it was expected that tests with tip no. 2 might produce greater impact depth, because the impact energy would be more localized. Similarly, tip no. 3 was the same size as tip no. 2, but it consisted of a harder rubber. It was considered that tests with tip no. 3 would produce greater impact depth (versus tip no. 2), because less energy would be dissipated through deformation of the rubber tip. In the cases of both tip nos. 2 and 3, it was believed that the changes in impact characteristics would not be drastic enough to create a device imparting impact to the samples radically different from using the hand.

It is evident from Figure 10 that the suppositions made in selecting alternative test tips were only partly correct. In general, as expected, tests made with tip no. 1 produced the least impact depth (Figure 10). However, little difference was found between the impact depths measured for tip nos. 2 and 3. Apparently, their hardness difference (Table 5) was not great enough to produce a noticeable effect on impact depth for the samples tested.

Another observation in Figure 10 is the groupings of impact depths for samples F1, F2, and F3 versus samples F4, C1, C2, and C3. The impact depths for the former group are, on the average, about 0.6 in. (1.5 cm), whereas they are about 0.3 in. (0.7 cm) for the latter group. These two groupings correspond to the friability rankings of "high" and "moderate" subjectively assigned to the samples (Table 4). This observation was comparabl to that found for the indentation test device in that greater indentation occurred with the samples ranked as having "high friability." As in the case of the indentation device, no significance was attached to the results.

The test results for the impact device produced no strong evidence that would warrant selecting a rubber tip other than no. 1, which was used in the original design of the impact device. All tips produced some indentation and the patterns for the samples were comparable. Moreover, no practical reasons were found during testing to change impact tips. Although the smaller tips generally produced slightly greater impact depth, the indentations given by the larger tip (no. 1) were generally sufficient to be readily seen. It is suggested that field testing of the device be conducted using the original tip.

4.9 Cohesion/Adhesion Test

ASTM E 736 is a standard test method for "measuring the cohesion/adhesion or bond strength (tensile) perpendicular to the surface of sprayed fire-resistive material applied to rigid backing" [10]. The spray-applied fireproofing samples in the present study were subjected to the ASTM E 736 procedure to provide a comparison of the cohesion/adhesion results with those obtained with the prototype devices for assessing friability. It was considered that the determination of sample friability, as examined using the prototype devices, might show a relationship to the cohesion/adhesion strength of the test samples. As stated in the ASTM E 736 standard, the method provides "an indication of the ability of sprayed fire-resistive material to remain in place and resist separation during anticipated service conditions." This statement was considered consistent with the concept of material friability which is taken as the ease of material dislodging through crumbling or powdering under service conditions

In brief, the E 736 procedure involves adhering a plate with an attached hook to the surface of the test specimen. One end of a spring balance is connected to the hook and a force is manually applied by pulling on the other end of the balance. The force at which specimen failure occurs is recorded. The results of the cohesion/adhesion tests are given in Figure 11. For all tests, the failure of the sample was found to be cohesive, occurring within the sample bulk. No failures occurred at the interface of the samples and their substrates.

The results (Figure 11) indicated that, for both the fibrous and cementitious materials, as the density increased, the cohesion strength generally increased. One test of sample C3 produced a much lower strength value of 34 lbf (151 N) than the other measurements on this sample. Reasons for this observation were not determined.

The pattern of increased cohesion strength with an increase of density closely resembled the surface compression/shear results obtained using the torque-screwdriver device (compare Figures 3 and 11). Note, for example, that the pass/fail points for dislodging the samples using the surface compression/shear device were comparable for samples F4 and C1, while the cohesion strengths of these two samples were also found by the ASTM E 736 method to be similar. These results may suggest that the compression/shear test provided an indirect measure of the cohesion strength of the samples.

It is evident from Figure 11 that no overlap of cohesion strength existed between the set of data for samples F1, F2, and F3, and the set of data for samples F4, C1, C2, and C3. The values of cohesion strength for all tests of samples F1, F2, and F3 fell at or below 14 lbf (62 N), whereas the values for samples F4, C1, C2, and C3 were 20 lbf (89 N) or more. As indicated previously, the former group of samples were categorized as having "high friability," while the latter group were considered as having "moderate friability." The discrimination of friability levels found in the surface compression/shear tests (as well as the indentation and impact tests) was also observed in the ASTM E 736 cohesion/adhesion tests.

5. SUMMARY AND CONCLUSIONS

This report describes Phase 2 of a study to develop a field test method for assessing the friability of spray-applied fireproofing and thermal insulating materials. Phase 2 was the laboratory evaluation of the prototype devices for conducting surface and bulk compression/shear, indentation, abrasion, and impact tests. These tests were performed on specially prepared fireproofing materials, produced to have a range of friabilities. Differences in response of the test samples were observed in the tests. The test devices were designed to impart forces somewhat comparable to those exerted by human hand actions that may be used by field inspectors in conducting friability assessments.

The surface and bulk compression/shear devices measure the resistance of a material to dislodgment as a function of the level of torque set on the test device. For these two types of tests, the patterns of the results were similar. It was found that, for a given type of material, as the density increased, the torque level at which dislodging occurred increased. For any fibrous sample, the torque levels resulting in dislodging were greater in the bulk compression/shear test than in the surface compression/shear test. This was attributed to the larger fins in the bulk device which consequently applied the compression/shea action over a greater area (thus, providing lower localized stress on the specimen). Although the pattern of results for the two compression/shear tests were similar, it was considered that both tests should be evaluated in field testing. The reason is that the surface and bulk properties of materials may have different characteristics which could lead to two types of field tests.

In the case of the indentation device, a measurement of the depth of indentation during testing is made. Here it was found that the two types of material, fibrous and cementitious, had differing behavior. For the fibrous materials, the indentation depth increased as the density decreased. However, little indentation of the cementitious samples occurred no matter what the density.

The abrasion device provides a measure of the sample's resistance to being abraded in a rubbing type of action under a reproducible bearing force. In the test, abrasion is indicated by the presence of a residue left on the felt disk, i.e., the abrasion surface of the device. It was found that all samples left a residue over the range of bearing forces examined. The amount of residue, as determined by image analysis, was extremely variable, and did not relate to the type or density of the material. Variable surface roughness of the samples may have contributed to the wide scatter in the results.

When the samples were subjected to testing using the impact device, all underwent some amount of indentation. The lower density fibrous materials experienced the greatest depths of indentation. A variable examined in the tests was the size and hardness of the tip of the impact device. The results indicated only a slight difference in impact depth for the large and small diameter tips. The depth was greater for the small tip because the impact energy was more localized on the sample. Because the results were not significantly different, it was recommended that the tip originally used in the design of the device be used for field testing.

A question to be addressed by the laboratory program was whether the devices could discriminate between materials having different levels of friability. The samples in the study were subjectively judged as having "high" and "moderate" friability. The results using the prototype devices indicated that, for the study samples, the surface and bulk compression/shear, devices provided some measure of discrimination. Similarly, the indentation and impact devices were somewhat discriminating. However, these results were not considered significant. In the case of the indentation device, the "moderate friability" samples were essentially not indented under the test conditions. The finding was not consistent with the descriptors of levels of friability indicating that some "moderately friable" samples may be easily indented. In contrast to the results with the surface and bulk compression/shear, indentation, and impact devices, the abrasion device was non-discriminating. All samples produced a residue in the test which may be important for showing ease of release of fibers of particles from the surface of a sample.

In conclusion, all devices evaluated in the laboratory phase (Phase 2) of the study will be included in the field phase (Phase 3) using in-place spray-applied fireproofings. Field data are needed to demonstrate the applicability of the devices for determining friability of sprayed-applied fireproofings in service. Results of the laboratory and field tests will be compared. It is anticipated that fibrous and cementitious materials will be included in the field phase, and thus will have different levels of friability. The friability levels will be classified according to the descriptors of friability given in Tables 2 and 3. The buildings containing the spray-applied fireproofings will be selected by GSA personnel.

6. ACKNOWLEDGMENTS

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Table 1. Spray-Applied Materials Used in the Laboratory Tests

Sample No.	Material Type	Density[a]	
		lbm/ft^3	kg/m^3
F1	Mineral Fibrous[b]	8	128
F2	Mineral Fibrous	12	192
F3	Mineral Fibrous	17	272
F4	Mineral Fibrous	22	352
C1	Cementitious[c]	17	272
C2	Cementitious	19	304
C3	Cementitious	21	336

a. Values to which the materials were manufactured. Measurements of the density indicated that individual specimens were within 15 percent of the reported average density, except f sample No. F1 which was within 25 percent [15].

b. This material consisted of glass fibers with hydraulic binders such as cements and plasters, mixed with water and spray-applied

c. This cementitious material consisted of a vermiculite and gypsum based factory-blended composite that, through the addition of wa on the job site, forms a slurry for spray application.

ble 2. Descriptors of Levels of Friability Taken from the EPA Algorithm Procedure, As Published in 1982[a]

riability Level	Descriptor
ot riable	Material that is hard and crusty. Cannot be damaged by hand. Sharp tools required to penetrate the material.
ow riability	Material that is difficult yet possible to damage by hand. Material can be indented by forceful impact. If the granular, cementitious asbestos-containing material is rubbed, it leaves granules on the hand but no powder.
oderate riability	Fairly easy to dislodge and crush or pulverize. Material can be removed in small or large pieces. Material is soft and can be easily indented by hand pressure. The granular, cementitious asbestos-containing material leaves a powder residue on the hands when rubbed.
igh riability	The material is fluffy, spongy, or flaking and may have pieces hanging down. Easily crushed or pulverized by minimal hand pressure. Material may disintegrate or fall apart when touched.

. This table is taken from Reference 2. It is noted that EPA no longer uses an algorithm for assessing the condition of asbestos-containing materials [6].

ble 3. Descriptors of Levels of Friability Taken from the GSA Algorithm Procedure[a]

riability Level	Descriptor
ow riability	Material that could be damaged by hand only if heavy force is applied. This includes most troweled materials.
oderate riability	Fairly easy to dislodge and crush or pulverize by hand. Material may be removed in small or large pieces.
igh riability	The material is fluffy, spongy, or flaking and may have pieces hanging down.

. This table is taken from Reference 1.

Table 4. The Friability Levels of the Samples as Subjectively Judged[a].

Sample No.	Assigned Friability Level	Comments
F1	High Friability	Pieces are readily pulled from sample by pinch with the finger tips; sample is readily indent with a finger tip; fibers are easily dislodged lightly rubbing with the palm of the hand.
F2	High Friability	Observations are akin to those of sample F1, although the resistance to dislodging appears be slightly greater. Nevertheless, the hand pressure used was still considered to be minim
F3	High Friability	Resistance to dislodging has increased in the three modes used: pinching, indenting, and rubbing. It is questioned whether the dislodg is due to "minimal hand pressure" or "fairly easy" to accomplish. To be conservative, the level assigned is "high friability."
F4	Moderate Friability	This sample has the most resistance of the fibrous materials. Still, pinching removes fibers from the surface fairly easily. Only slight indentation occurs using a finger tip. Fibers are abraded from the surface by rubbing
C1	Moderate Friability	The surface texture is rough and irregular. Surface protrusion of material can be pinched away with the finger tips using pressure felt be greater than "minimal hand pressure." The surface may be indented with a finger tip. Rubbing with the palm of the hand produces a powdery residue.
C2	Moderate Friability	Observations are akin to those of sample C1, except that the resistance to pinching and indenting appears to have increased slightly. Rubbing of the surface gives a powdery residue.
C3	Moderate Friability	The resistance to pinching and indenting is noticeably higher than that for sample C2. Indentation is slight with strong finger pressu Hard rubbing of the surface with the palm of t hand produces a powdery residue.

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[a] The assignments were made by the report's authors.

ble 5. Variables Examined in the Laboratory Tests

st	Variable			
rface mpression/ ear	Torque Level:	1 to 10 lbf·in. in 1 lbf·in. increments (0.1 to 1.1 N·m in 0.1 N·m increments)		
	Bearing Force Level:	1 and 2 lbf (5 and 10 N)		
lk mpression/ ear	Torque Level:	2 to 30 lbf·in. in 1 lbf·in. increments (0.2 to 3.3 N m in 0.1 N m increments)		
dentation	Bearing Force Level:	Descriptor	Value	
		Level 1	4.5 lbf (20 N)	
		Level 2	9 lbf (40 N)	
		Level 3	13.5 lbf (60 N)	
		Level 4	18 lbf (80 N)	
rasion	Bearing Force Level:	Descriptor	Value	
		Level 1	4.5 lbf (20 N)	
		Level 2	9 lbf (40 N)	
		Level 3	13.5 lbf (60 N)	
		Level 4	18 lbf (80 N)	
pact	Type of Tip:	Descriptor	Diameter	Shore Hardness
		No. 1	1.5 in. (38 mm)	Type 2A, 65
		No. 2	1 in. (25 mm)	Type 2A, 65
		No. 3	1 in. (25 mm)	Type 2A, 73

Table 6. Comparison Between Pass/Fail Points for the Fibrous Materials Determined in the Surface and Bulk Compression/Shear Tests.

Sample No.	Pass/Fail Point			
	Surface Torque		Bulk Torque	
	lbf·in.	(N·m)	lbf·in.	(N·m)
F1	2.0	(0.2)	2.5	(0.3)
F2	3.5	(0.4)	6.0	(0.7)
F3	4.7	(0.5)	15	(1.7)
F4	6.0	(0.7)	28-30	(3.1-3.3)

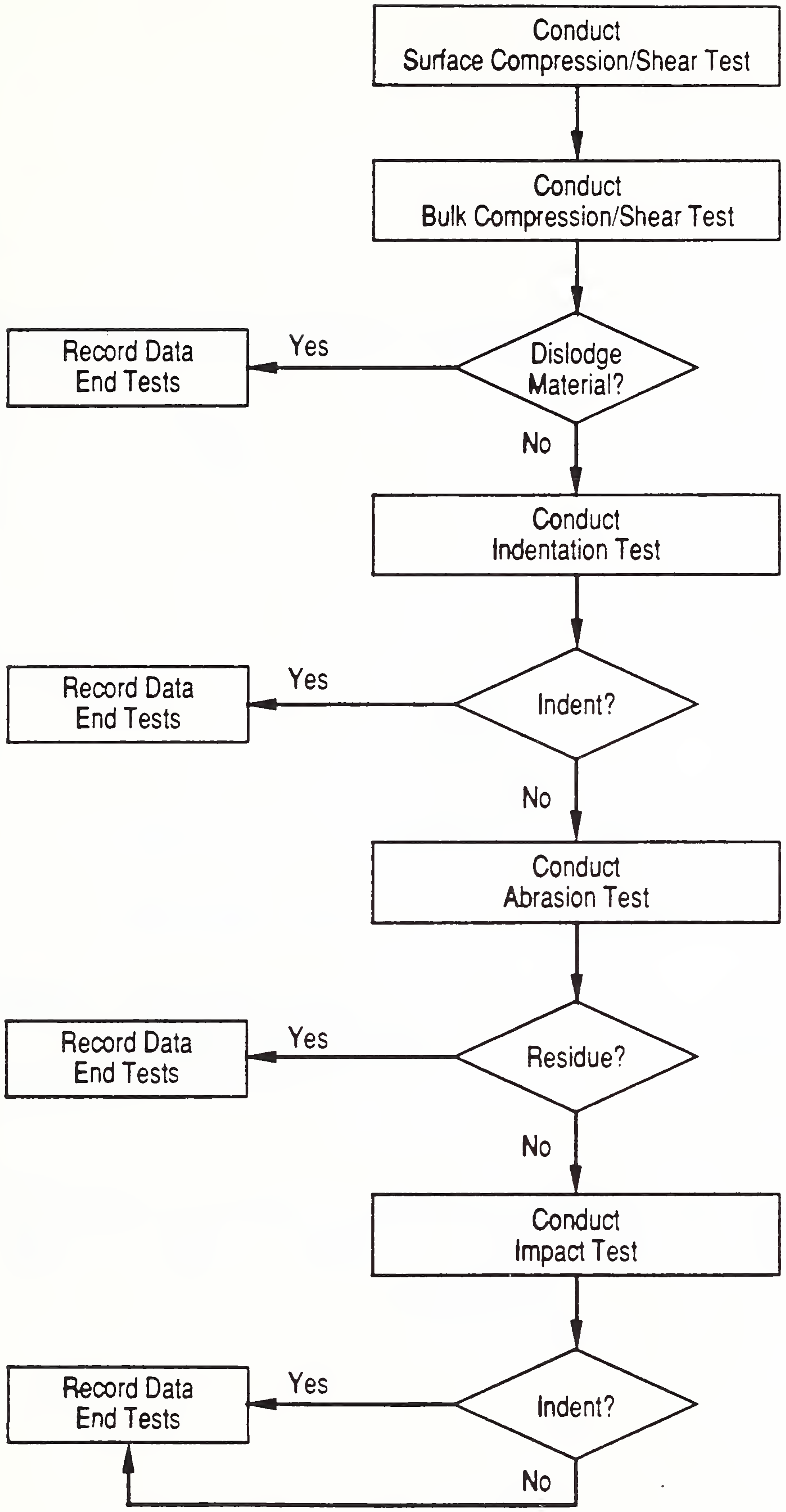

Figure 1. Flow Diagram Indicating the Sequence of Conducting Friability Tests.

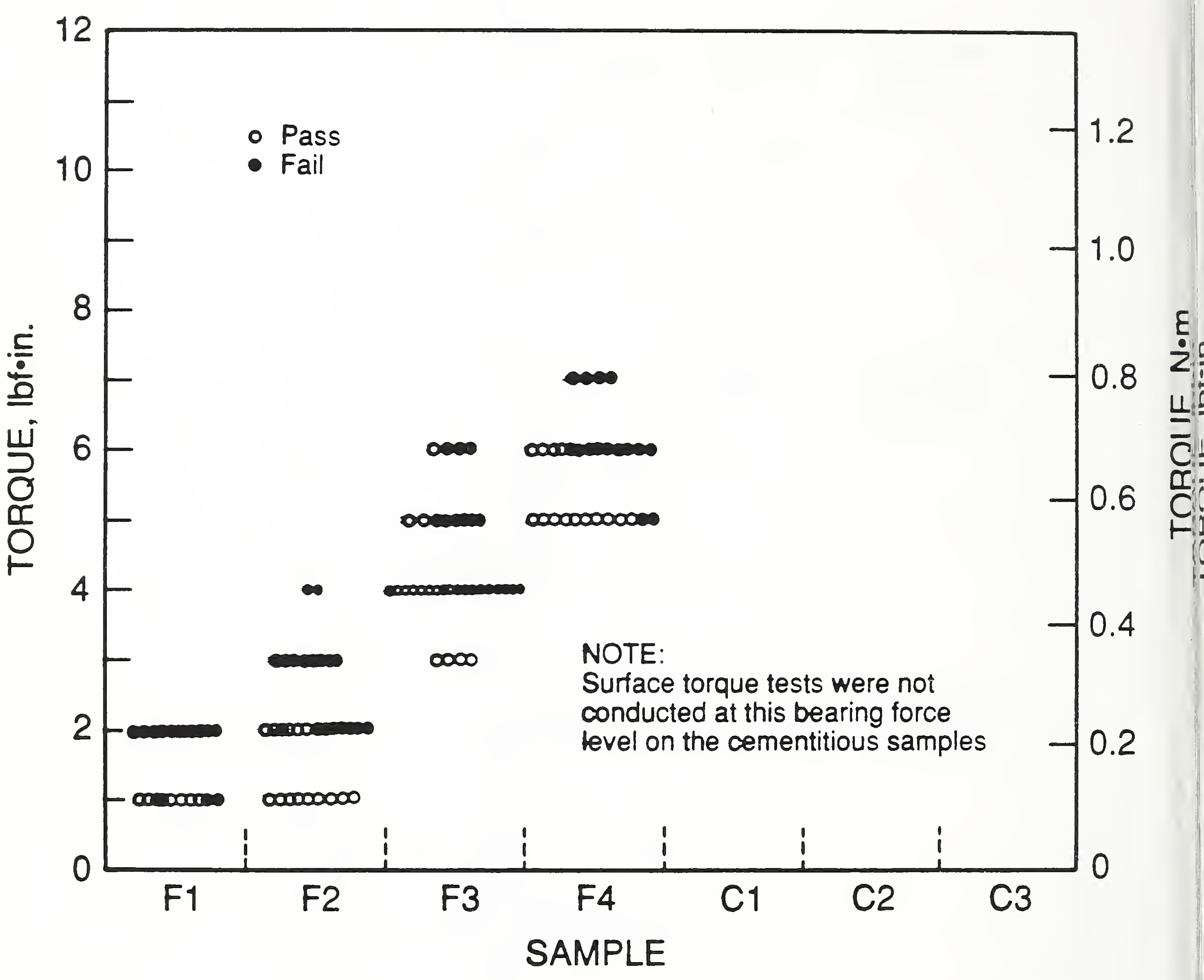

Figure 2. Results Using Prototype Device for Conducting Surface Compression/Shear Tests. Tests Were Conducted at a Beari Force Level of 1 lbf (5 N).

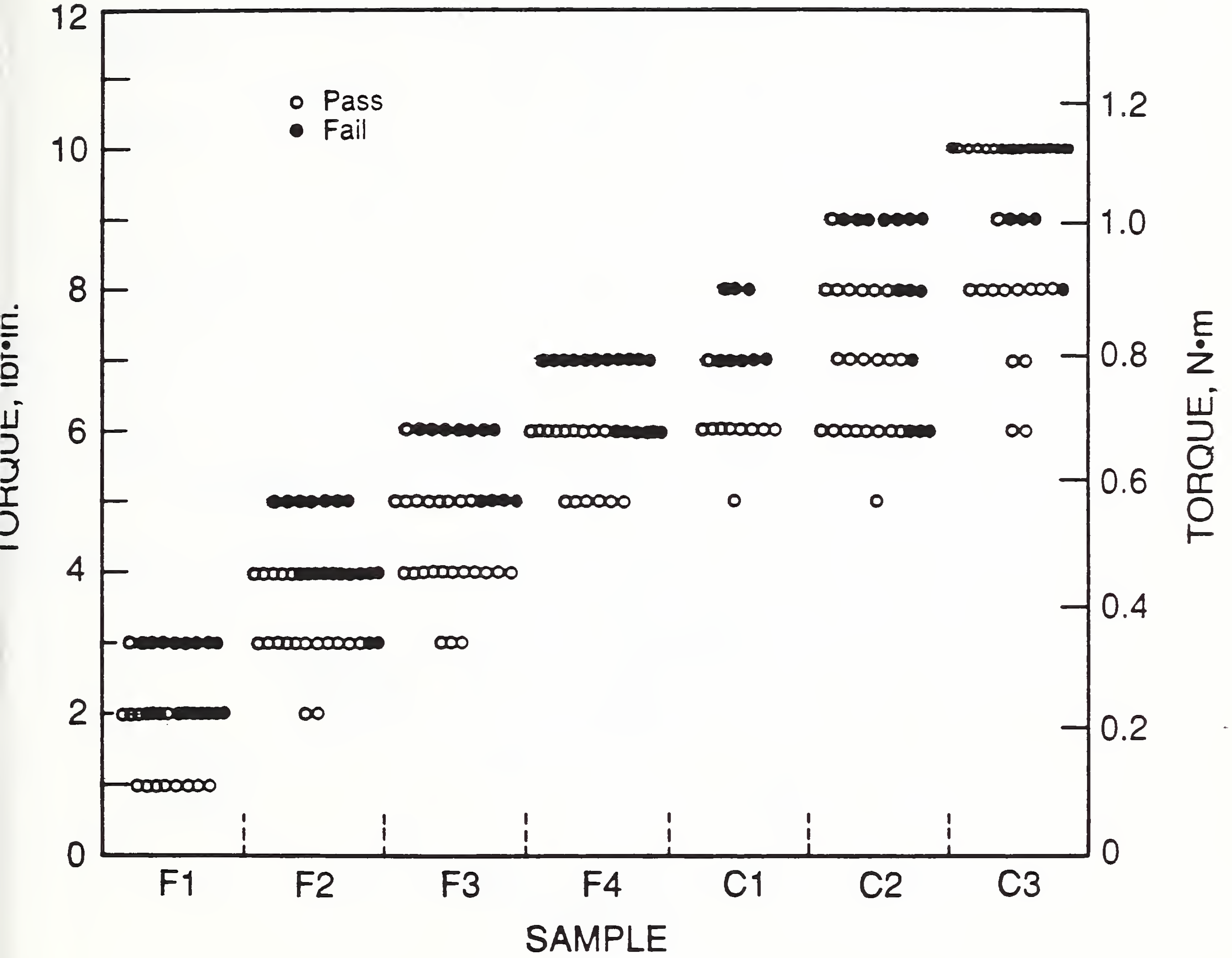

Figure 3. Results Using Prototype Device for Conducting Surface Compression/Shear Tests. Tests Were Conducted at a Bearing Force Level of 2 lbf (10 N).

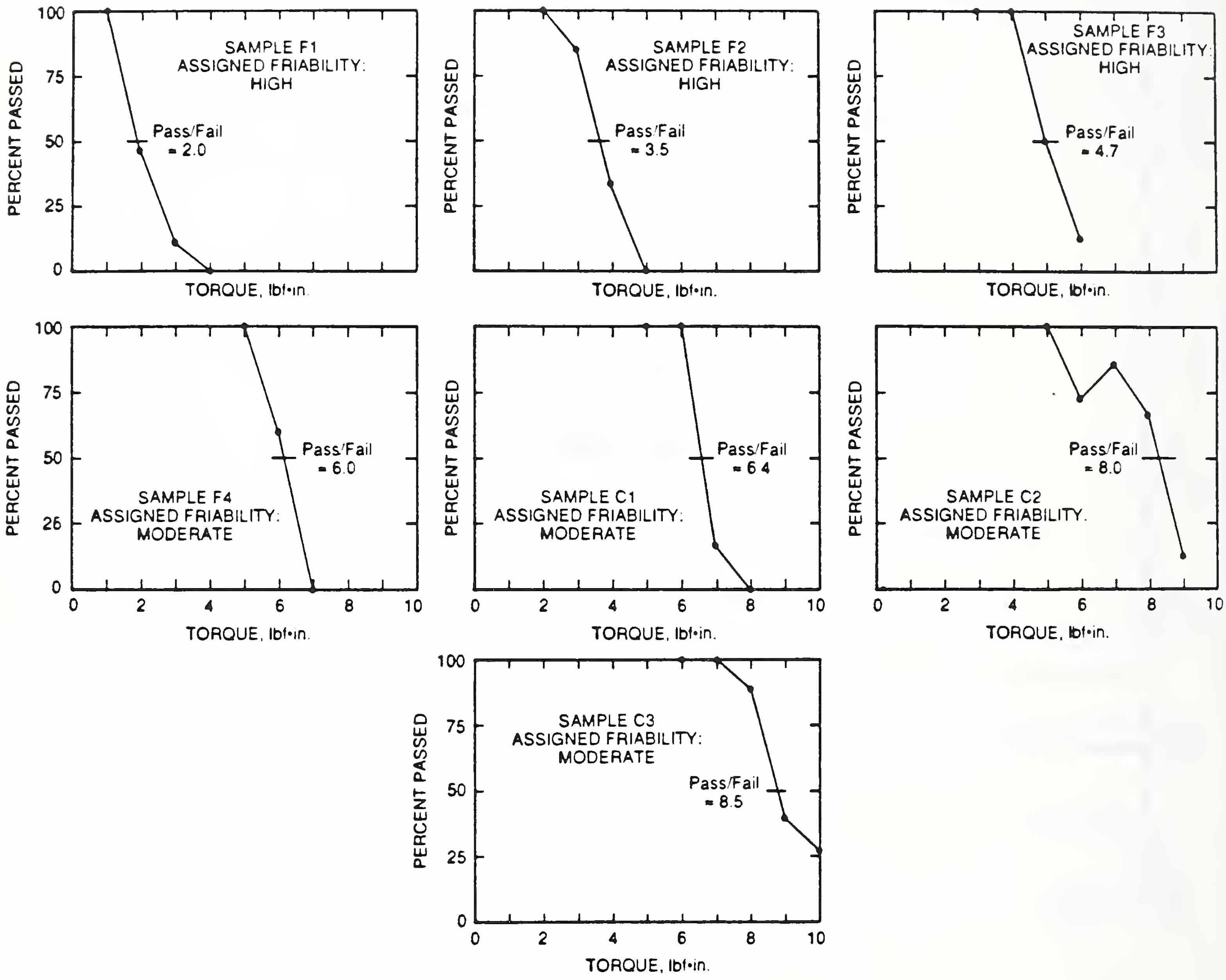

Figure 4. Results of the Surface Compression/Shear Tests: Percent the Test Squares Passed Versus Torque Level.

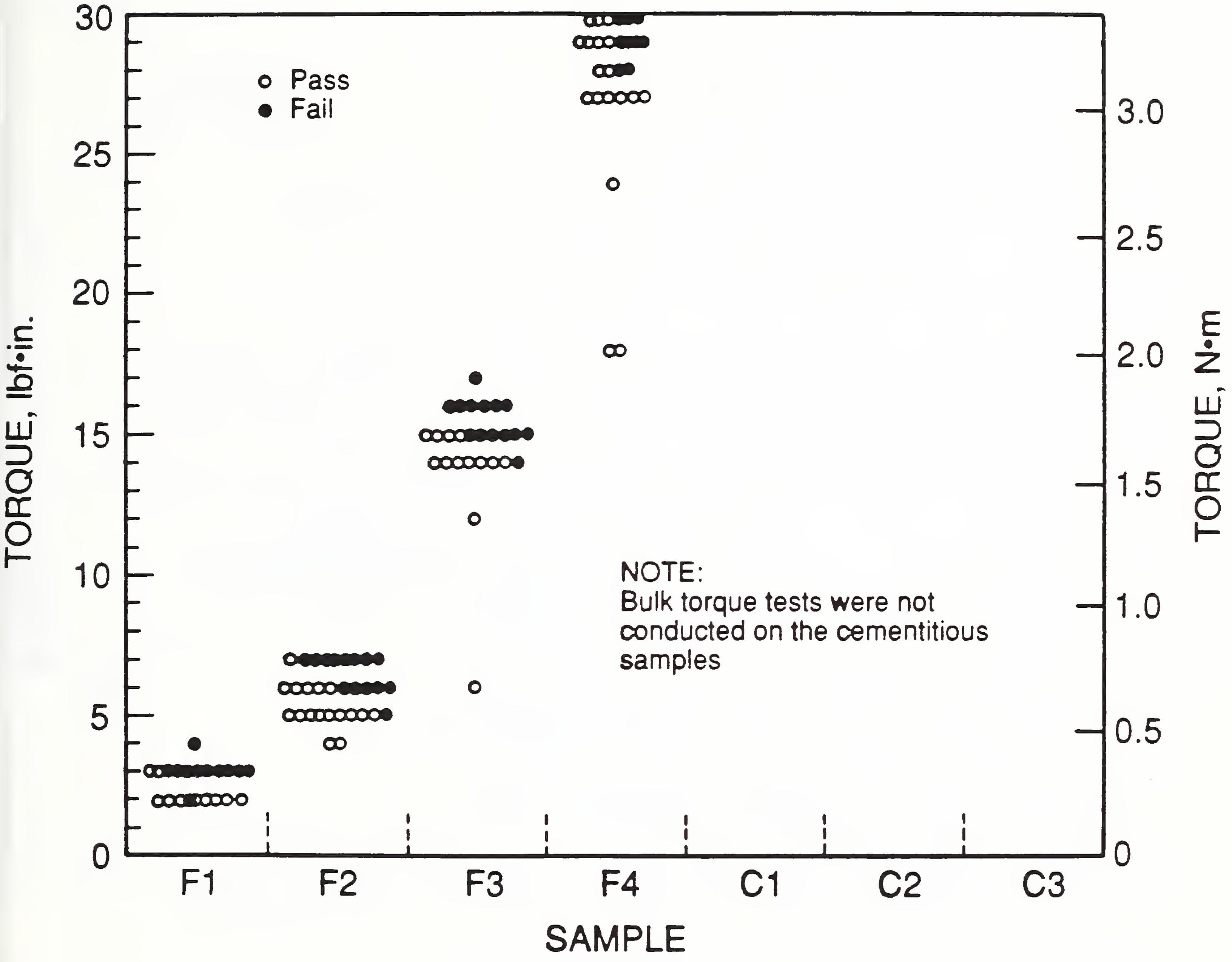

Figure 5. Results Using the Prototype Device for Conducting Bulk Compression/Shear Tests.

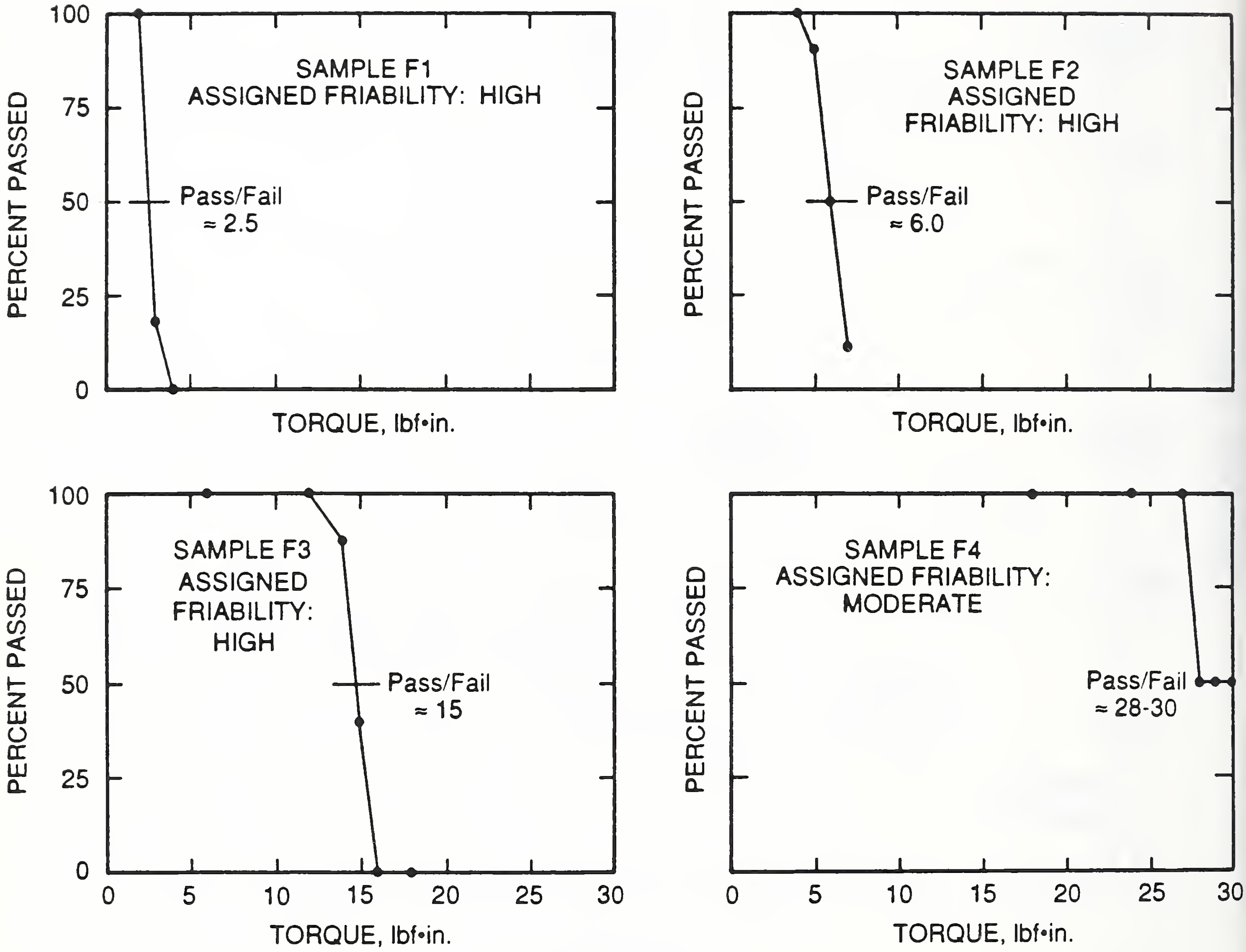

Figure 6. Results of the Bulk Compression/Shear Tests for the Fibr Samples: Percent of the Test Squares Passed Versus Torq Level.

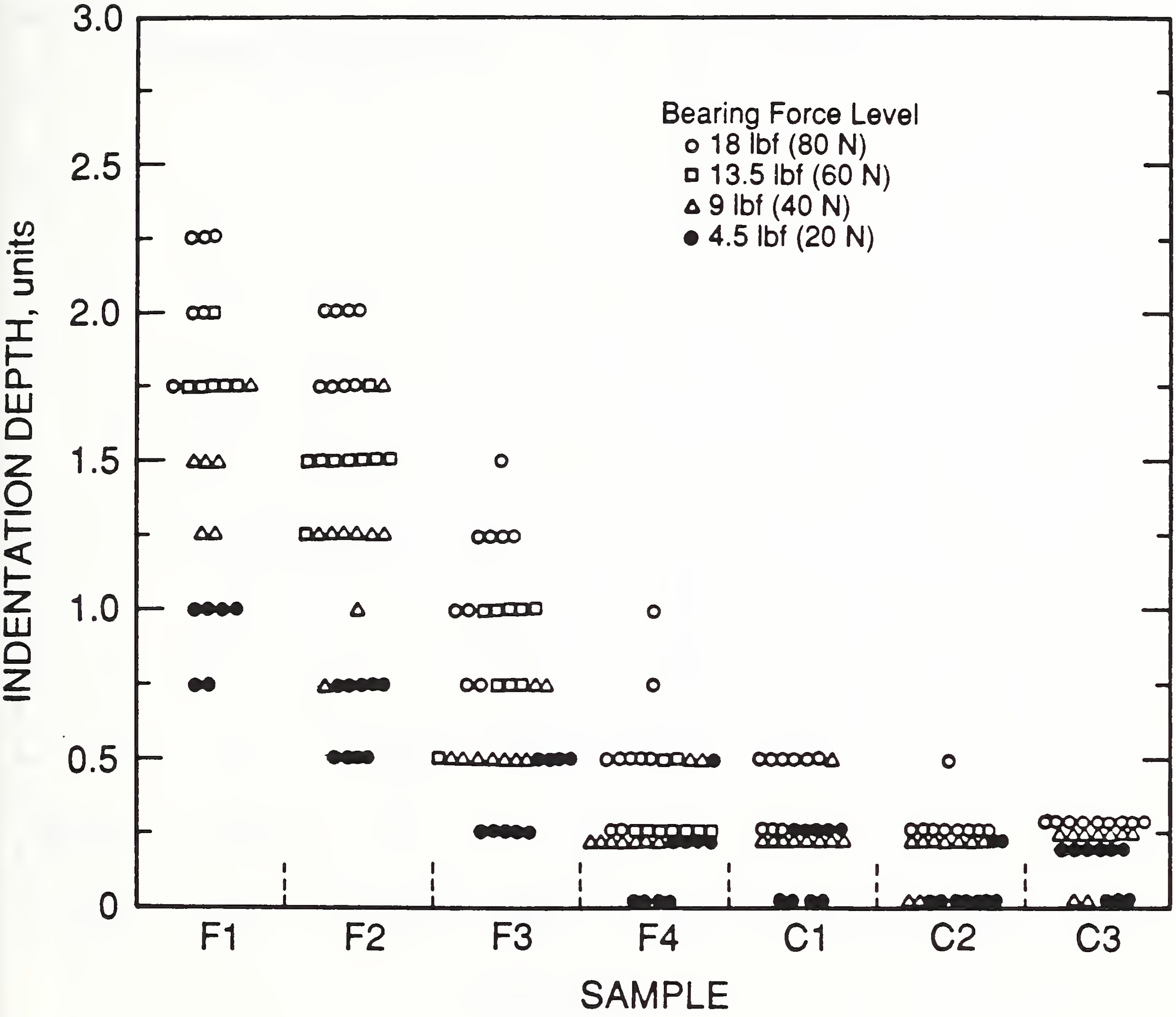

Figure 7. Results Using the Prototype Device for Conducting Indentatio
Tests.

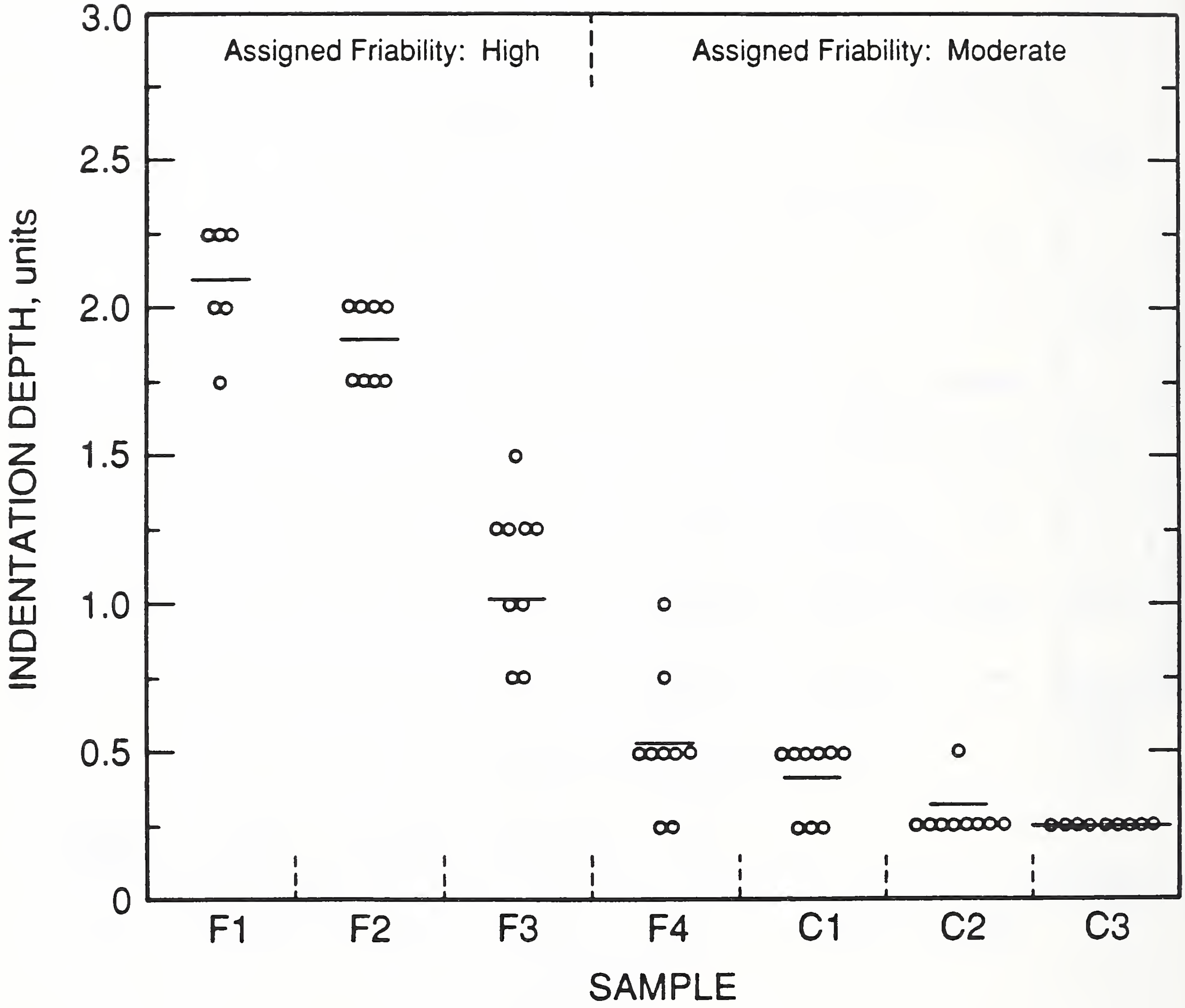

Figure 8. Results of the Indentation Tests Conducted at the Bearin
Force Level 4. The Horizontal Lines Represent Averages.

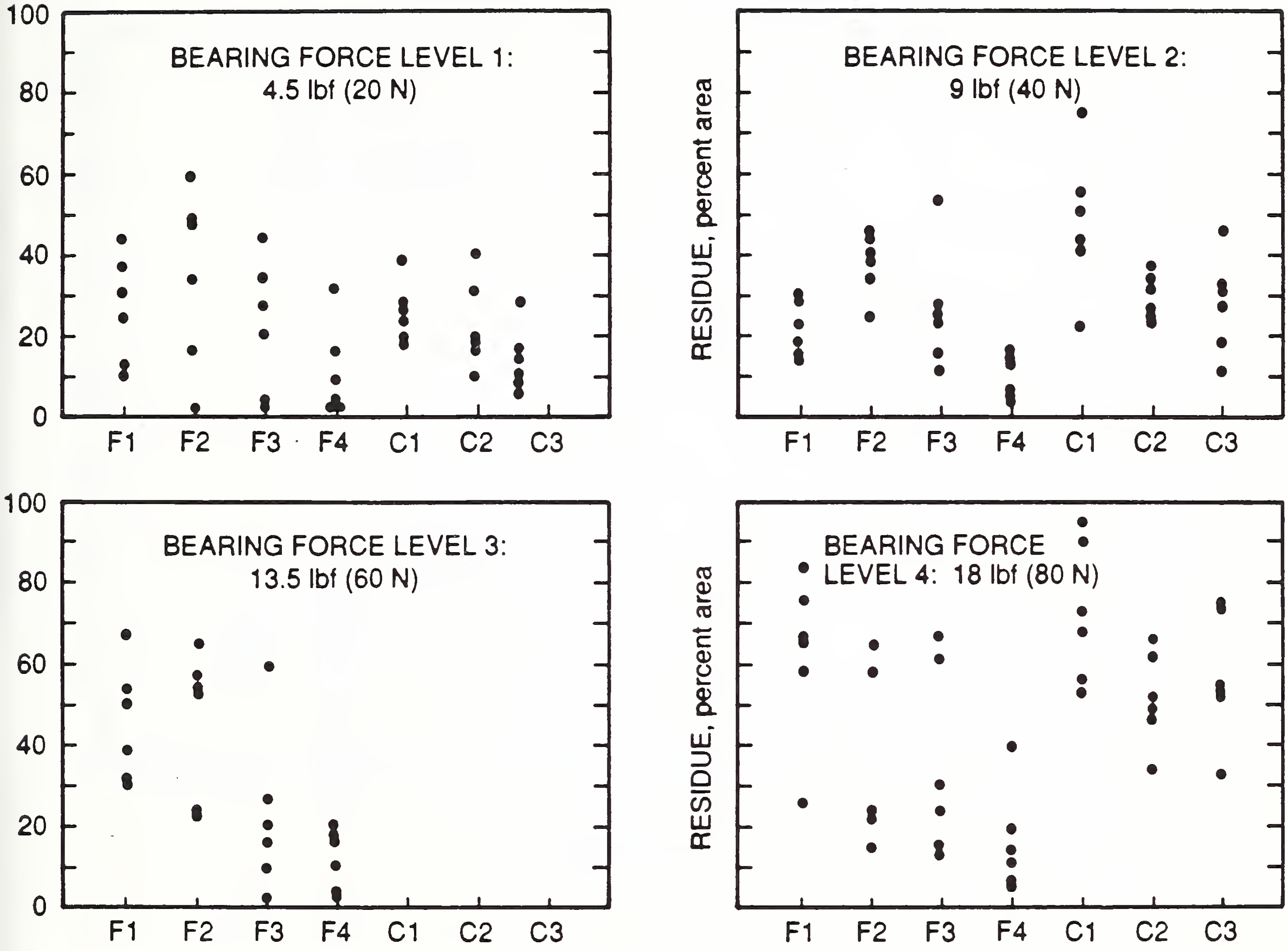

Figure 9. Abrasion Test Results: Percent Area of the Felt Covered by a Residue, As Determined by Image Analysis.

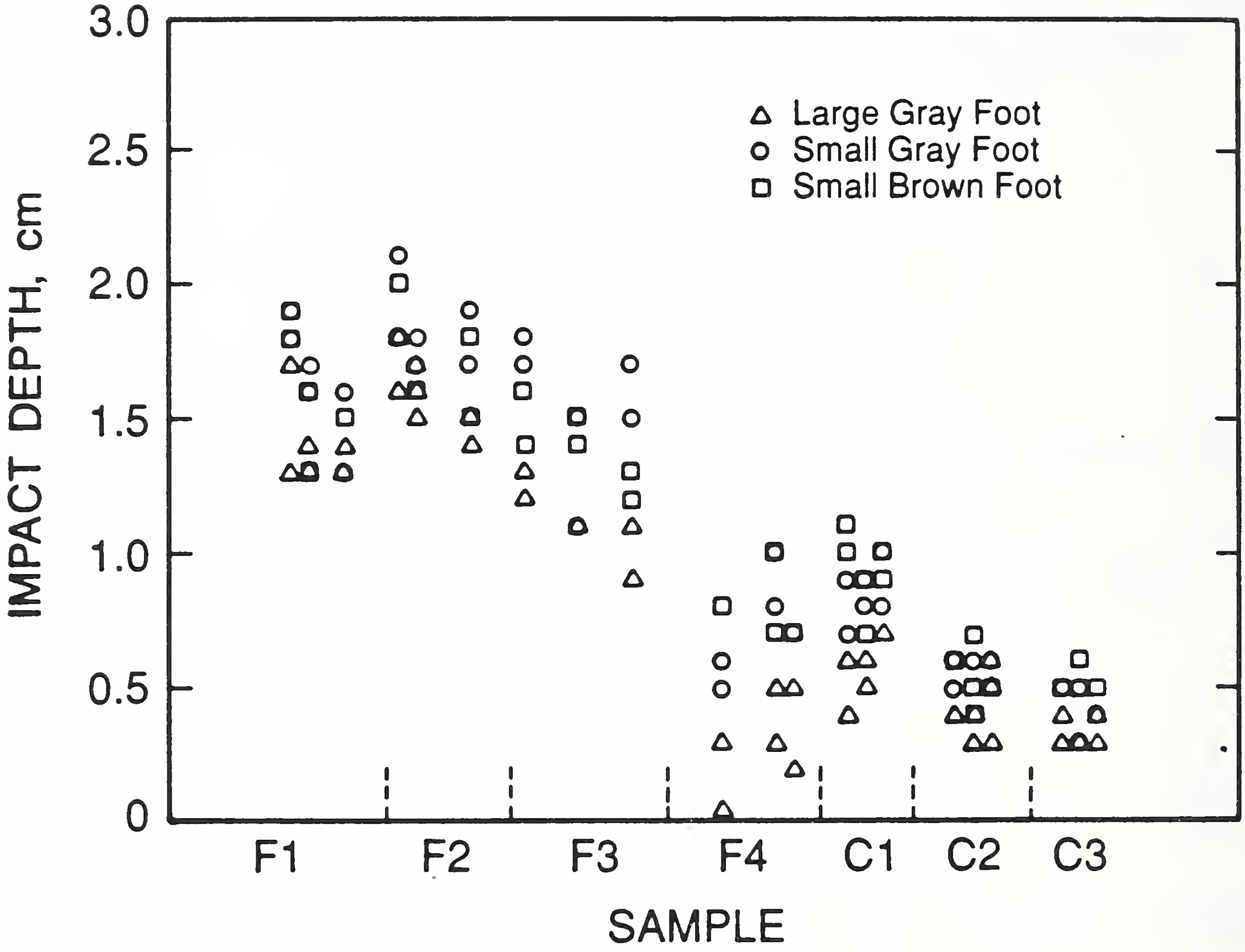

Figure 10. Results Using the Prototype Device for Conducting Impact Tests.

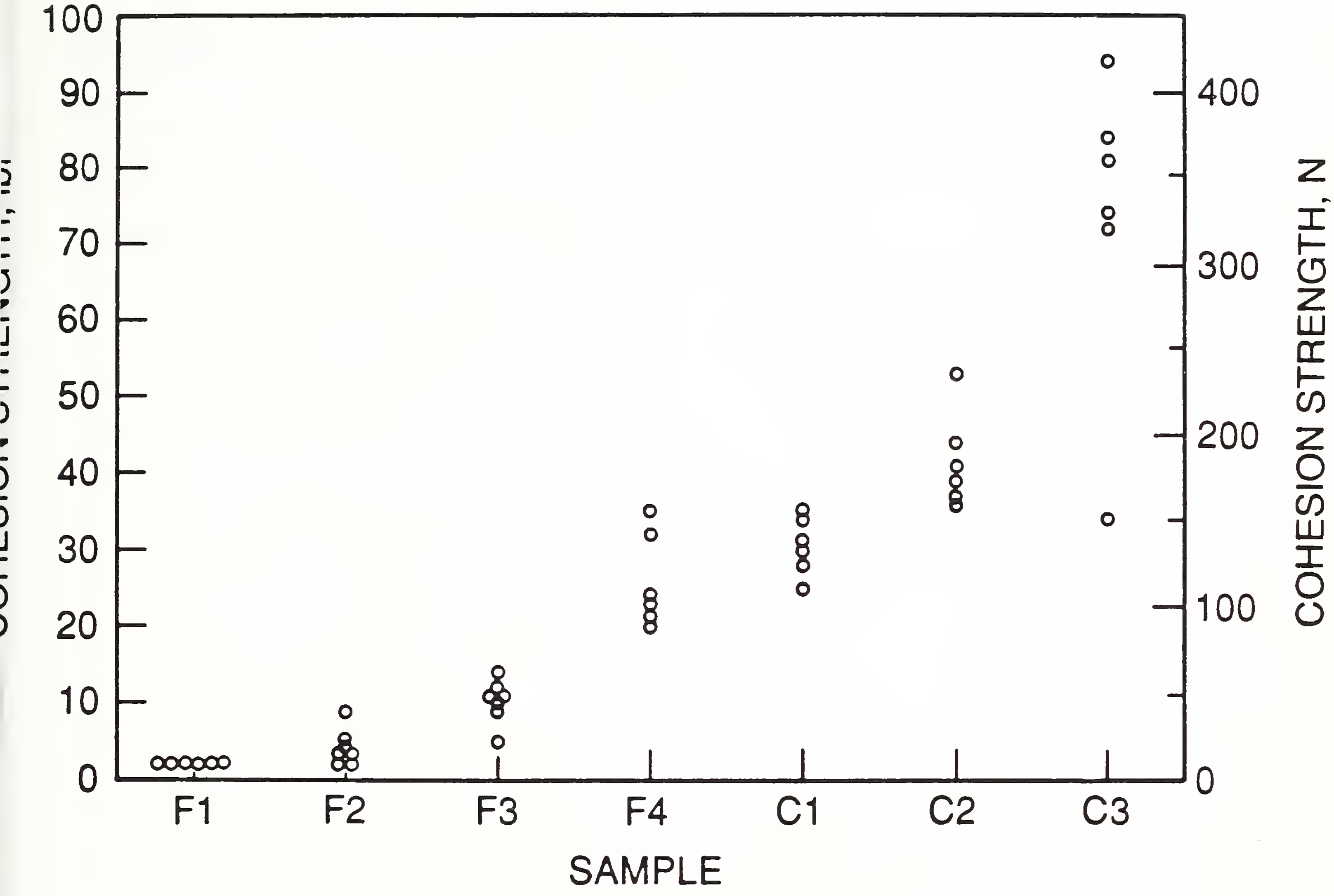

Figure 11. Results of the ASTM E 736 Tests of the Spray-Applied Samples.

APPENDIX A. PHOTOGRAPHS OF THE PROTOTYPE TEST DEVICES

This appendix presents photographs of the prototype test devices for conducting the surface and bulk compression/shear, indentation, abrasion, and impact tests on spray-applied fireproofings and thermal insulations. Figures A1 and A2 are photographs for the modified surface and bulk compression/shear devices and have not been previously published. The photographs for the indentation, abrasion, and impact devices were previously presented in the Phase 1 report [5].

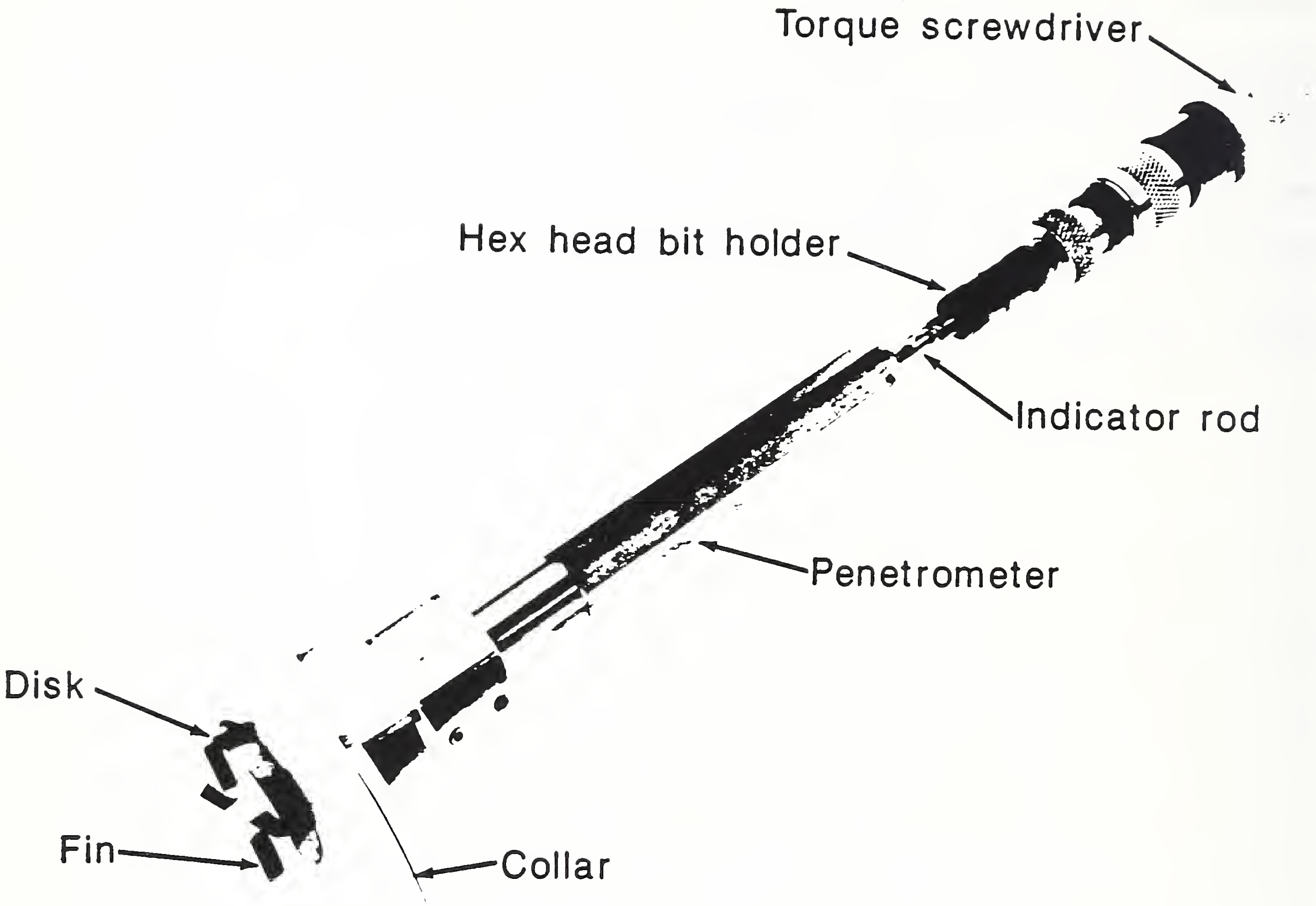

Figure A1. Prototype Device for Conducting Surface Compression/ Shear Tests

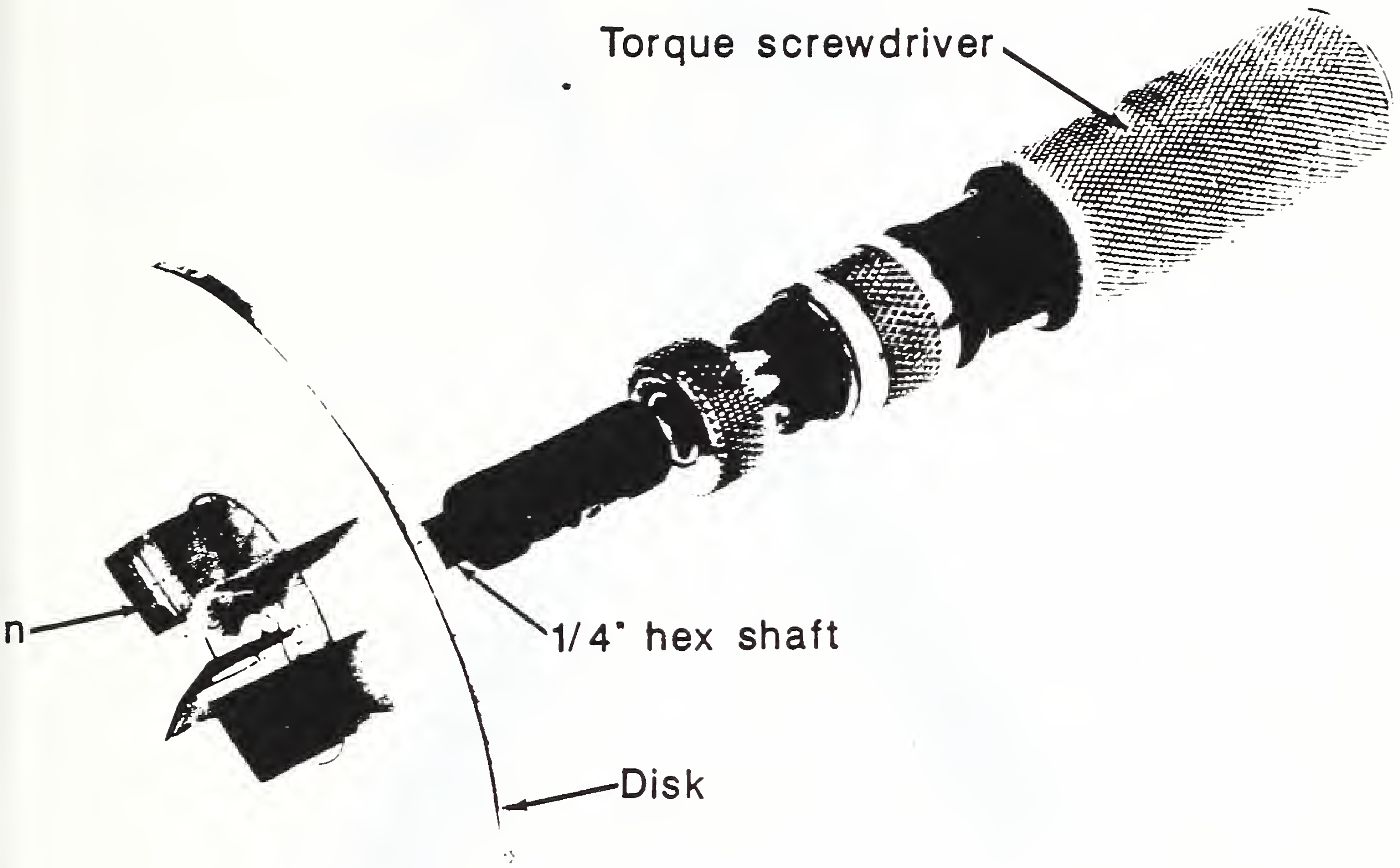

Figure A2. Prototype Device for Conducting Bulk Compression/ Shear Tests

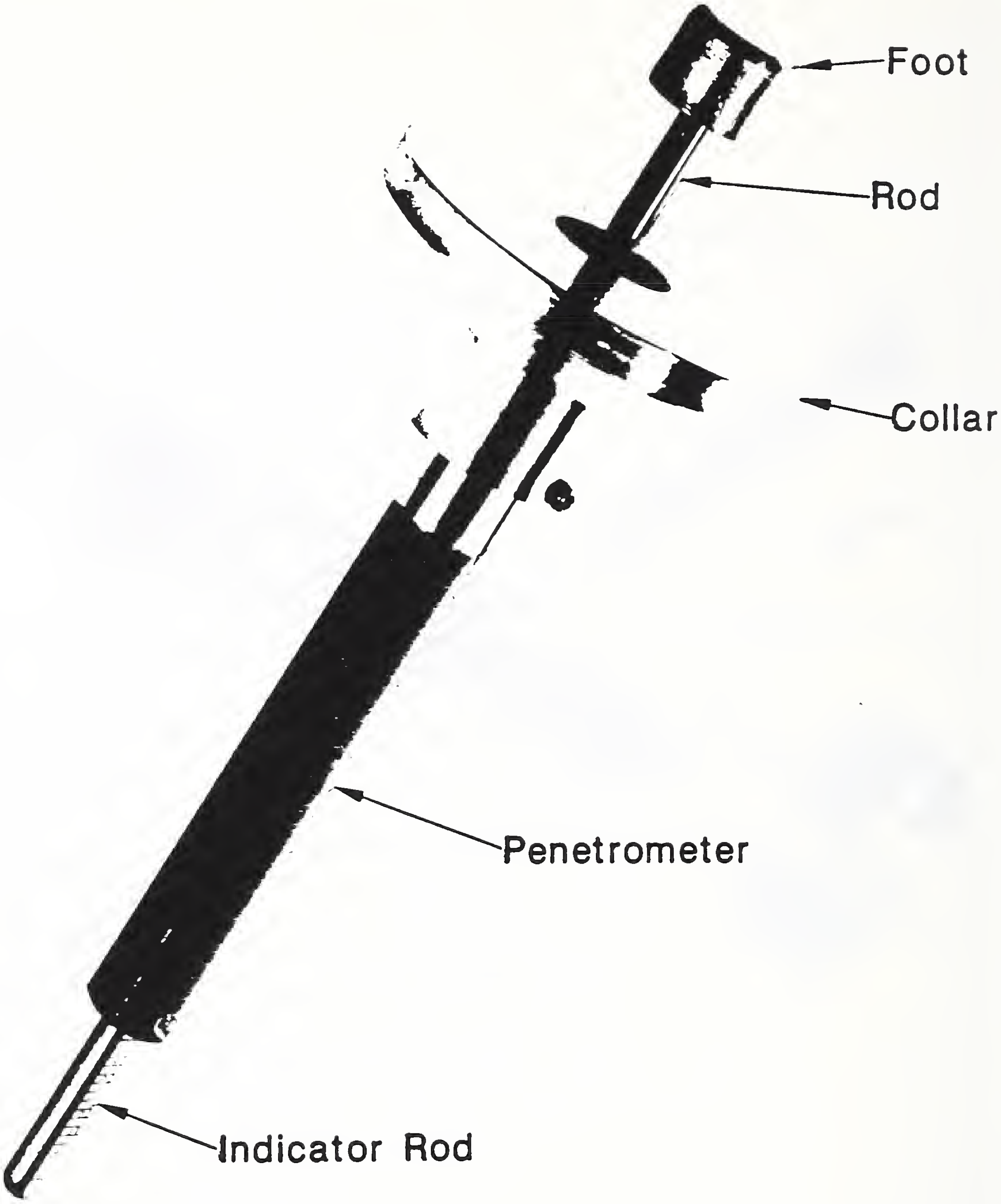

Figure A3. Prototype Device for Conducting Indentation Tests

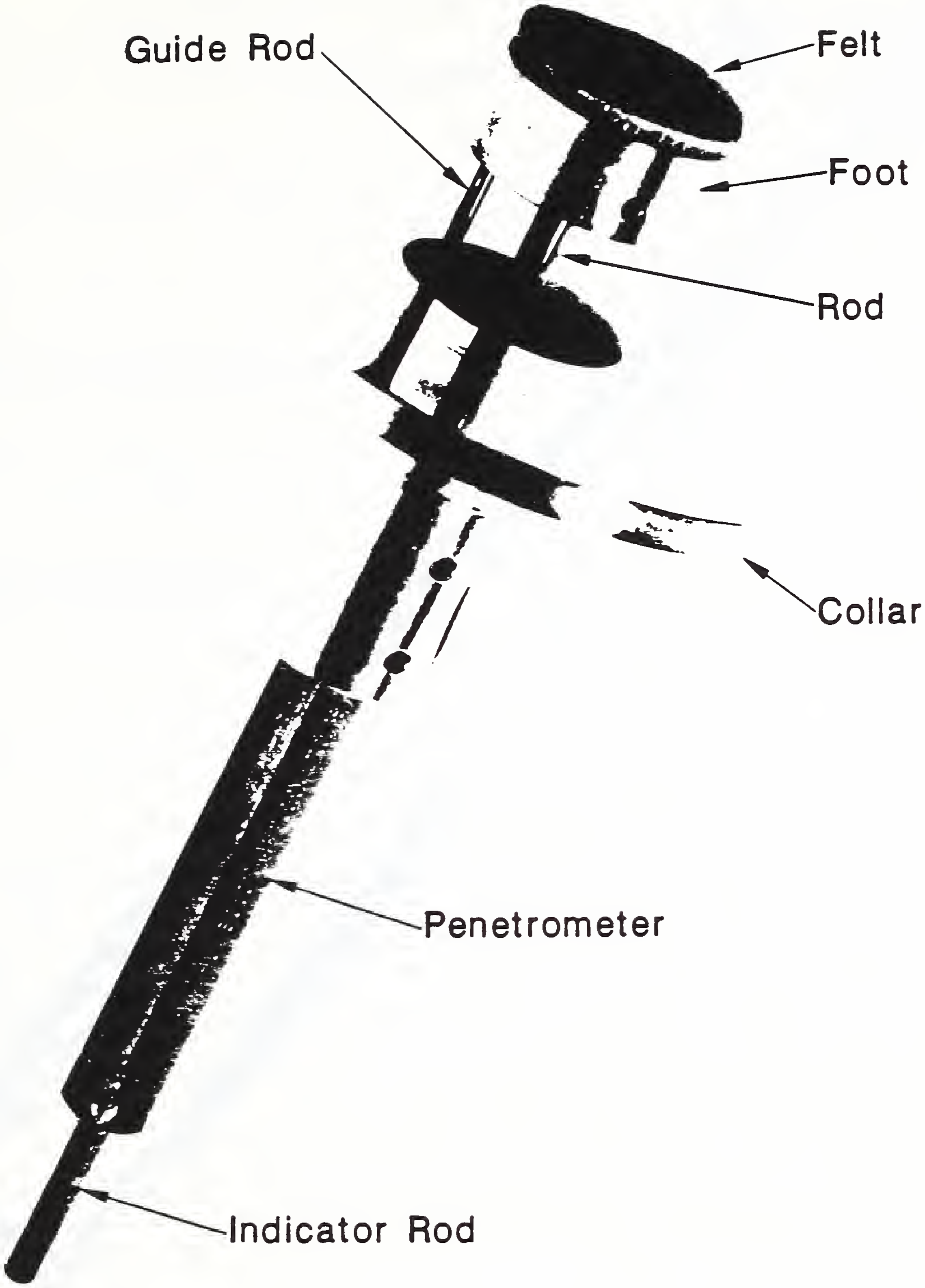

Figure A4. Prototype Device for Conducting Abrasion Tests

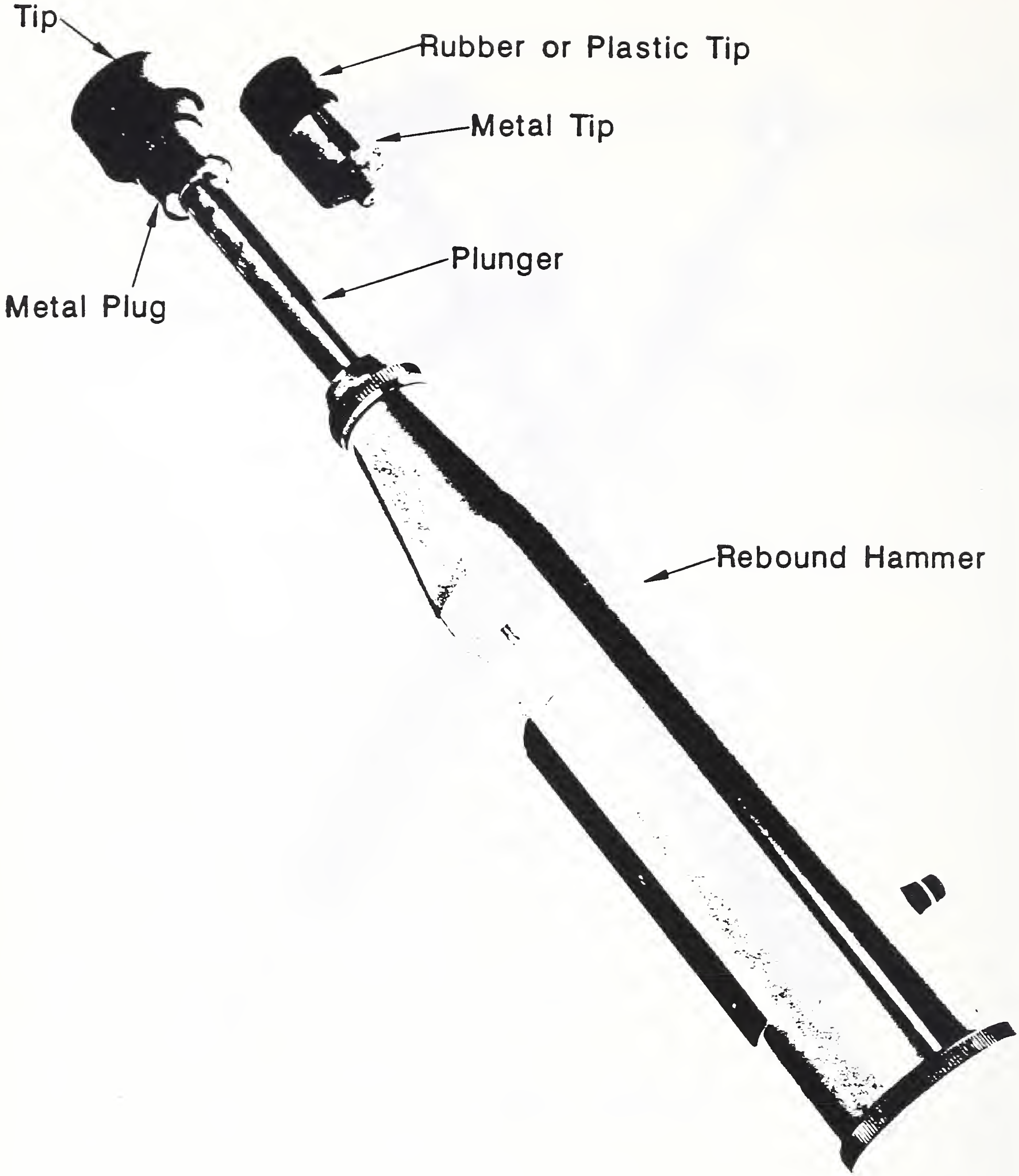

Figure A5. Prototype Device for Conducting Impact Tests

APPENDIX B. DESCRIPTION OF THE SURFACE AND BULK TEST DEVICES

This Appendix presents descriptions of the modified surface and bulk compression/shear devices. The indentation, abrasion, and impact devices were used in the study as previously described [5]. Their descriptions are not repeated here.

B.1 Description and Use of the Prototype Device for Conducting Surface Compression/Shear Tests.

The surface compression/shear device was developed based on the use of a commercially available torque screwdriver. In this study, the screwdriver was the model TS-30, manufactured by the Utica Tool Co. Inc.[3] Torque screwdrivers are designed such that, when torque is applied to the handle at a value below a pre-set level, the handle and shaft of the driver rotate together. When the amount of applied torque reaches the set level, an internal clutch in the driver releases and the screwdriver handle turns without rotation of the driver shaft. This limits the amount of torque that may be applied to a screw or other object. The torque screwdriver used for the prototype compression/shear test devices could be set for maximum torque levels ranging from 1 to 30 lbf·in. (0.1 to 3.4 N·m) in increments of 1 lbf·in. (0.1 N·m).

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[3] Certain trade names or company products are mentioned in this appendix to specify adequately the experimental procedure and equipment used. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the products are necessarily the best available for the purpose.

In developing the test for the surface compression/shear properti of a specimen, it was proposed to attach a disc with fins on its face to the torque screwdriver. The disc could be pressed down on the test material so that the fins would penetrate it. When rotated, the fins would subject the material to compression and shear forces. Dislodgment of the material would occur upon rotation of the fins, depending upon the level pre-set level of torque. If a low torque level was set, then rotation of the screwdriver handle would occur and no dislodgment of the material would take place.

To provide for a reproducible bearing force and to limit the bearing force with which the fins of the disk would be set in contact with the sample surface, the disk and fins were spring-loaded to the torque screwdriver. This was done through modificat of a commercially available "pocket" penetrometer used for soil testing. The penetrometer was the model H-4200, manufactured by the Humboldt Mfg. Co. The unmodified penetrometer consisted of a 5/8 in. (16 mm) hex-shaped aluminum housing tube with a 1/4 in. (6 mm) penetration rod protruding from one end. This rod was attached to a calibrated spring housed in the aluminum tube. The calibration was in kg/cm^2. The end of the tube opposite the penetration rod contained an indicator rod with graduation marks every 0.25 kg/cm^2 of load. This calibrated spring provided the spring-loading and control of the bearing force of the surface compression/shear device to the surface of the test sample. In modifying the penetrometer, the rod was made to rotate freely in the housing.

To attach the penetrometer to the torque screwdriver, a 1/4 in. (6 mm) hex-head shaft was welded to the indicator rod (Figure A1). This shaft was mounted in the bit holder placed on the end of the torque screwdriver. The disk and fins for the surface compression/shear device were attached to the penetration rod of the modified penetrometer.

The disc for the surface compression/shear device was machined from aluminum. It was 1.5 in. (37 mm) in diameter and 0.5 in. (13 mm) thick with four fins on the face side. The fins were 1/8 in. (3 mm) high and 1/2 in. (13 mm) long. They were 1/16 in. (1.6 mm) thick at the base and machined on one side of the tips (penetration points) to a knife edge (45° bevel). The reverse sides of the 45° bevel of the fin tips were normal to the disc when it was turned in a clockwise rotation (direction in which the torque screwdriver turned). The four fins were spaced 90 degrees apart with their outer edges being flush with the outer edge of the disc. The disc was secured to the penetration rod of the penetrometer using a small allen head screw.

A collar having a face 5 in. (126 mm) in diameter was placed around the disk and fins. The collar configuration was such that the disk and fins could retract into it and seat flush with the collar face. The position of the collar around the housing of the penetrometer was adjustable in order to control the amount of bearing force applied during surface compression/shear testing. At any preset position of the collar, the maximum bearing force was reached when the collar face became flush with test sample surface.

Because the configuration of the torque screwdriver was fixed, a relationship existed between the torque level set on the screwdriv and the amount of force applied by a fin of the surface compression/shear device. The maximum force produced by the compression/shear devices was derived from a simple calculation based on the average distance from the center of the torque screwdriver shaft to the center of the fins: the average force per fin was about 0.5 lbf (2 N) per 1 lbf·in. (0.1 N·m) increment of torque. In conducting friability assessments of the spray-applied fireproofings, no attempt was made to determine the forces or stresses in the test materials at the fins. Only the torque set on the compression/shear device was recorded.

B.2 Description and Use of the Prototype Device for Conducting Bulk Compression/Shear Tests.

The prototype device (Figure A2) for conducting bulk compression/s tests was also based on the torque screwdriver, model TS-30, manufactured by the Utica Tool Co., Inc. The major differences between the bulk and surface test devices were: (1) the bulk device did not have a spring-loaded disk for bearing the fins on the sample surface, and (2) the fins of the bulk device were longer to provide deeper penetration into the sample. Thus, in developing the proposed test for the bulk compression/shear properties of a specimen, a disc with fins on its face was attached directly to the torque screwdriver. The disc could be pressed down on the test material until its face was flush with the sample surface, so that the fins penetrated the sample. Depending upon the pre-set torque level, dislodgment of the material would occur upon manual rotation of the screwdriver handle. Depending on the resistance of the sample, if the torque level was set relatively low, then rotation of the screwdriver handle would occur and no dislodgment of the material would take place. Conversely, at a relatively high torque level, dislodgment would occur.

For the attachment of the disc (Figure A2) to the driver, a shaft made from a 1/4-in. (6 mm) hex bit was secured on the back side of the disc. This shaft was mounted in a 1/4-in. (6 mm) bit holder placed on the end of the screwdriver. The disc used for the bulk compression/shear device was machined from aluminum. It was 4 in. (102 mm) in diameter and 1/8 in. (3 mm) thick with four fins on the face side. The fins were 1/2 in. (13 mm) high, 1/2 in. (13 mm) long, and 1/8 in. (3 mm) thick. As was the case for the surface compression/shear disc, the fins were also machined to a dull knife edge (45° bevel) on their tips. For this disc, the four fins were set 90 degrees apart with their outer edges set 1 1/4 in. (32 mm) from the outer edge of the disc.

APPENDIX C. FORCES ASSOCIATED WITH HAND ACTIONS

C.1 Introduction

The maximum forces which the hand can impart for each type of mechanical action used to assess friability needed to be considered in setting limits of force in the mechanical tests. A review of the literature regarding forces associated with hand actions indicated that data on the subject were limited [5]. NIST obtained the assistance of Professor K.H.E. Kroemer, Virginia Polytechnic Institute and State University, Department of Industrial Engineering, to conduct an initial study on hand forces appropriate to the investigation of friability of asbestos-containing materials. He prepared a report[4] entitled, "Finger and Hand Strength." This Appendix compares selected results of Kroemer's study to the capacities of the prototype devices.

C.2 Hand Actions Compared to the Prototype Devices

As given in Tables 2 and 3 in the main body of this report, the descriptors for levels of friability only reference hand actions such as impact, rubbing, and indentation. As previously discussed [5], other actions such as pinching and squeezing, pushing, pulling, and scratching might be used by field inspectors to assess friability. Prof. Kroemer measured the forces associated with 11 hand actions. Five of these hand actions were selected as having appropriate bearing to the mechanical actions of the prototype devices. The five are: tip pinch, pad pinch, poke, scratch or hook, and palm press. These action are described in

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[4]. Personal communication, Order No. 43NANB 712191,

Table C1. Pinching was considered similar to the mechanical action of the compression/shear test devices. Indentation was taken comparable to a poking action with the finger or thumb, while abrasion was considered comparable to a rubbing action of the four fingers (scratch or hook) or pressing with the palm of the hand.

Hand impact was not addressed in this comparison of maximum forces exerted by hand actions and the capacities of the prototype test devices. The reason was that, in the limited tests conducted impact testing was not performed because the necessary precautions could not be assured to prevent damage or harm to the test subject.

The test protocol is described in Kroemer's report. Two groups of subjects were used: 21 students and 12 shop personnel. For all tests, the shop personnel group was found to exert higher average forces than the student group. This was attributed to the shop personnels' common use of their hands in performing shop work for some period of time. In this Appendix, the data for the shop personnel were used for comparison to the capacities of the prototype devices.

C.3 Comparison of Hand Actions with Prototype Devices

Table C2 presents a comparison of the maximum hand forces exerted by the shop personnel group, for the five selected hand actions (Section C.2), and the capacities of the prototype devices. In developing the prototype devices, it was intended to have their capacities comparable to the maximum forces generated by hand actions considered similar to the mechanical actions of the devices. It is evident from Table C2 that, for most tests, the maximum force of a given hand action was greater than the capacity of the associated prototype device. Only in the case of the surface compression/shear test was the maximum force of the tip pinch hand action less than the capacity of the device. For purposes of this study, the differences between the maximum forces generated by the hand actions and the capacities of the devices were considered acceptable. The forces which could be applied by the prototype devices were within the range of forces generated by the selected hand actions, and in most cases, comparable to the maximum forces of the hand actions. In conducting the laboratory tests to evaluate the prototype devices, many tests were performed at force levels less than the capacities of the devices.

As mentioned in Appendix B, the maximum force produced by the compression/shear devices was derived from a simple calculation based on the average distance from the center of the torque screwdriver shaft to the center of the fins which indicated that the average force per fin was about 0.5 lbf (2 N) per 1 lbf·in. (0.1 N·m) increment of torque. On this basis, because the maximum value of torque generated by the screwdriver was 30 lbf·in. (3.4 N·m), the capacity of the compression/shear device was estimated as about 15 lbf (67 N) per fin.

able C1. Description of Hand Actions Compared to Prototype Devices

and ction	Description
ip inch	Force Between Opposing Tips Posture: the thumb tip opposes the tip of each finger Transmitting surface: opposing tips of digits Direction of force: through centers of opposing surfaces Digits: 1 opposing 2; 1 opposing 3; 1 opposing 4; and 1 opposing 5
ad inch	Force Between Opposing Pads Posture: the thumb pad opposes the pad of each finger Transmitting surface: opposing pads of fingers Direction of force: through centers of opposing surfaces Digits: 1 opposing 2; 1 opposing 3; 1 opposing 4; 1 opposing 5; and 1 opposing 2 & 3 combined
oke	Tip Force, Straight Digit Posture: arm, hand, and digit are fully extended, horizontal, and unsupported. Palm is about horizontal. Thumb is abducted. Transmitting surface: tip of the digit Direction of force: in line with the extended digit Digits: thumb, index, middle, ring, and little
cratch r Hook	Pad Force, Bent Digit Posture: The included angle between the distal and proximal phalanges of the tested digit is approximately 90°. For digit 1, the metacarpal portion is abducted at the discretion of the subject. Transmitting surface: pad of the digit Direction of force: parallel to the proximal phalanx of the tested digit Digits: thumb, index, middle, ring, and little
alm ress	Palm Force Posture: arm, hand, and fingers are fully extended, horizontal, and unsupported. Transmitting surface: palm of the hand Direction of force: perpendicular to the palm

Table C2. Comparison of Maximum Hand Action Forces With the Capaciti of the Prototype Test Devices[a]

Test	Friability Level	Hand Action[b]	Hand Action Force, max.[c]		Capacity Test Devi	
			lbf	N	lbf	N
Surface Compression/ Shear	High/ Moderate	Tip Pinch[d]	14 (4)	63 (16)	15	67
Bulk Compression/ Shear	High/ Moderate	Pad Pinch[e]	21 (4)	95 (19)	15	67
Indentation[f]	Moderate	Poke-finger[g]	19 (6)	86 (28)	18	80
		Poke-thumb	31 (9)	138 (41)	18	80
Abrasion[f]	Moderate/ Low	Scratch or Hook (with 4 fingers)	57 (14)	252 (63)	18	80
		Palm Press	52 (15)	233 (65)	18	80

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a. In conducting the laboratory tests, many were performed at force levels less than the capacity of the devices.
b. A description of the hand actions are given in Table C1.
c. Data are taken from Kroemer's report. Numbers in parentheses are standard deviations for the average maximum forces.
d. The data are for pinching with the tips of the thumb and the middl finger, which was the strongest of the measured tip pinch actions.
e. The data are for pinching with the pad of the thumb and the pads the index and middle fingers, which was the strongest of the measu pad pinch actions.
f. The force is the normal or bearing force applied during testing.
g. The data are for poking with the middle finger, which was the strongest of the measured finger poke actions.

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

.1. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

This report describes the results of the second phase of a study to develop a field test method for assessing the friability of spray-applied fireproofing and thermal insulating materials. Phase 2 is the laboratory evaluation of the prototype devices for conducting surface and bulk compression/shear, indentation, abrasion, and impact tests. These tests were performed on specially prepared fireproofing materials, produced to have a range of friabilities. Differences in response of the test samples to dislodgment or indentation were observed in the tests.

In the surface and bulk compression/shear tests, it was found that, for a given type of material, as the density increased, the torque level at which dislodging occurred increased. In the indentation tests of the fibrous materials, the indentation depth increased as their density decreased. However, little indentation of the cementitious samples occurred regardless of their density. In tests using the abrasion device, all samples left a residue over the range of bearing forces examined. The amount of residue, as determined by image analysis, was extremely variable, and did not relate to the type or density of the material. With regard to the impact tests, all samples underwent some amount of indentation. The lower density fibrous materials experienced the greatest depths of indentation.

The results indicated that the surface and bulk compression/shear, indentation, and impact devices provided some measure of discrimination between samples subjectively judged as having "high" and "moderate" friability. In contrast, the abrasion device was non-discriminating in that, for all tests, a residue was produced. It was concluded that all devices be included in the field phase of the study using in-place spray-applied fireproofings having different levels of friability.

.2. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

abrasion; asbestos-containing materials; compression; fireproofing; friability; impact; indentation; mechanical tests; shear; spray-applied; test devices; test methods; thermal insulations

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