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Friability of Spray-Applied Fireproofing and Thermal Insulations: The Basis for a Field Test Method

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U.S. DEPARTMENT OF COMMERCE, C. William Verity, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

ABSTRACT

This investigation was Phase 1 of a two part study to develop a test method that can be used in the field to measure the friability of spray-applied fireproofing and insulating materials containing asbestos fibers. The objective of the first phase was to establish the technical basis for development of a test method to measure friability quantitatively. The test method is intended for use in lieu of current field procedures which involve evaluation by hand pressure and are subjective. A flow chart was prepared outlining a systematic sequence for conducting the field assessments. Four test methods were selected: compression/shear, indentation, abrasion, and impact. For each of the four tests, mechanical devices were devised by modification of existing material test apparatus. A description of the test devices is given in the report. Preliminary laboratory tests, conducted on specially prepared spray-on (non-asbestos) materials having a range of friability, were performed. The results suggested that the devices could distinguish differences in friability between the test samples. Further evaluation of the prototype test devices will be made in the laboratory and field in Phase 2 of the study.

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

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1. INTRODUCTION

1.1 Background

Between the mid-1930s and the late 1960s, asbestos-containing materials were widely used in building constructions [1]. The predominant application was the spraying of fireproofing, and of thermal and acoustical insulation, on structural members, walls, and ceilings. Many factors made these materials attractive for use. For example, in the case of fireproofings, spray-on asbestos-containing materials were inexpensive, were quick to install, involved only one building trade, and were easily integrated within the overall construction process [2].

Most spray-on asbestos-containing materials are considered friable, in that they may be readily crumbled or pulverized to release airborne asbestos fibers into the building environment [1]. The degree of friability of the asbestos-containing fireproofing and insulation varies between installations. The variation can be due to the nature or composition of the material, or its deterioration. Guidelines for selecting appropriate abatement techniques include consideration of the friability of the asbestos-containing material.

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 constructions. At present, GSA owns approximately 2500 buildings. A recent GSA survey indicated that almost 1200 of them have asbestos-containing material. In some of these buildings, GSA must assess the condition of the asbestos-containing material, monitor changes in condition over time, and recommend appropriate abatement actions.

GSA has prepared an algorithm-based procedure for use in the assessments of its buildings that have asbestos-containing materials [3]. The GSA algorithm was developed on the basis of modifications and additions to an earlier EPA algorithm [4]. The GSA assessment procedure is intended to "provide a relative index that indicates an overall risk potential" [3]. The use of the algorithm allows GSA to estimate which buildings potentially have the most severe problems. It also allows GSA to rank the results of the condition assessments in a priority order for those buildings needing abatement actions.

The GSA algorithm assesses the friability of the asbestos-containing material from a subjective and non-defined test using the hand (see Chapter 2). 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 Bureau of Standards (NBS) to develop a field test procedure for assessing and monitoring the friability of spray-applied asbestos-containing materials.

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

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

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. The study is divided into two phases. The objective of Phase 1 is to establish the technical basis for development of the test method. In Phase 2, the test method will be developed. As indicated, this report presents a summary of the first phase.

1.3 Scope of the Study

The scope of Phase 1 was limited to research activities associated with the development of the technical bases for the field test method for assessing friability. Any determination that the in-place materials contain asbestos was beyond the study scope. Confirmation that asbestos is or is not present in existing spray-applied fireproofing and insulation is another factor considered in procedures concerning condition assessment. No testing for the presence of asbestos was conducted during the study.

The activities performed in Phase 1 of the study included:

- o A review of appropriate test methods, which have been used or have potential for use, for determining the friability of spray-applied fireproofing and insulation materials. Sources of information included the archival literature, reports from Federal and foreign government agencies, standards organizations, and individuals having knowledge in friability testing of insulations or condition assessment of asbestos-containing materials. Included was a review of past activities carried out by ASTM Committee E06 regarding friability of spray-on fireproofings [5].
- o A review of current subjective techniques for assessing the friability of spray-applied asbestos-containing materials in the field. This included discussions with individuals responsible for conducting field condition assessments.

- Field inspections of spray-applied asbestos-containing materials.
- The development of a conceptual model for determining the level of friability in order to assist in proposing suitable mechanical tests. The conceptual model was developed based on consideration of hand actions (possibly used by field inspectors in friability determinations) and the current descriptors of levels of friability of spray-applied asbestos-containing material.
- The development of prototype test devices for conducting friability tests in the field. Preliminary laboratory evaluation of the devices using specially prepared spray-on fireproofings which did not contain asbestos was performed.

2. CURRENT METHOD OF ASSESSING FRIABILITY

2.1 Definition of Friability

As indicated in the Code of Federal Regulations (40 CFR 61, Subpart M), a friable asbestos-containing material "means any material containing more than 1 percent asbestos by weight that hand pressure can crumble, pulverize, or reduce to powder when dry" [6]. This definition contains two major factors that impact on asbestos abatement measures, namely, asbestos content and ability to release asbestos fibers through crumbling by hand pressure. Algorithm procedures for assessing the condition of sprayed-applied asbestos-containing materials were developed by the Environmental Protection Agency (EPA) to provide a method for predicting the potential for fiber release and subsequent contamination of the building space [4].

The key descriptor considered to relate to the potential for fiber release is the "friable" nature of the asbestos-containing material. A dictionary definition of the word, "friable," states that it is an adjective indicating "easily crumbled, pulverized, or reduced to powder" [7]. This definition is comparable to that given in the Code of Federal Regulations (CFR) except that the CFR indicates that the material is dry and the stimulus for crumbling is hand pressure. From the point of view of risk management, it is considered that if the material is not friable, then it cannot be readily crumbled, pulverized, or powdered to release fibers into the building space. Conversely, friable materials are more likely than non-friable materials to release fibers when disturbed or damaged [1,8]. The Federal Construction Council, Consulting Committee on Asbestos, has stated that, in all cases where friable materials are present, the hazard posed may not justify immediate corrective action, and that, for each case, a hazard assessment must be made [1].

The concept of friability of spray-applied asbestos containing materials is associated with the ability of the fireproofing or thermal insulation to release particles which may become airborne and be inhaled. From this point of view, it has been suggested that characterization of these materials could be carried out by assessing ease of materials release rather than ease of crumbling [9]. Some initial work has been conducted on the ease of materials release (referred to as "releasibility rating"), but no procedure for field condition assessment has been developed [9].

The EPA has reviewed means of fiber release from the spray-on materials [4]. Three major modes for release and dispersion of fibers into buildings were identified:

1. Fallout -- Constant release of fibers which occurs as a result of weak bonds in the material as it was installed or which have developed over time due to the deterioration of the bonding materials.
2. Impact -- Any direct contact with the material that knocks fibers loose.

3. Resuspension -- Secondary dispersal or reentrainment of fibers which have previously been released by fallout or impact.

A summary of the EPA review of the three modes of fiber release and dispersion is given in Table 1. As is evident, many factors could affect the release of fibers and their resuspension. 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. For example, an approach for future investigation might be based on consideration of the energy involved in fracturing or deforming the material.

2.2 Assessing Friability Using Algorithms

Algorithms were developed by EPA to provide a numerical method to assist in evaluating the potential hazard of exposure to asbestos fibers released from spray-applied materials and to determine appropriate corrective actions [4]. Currently used algorithms (GSA [3] and the Navy [10]) are based on that developed by EPA. Table 2 presents a summary of the factors that were incorporated into the EPA algorithm [4].

Since 1985, EPA no longer suggests the use of algorithms for assessing the potential of fiber release from asbestos-containing materials [8]. The agency has indicated that such use has "met with mixed success." In particular, in tests conducted for EPA, the ratings achieved according to the algorithm procedure were not found to relate to the levels of measured airborne asbestos [8]. Algorithm methods are intended to consider individual factors affecting potential for fiber release, whereas air monitoring is an indicator of fiber level at the time the measurement is made. EPA has indicated that a simple, nonnumerical rating system, based on a consideration of the factors affecting asbestos-release (Table 1) is useful [8]. In using the nonnumerical rating, EPA has indicated that the material should be considered friable if, upon rubbing, it crumbles or produces a light powder residue.

Where algorithms are employed to assess the condition of sprayed-applied asbestos-containing materials, eight factors concerning material use and its condition are assigned a numerical value. The eight factors in the algorithm have been selected based on consideration of modes causing release of the spray-applied asbestos-containing material (Table 1). The first seven algorithm factors (material condition, water damage, exposed surface area, accessibility, activity, air plenums, and friability) are evaluated in the field by the inspector. The eighth factor (asbestos content) is determined from a laboratory test on samples removed from the installation. In using the algorithm to obtain a numerical indication of the potential for asbestos exposure, the sum of the numerical ratings for the first six factors (Table 2) is taken. That sum is, in turn, multiplied by the ratings obtained for factors 7 (friability) and 8 (asbestos content). Thus, if the material contains no asbestos or is assessed not to be friable, the algorithm yields a numerical value for potential of fiber release of zero.

The fact that the numerical rating factor for friability is used as a multiplier in the algorithm emphasizes the importance of evaluating this property in a satisfactory manner. The current directives given to field inspectors for assessing friability indicate that they are to use their hands in providing the numerical value for the algorithm. For example, in the original EPA inspection manual outlining its algorithm, it was stated [4] that "in order to evaluate the friability of the material, it must be touched."

Figure 1 is a copy of an EPA summary of the types of spray-applied asbestos materials in place in existing constructions [4]. The summary was prepared by EPA based on extensive field surveys. It is evident from Figure 1 that different types of spray-on asbestos-containing materials have been used in buildings. It is also evident that these materials have different physical properties and vary in the level (or degree) of friability. It is considered that "the more friable the material, the greater the potential for asbestos fiber release and contamination" [4].

The algorithm developed by EPA considered four levels of friability. Table 3 lists the descriptors associated with the four levels of friability as given in the EPA algorithm. Table 4 gives similar descriptors of friability from the GSA algorithm. These two tables contain comparable descriptors of friability. This is not unexpected, since, as previously noted, the GSA algorithm was based on that of EPA [4]. The EPA descriptors are broader in scope than those of GSA. In particular, the GSA algorithm does not make reference to non-friable materials. In developing its algorithm, GSA intended to have a method for assessing the condition of "surfacing" asbestos-containing materials. Surfacing materials are those that are sprayed or troweled on ceilings (or above suspended ceilings), walls, and structural members [3]. GSA considered, a priori, that in the cases of the sprayed-on, troweled-on and wet-applied surfacing materials in its buildings, the materials were considered to have some degree of friability. Thus, a category of "not friable" was not included in the GSA algorithm.

3. APPROACH TO DEVELOPING A FIELD TEST FOR FRIABILITY

3.1 Mechanical Tests Related to Hand Actions

The rationale behind the assessment of the friability of the asbestos-containing material is to have an indicator of the potential for release of asbestos fibers into the building environment. Abatement actions taken to minimize risk of exposure consider that, as the friability of the material increases, the potential for fiber release and contamination increases.

The use of the hand to estimate the level of friability is only a comparative indicator of the ease of dislodging, or material release to cause fibers to be airborne. In assessing friability using the hand, the forces involved in dislodging the material can be no greater than those obtainable by the hand, and thus, presumably, relatively low. This is consistent with the dictionary definition of "friable" as being easy to crumble or pulverize. Obviously, a major limitation in using the hand is that it is a subjective test. Hand strengths vary between individuals, and thus it is possible that various inspectors can assign different levels of friability to the same in-place material.

A field test for friability must be practicable in that the equipment should be relatively easy to transport, set up, and use. The cost of conducting the tests must also be relatively low. For example, the assessment of the condition of spray-applied asbestos-containing materials in a large multi-story building may involve hundreds of measurements. Techniques that would be time-consuming for each measurement are far less desirable than short, quick procedures as candidates for test method development.

The approach taken in the study to develop a field test for friability is to provide mechanical tests related to the hand actions possibly used by field inspectors. The selected test procedures are chosen with consideration of the levels of friability and the friability descriptors outlined in the algorithms coupled with the degree of typical force which the human hand can exert in various actions used by field inspectors. Such an approach is considered a positive step in quantifying the procedure used in the building industry since the late 1970s for condition assessment. In particular, the approach taken is consistent with that presently used in the field by GSA for providing rankings of the priority of needed abatement options for GSA buildings.

In relating the test procedure to directives given in algorithms, it was decided to use the friability descriptors given in the EPA-developed algorithm (Table 2). The EPA algorithm considered all types of spray-on materials, and was not limited to materials assumed, a priori, to have some degree of friability, as was the case for the GSA-developed algorithm. In taking this approach, the field test procedure developed in the present study would be applicable to both types of spray-applied materials (i.e., fibrous and granular cementitious) and all levels of friability.

The four levels of friability generally considered in algorithms are: not friable, low friability, moderate friability, and high friability (Table 3). It is evident from Table 3 that the current methods for friability assessment depend upon using the hand in some manner such as impact, rubbing, indenting, and other ways that are not quantitatively defined (e.g., minimal hand pressure).

In developing a field friability test procedure of mechanical tests related to hand actions possibly employed by field inspectors, two key factors need to be addressed:

1) The relationship between the descriptors of the four levels of friability and specific hand actions used at each level should be set forth in a logical manner. This would provide background as to which mechanical tests could be focused on in the laboratory work. Although all background information needed to decide which mechanical tests to conduct may not be available, at least the selection of the candidate tests would be based on hand actions that are consistent with present methods for friability assessment. As an example of the type of information which is not available regarding

test method selection, it has been found through discussions with individuals conducting field assessments that most all hand actions may be used in the field in attempts to dislodge asbestos-containing materials from a substrate. However, the frequency of the various possible types of hand action used is not available.

2) The maximum forces which the hand can impart for each type of mechanical action used to assess friability should be considered in order to set limits of force in the mechanical tests. A review of the literature regarding forces associated with hand actions indicates that data on the subject are limited. NBS obtained the assistance of Prof. 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. The results of his study will be presented in the final report of this investigation.

The paragraphs which follow provide an outline describing the relation of the levels of friability to hand actions (and thus mechanical tests). Based on the discussion in these paragraphs, a flow diagram for conducting field tests of friability was developed and candidate mechanical tests were selected.

3.1.1 Materials in the Category of "Not Friable"

Materials in this category "cannot be damaged by hand," and thus, would be expected to be "concrete like" (Figure 1). The description of friability levels (Table 3) provides no information as to what hand actions a field inspector would use to determine that the material cannot be damaged by hand. It is assumed that one forceful hand action would be an impact motion such as punching. Another might be a concentrated scratching motion with the tip of a nail. In the case of punching, if such action would not damage the spray-on asbestos-containing material at a force comparable to the maximum that could be imparted without damage to the hand, then the material could be considered "not friable." This suggests that an impact test should be used as a candidate for this level of friability.

3.1.2 Materials in the Category of "Low Friability"

Materials in this category "are difficult yet possible to damage by hand." Materials included here might be expected to approach "concrete like," or be "granular cementitious" (Figure 1). The descriptor of friability levels (Table 3) specifically indicates that two hand actions are involved here. First, "the material can be indented by forceful impact." Thus, to determine this level, an impact test is required. It is assumed that the same impact test pertaining to the non-friable materials could be used to measure low friability.

Second, the descriptor for low friability also states that "if the granular, cementitious asbestos-containing material is rubbed, it leaves granules on the hand..." The rubbing action by the field inspector is taken to be an abrasion motion. Thus, an abrasion test is also assumed as a need to determine that a material is characterized as having low friability.

3.1.3 Materials in the Category of "Moderate Friability"

Materials in this category are "fairly easy to dislodge and crush or pulverize, and may be removed in small or large pieces." Materials included here might be both "granular cementitious and fibrous" (Figure 1). Although fibrous materials are generally considered to be in the category of high friability, it should not be ruled out, a priori, that some fibrous materials would fall in the moderate friability level. For moderate friability, the level descriptor (Table 3) specifically mentions rubbing and indentation. In the former case, an abrasion test would be required, whereas in the latter case, an indentation test would be needed.

However, in addition to the hand actions specifically denoted, it is envisioned that many other actions might be used to "remove small or large pieces" of asbestos-containing material from its substrate. These actions may be imagined to include pinching, squeezing, scratching, clawing, pushing, and pulling on the surface, particularly where the material surface is non-uniform and contains irregularities which could provide a location for gripping. Thus, the mechanical tests having possible applicability to the level of moderate friability include compression (pinching, squeezing), shear (pushing), tension (pull), and a combination of indentation/tension/shear (poking, clawing, scratching actions).

3.1.4 Materials in the Category of "High Friability"

Materials in this level are "easily crushed or pulverized by minimal hand pressure and they may disintegrate or fall apart when touched." Materials included here would be generally expected to be "fibrous" (Figure 1). The descriptor of friability levels (Table 3) makes no reference to any specific hand actions. It is assumed that, in general, any hand action that dislodges the material in practice could be used. It is, thus, considered that any of the hand actions given in the sections above could also be used as an indicator of high friability. Potential mechanical tests could then include compression, tension, and shear. Whatever the test selected, the amount of pressure exerted in the test should be low, in keeping with the directive that the material is damaged by "minimal hand pressure." Selection of the same appropriate mechanical test procedure here, as for the category of "moderate friability," would provide a means for distinguishing between the two levels, provided that the tests were conducted at different pressure levels.

3.2 Methodology for Conducting Mechanical Tests

The foregoing discussion indicates that a number of mechanical tests related to hand actions may possibly be used in the field, depending upon the level of friability of the spray-on material. Table 5 is a summary of some hand actions and possible mechanical tests that are considered to relate to the different levels of friability. This table indicates that, for the moderate and high friability levels, there is an overlap of the types of mechanical tests. Thus, the same tests may potentially be used for each category, but the pressure levels would have to vary.

For a given level of friability (notably, high and moderate), there is no need to conduct all mechanical tests suggested by the implied hand action. It is only necessary to have a suitable test that is consistent with field practice, and demonstrate that the material is, or is not, resistant to the pressure exerted in the test. Resistance in this case means that material cannot be dislodged or released from its substrate, or indented, under the given test conditions.

Based on Table 5, the following test procedures were selected for preliminary testing:

Friability Level	Mechanical Test
High	Compression/Shear
Moderate	Compression/Shear Indentation Abrasion
Low	Abrasion Impact
Not Friable	Impact

Figure 2 is a flow diagram of the suggested sequence for conducting the field tests. The device selected for the compression/shear tests was based on modification of a torque screwdriver, which is why torque is mentioned in the flow diagram. All devices for conducting these tests referred to in Figure 2 are described in Chapter 4 of this report. In using the flow diagram for conducting field assessments of asbestos-containing materials, tests should be conducted in turn until a positive result is obtained (e.g., material is dislodged from spray-on fireproofing or insulation), or until the final test (impact) indicates that the sample is not friable. In the case of friable materials, the level of friability is denoted by the location in the flow diagram at which the result of the test is positive. Proper safety precautions will need to be followed when the field tests are conducted.

In Figure 2, note that different test methods result in placing the material in the same friability category. For example, compression/shear, indentation, and abrasion tests may all categorize a material as moderately friable. For purposes of the present study, there is no intent to imply that different subcategories of friability exist in these cases. This is consistent with the different descriptors for a given level of friability (Table 3).

It is evident from Figure 2 that the first four tests (two concerning high friability, and two for moderate friability) involve compression/shear tests conducted on the surface and bulk of the samples. The use of compression/shear tests for both bulk and surface properties was suggested based on initial testing of non-asbestos containing spray-on materials in the NBS laboratories. It was found that the surface compression/shear characteristics and bulk compression/shear characteristics of individual specimens could be different under similar test procedures and warrant separate examination. In particular, for the laboratory specimens, the surface was more susceptible to crumbling than the bulk of the material. Since the surface of in-place materials could be the most likely source of fiber release, the surface compression/shear tests should be conducted first.

4. PROTOTYPE TEST DEVICES FOR FRIABILITY ASSESSMENT

This section of the report describes the prototype mechanical test devices developed for assessing the friability of spray-applied asbestos-containing materials in a manner consistent with that used by inspectors in the field. The four tests were considered for use with the flow chart given in Figure 2: (1) a compression/shear test (surface and bulk), (2) an indentation test, (3) an abrasion test, and (4) an impact test. As is evident from Figure 2, the asbestos-containing material is categorized into one of the four levels of friability according to the results of the tests.

In developing the prototype test devices, some criteria dealing with practicality were kept in mind. The devices had to be easy to transport and use by one person, and thus, relatively light in weight and compact. It was considered that they should not require electrical power for operation, but be capable of being manually operated. Where possible, they should use readily available test equipment in their production, and preferably with only minor modification. In addition, the devices should be readily calibrated during production. Each device should also have a built-in mechanism to limit the pressure applied. In this way, the operator may only apply the load intended in the test procedure.

4.1 Description and Use of the Test Devices

4.1.1. Compression/Shear Test Device. Two compression/shear measurements are made on a specimen, one involving the surface and the other concerning the bulk (Figure 2). Both use a commercially available torque screwdriver as the basis of the test device. The screwdriver was a model TS-30, manufactured by the Utica Tool Co. Inc.[1] Torque screwdrivers are designed such that, when torque is applied to the handle at a value below a 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 freely without rotation of the driver shaft. This limits the amount of torque that may be applied to a screw or other object used with this type of screwdriver. The torque screwdriver used for the prototype compression/shear test device 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).

In proposing the test for the compression/shear properties of a specimen, a disc with fins on its face was attached to the torque screwdriver. The disc can be pressed down on the test material so that the fins may penetrate it. Dislodgment of the material

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1. Certain trade names or company products are mentioned in the text here and in subsequent chapters 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.

may occur upon rotation of the screwdriver, depending upon the torque level at which it was set. If the torque level was set low, then free rotation of the screwdriver handle would occur and no dislodgment of the asbestos-containing material would take place. For the attachment of the disc 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.

In performing the preliminary tests, the difference between conducting a surface compression/shear test and a bulk compression/shear test was in the size of the disc and the configuration of the disc fins. Figure 3 is a photograph of the torque screwdriver and attached disc for surface compression/shear testing. The disc for surface compression/shear was machined from aluminum. It was 3 in. (75 mm) in diameter and 0.5 in. (13 mm) thick with six 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 top surface to a dull knife edge (45° bevel). The reverse side of the top surface of the fins was normal to the disc when it was turned in a clockwise rotation. The six fins were spaced 60 degrees apart and 1/2 in. (13 mm) from the outer edge of the disc.

A photograph of the torque screwdriver and disc for bulk compression/shear testing is given in Figure 4. The disc used for conducting bulk compression/shear testing was machined from brass. It was 2 1/4 in. (57 mm) in diameter and 1/4 in. (6 mm) thick with four fins on the face side. The fins were 1/2 in. (13 mm) high, 3/4 in. (19 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 top surfaces. For this disc, the four fins were set 90 degrees apart and set flush with the outer edge of the disc.

In using the compression/shear test device, a torque level, at which free rotation of the screwdriver handle would occur, was selected. The disc (either for surface or bulk compression/shear) was set flush on the surface of the test specimen, with the fins of the disc penetrating the specimen. The screwdriver handle was manually turned such that either material was dislodged from the test specimen or free rotation of the driver handle took place.

4.1.2. Indentation Test Device. The indentation test device was developed through modification of a commercially available "pocket" penetrometer. Such tools are used for soil testing. The indentation test device is shown in Figure 5. The penetrometer modified in the study was model H-4200, manufactured by the Humboldt Mfg. Co. It had a scale calibrated in kg/cm^2.

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 is attached to a calibrated spring housed in the aluminum tube. The end of the tube opposite the penetration rod contains an indicator rod with graduation marks every 0.25 kg/cm^2 of load. To use the penetrometer, the penetration rod is placed on the test surface and a load is applied. When resistance to penetration is met, the penetration rod retracts into the housing tube and the spring is loaded in compression. The indicator rod is pushed out of the housing as the penetration rod retracts, providing a measure of the penetration resistance of the test surface.

In the present study, modification of the end of the penetration rod of the commercially-available penetrometer was done to distribute the penetration load over a larger surface area and to provide control of the applied penetration force. In this regard, a foot, 3/4 in. (19 mm) in diameter and 1/2 in. (13 mm) thick was attached to the end of the penetration rod (Figure 5). The size of this foot was selected to be comparable to that of the tip of an adult male index finger. A collar, 3 in. (75 mm) in diameter, was mounted around the penetration rod. The collar was secured to the housing of the penetrometer using a set screw which allowed its repositioning at various positions along the housing. The face of the collar was perpendicular to the penetration rod to provide constant angle of loading to the test surface. Contact of the collar on the specimen surface provided a stop to allow loading to a predetermined level during indentation testing and also to control overloading during testing.

In using the indentation test device, the foot of the modified penetrometer was placed on the surface of the test specimen. Then, a load was manually applied to the device until the collar was flush with the test specimen surface. In this way, the foot of the penetration rod either indented the test specimen or the rod retracted into the housing, causing the indicator rod to extend. The amount of extension of the indicator rod was an indication of the amount of retraction of the penetration rod (or lack of indentation into the test specimen). For example, if the indicator rod extended fully, then indentation of the test specimen did not occur.

The maximum load 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 housing resulted in different test loads.

4.1.4. Abrasion Test Device. The abrasion test device was also developed with modification of the H-4200 "pocket" penetrometer. The concept for the abrasion test device was based on the chalk test apparatus described in ASTM Standard D 659 for "Evaluating the Degree of Chalking of Exterior Paints" [11]. In conducting this ASTM test, a piece of black felt fabric is rubbed, using a prescribed procedure, on the painted surface, and the felt is visually examined for the amount of powdered residue ("chalk") that is retained on its surface.

Figure 6 shows a photograph of the abrasion test device. It can be seen that a collar has been mounted around the penetrometer housing. For this device, the collar was 5 in. (125 mm) in diameter. The position of the collar on the housing was adjustable in order to control the amount of applied load. A foot, 1 1/2 in. (38 mm) in diameter and 5/8 in. (16 mm) thick, was attached to the penetration rod of the penetrometer. A guide rod was extended from the rear face of the foot through the collar to prevent rotation of the foot and penetration rod during abrasion testing. This was necessary since the penetration rod of the unmodified penetrometer was free to rotate. The rotation had to be eliminated to use the tool as an abrasion device.

The front face of the foot was planar and perpendicular to the penetration rod. Black felt was attached to the foot using "hook and loop fasteners" (commonly called Velcro). One piece of Velcro, which was available with a self-stick adhesive backing, was adhered to the front face of the foot. Another piece of Velcro was adhered in the same manner to a 1 1/2 in. (38 mm) diameter disc of black felt. When the two pieces of Velcro were connected together, the felt was attached satisfactorily to the abrasion test device to remain securely in place during abrasion testing. By using the Velcro to attach the felt to the test device, the felt disc could be replaced, as needed, for each test.

In conducting the abrasion test, the felt-faced foot of the device was set on the surface of the specimen. Load was applied until the collar was flush with the surface of the test specimen. At that point, the device was manually rotated 90 degrees. The felt was visually examined for the presence of a powdered or granular residue. For each subsequent test, the felt was removed from the foot of the device and a new piece was attached.

4.1.4. Impact Test Device. The prototype test device for impact was based on a commercially available rebound hammer that has had extensive field use for testing the hardness of in-place concrete. For this study, the hammer was modified to allow the addition of removable tips of varying size and hardness to the hammer head in order to vary the impact characteristics.

Figure 7 shows a photograph of the impact device. The unmodified commercially available hammer was manufactured by Tecnotest. This hammer is a plunger type with a spring loading mechanism. The spring is loaded by placing the head of the hammer on the surface to be tested, and applying a force by pushing on the base of the hammer. As force is applied, the plunger retracts into the hammer body and the spring contracts until a predetermined force level is reached. At this point, the spring is released imparting an impact energy of 1.6 lbf·ft (2.2 N·m). The modification of the hammer head involved the addition of a metal plug (by welding) into which screw threads were tapped. In this way, removable plastic and rubber tips could be used on the hammer. The tips selected for study were those used with a standard aluminum mallet that has removable screw-mounted tips. To date, the tips used with the modified rebound hammer in the friability test program have been made of soft rubber, chosen to have a hardness akin to that of the outside edge of the hand. Two tips were used in the initial testing. One tip had a Shore durometer hardness, type 2A, of 65 and was 1 1/2 in. (38 mm) in diameter. The second tip had a Shore hardness, type 2A, of 73 and was 1 in. (25 mm) in diameter. The hardness of the rubber tips should be periodically checked to determine that it does not change over time.

To use the impact test device, the tip of the modified hammer was placed on the surface of the test specimen. The hammer was manually loaded by pushing on the it until impact occurred. The specimen was examined visually to determine whether indentation occurred.

It is difficult to relate the use of the impact hammer to the impact levels associated with hand punching, since no data on the values of hand impact energies relevant to this study were found in the literature. Research may be needed to obtain such data. However, such an investigation was considered complex and beyond the scope of the present study, particularly in view of the necessary precautions that needed to be exercised if human subjects were used to obtain the needed data. As a first step in relating the use of the impact hammer to the impact levels associated with hand punching, an empirical test was conducted on gypsum (drywall) board. In this test, the drywall was supported on the edges using nominal 2x4 studs and the impact was exerted away from the board edges. It was found that the impact hammer, with either of the described tips attached, would damage 1/2 in. (13 mm) drywall, when used on the front surface of the board. The damage was considered minor, in that slight indentation or cracking of the drywall was observed at the point of impact. It was assumed that this impact was comparable to "forceful impact" (Table 3) using the hand, since experience has shown that drywall may be damaged by hand punching.

4.2 Preliminary Testing

Preliminary testing was conducted using the prototype devices and laboratory test samples of spray-applied fireproofing. The results of the preliminary tests are given in this section of the report. The results suggested that use of the prototype test devices was capable of distinguishing different levels of friability of the test materials. Extensive evaluation of the devices was beyond the scope of the first phase of the study, and will be conducted in Phase 2. Included in Phase 2 will be an evaluation of the precision of the test devices as determined through laboratory testing.

4.2.1 Test Materials. Both mineral fibrous and cementitious spray-applied fireproofing materials (Table 6) were obtained for preliminary evaluation of the test devices. These materials were specially prepared to simulate the range of friability levels given in the algorithms for the condition assessment of asbestos-containing materials. The average densities of the test materials, as provided by the material suppliers, are given in Table 6. Measurements of the density indicated that individual specimens were within 15 percent of the reported average density, except for sample No. F1 which was within 25 percent. The nominal average thickness of both the mineral fibrous and cementitious samples was 1 in. (25 mm). 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. Both types of samples were placed on a rigid laboratory bench during preliminary testing.

These spray-applied samples were examined manually according to the directives for judging the friability of asbestos-containing materials (Table 3). As judged subjectively, it appeared that, as the density of a given type of material increased, its resistance to being dislodged, crumbled, or pulverized using hand actions increased.

4.2.2 Preliminary Observations with the Compression/Shear Test Device. The surface compression/shear test was conducted on two or three locations of the specimens at a number of different torque levels, as set on the screwdriver. For samples F1, F2, F3, F4, and C3, it was found that the torque levels, at which material was dislodged from the surface of the samples, were 5, 5, 10, 14, and 20 lbf·in.(0.6, 0.6, 1.1, 1.6, and 2.3 N·m), respectively. This provided initial evidence that the surface compression/shear test could distinguish between the samples available.

Similar results were observed when the compression/shear test was conducted on the bulk of the samples. For samples F1, F2, F3, and F4, dislodging of material occurred at 10, 10, 14, and 16 lbf·in.(1.1, 1.1, 1.6, and 1.8 N·m), respectively. It is noted that the fins did not totally penetrate into the bulk of sample F4. Also, little penetration of the fins on the disc of the screwdriver occurred with the cementitious samples. Thus, no torque value for dislodging the cementitious material was obtained.

4.2.3 Preliminary Observations with the Indentation Device. The results of the preliminary testing using the indentation test device indicated that varying behavior of the different samples could be observed. For the mineral fibrous materials, the indentation resistance of the material increased with an increase in density. The preliminary test was conducted at a load of 7.7 lbf (3.5 kgf). The extent of indentation was estimated in units of depth. For samples F1, F2, F3, F4, and C3, the indentation was 2.1, 1.7, 0.9, 0.6, and 0.2 units, respectively.

4.2.4 Preliminary Observations with the Abrasion Test Device. Preliminary testing using the abrasion test device was conducted only on the cementitious materials, because the descriptors for friability (Table 3) made reference to rubbing actions only with cementitious materials. In conducting preliminary abrasion tests, the collar on the abrasion test device was set so that the load applied to the surface of the sample was 4.4 lbf (2 kgf). Although, in the preliminary tests, the abrasion test was only applied to the cementitious materials, it is considered applicable to all types of materials. The test may be akin to rubbing the material to determine whether a residue is produced.

The results using the device were comparable to those using the hand. When rubbed with the fingers, the three cementitious samples left a residue on them. The device also gave residues on the black felt for all three cementitious samples. No difference in the amount of residue on the felts could be visually distinguished for each of the samples. Further analysis of the amount of residue was not made during Phase 1, but will be conducted during Phase 2.

4.2.5 Preliminary Observations with the Impact Test Device. All laboratory samples (Table 6) could be indented using the hand. Thus, it was expected that all samples would undergo some degree of indentation using the impact test device. This was found to be the case. The low density fibrous materials (F1 and F2) were found to have the greatest extent of indentation. Quantification of the extent of impact indentation will be done in Phase 2 of the study.

The impact test device was applied to vinyl asbestos floor tile. These tiles are normally considered to be non-friable [10]. It was visually observed that the impact hammer did not indent the tiles.

5. SUMMARY AND CONCLUSIONS

This investigation was Phase 1 of a study to develop a test method that can be used in the field to measure the friability of spray-applied fireproofing and insulating materials containing asbestos fibers. These materials are considered friable if, when dry, they can be crumbled, pulverized, or reduced to powder using hand pressure. The objective of Phase 1 was to establish the technical basis for development of an objective friability test method for use in lieu of current field procedures which are subjective. Currently, inspectors conducting field assessments must touch the spray-on material with the hand to determine whether it can be crumbled, powdered, or pulverized. One of four levels of friability is assigned to a material depending upon the hand action used and the amount of force applied.

In conducting the study, a review of friability tests that have been applied or considered to have potential for application to asbestos-containing materials was made. None of the reviewed tests was found suitable.

It was proposed to develop mechanical tests for field use. A flow chart was developed outlining a systematic sequence for conducting the field assessments. Four test methods were suggested for development: a compression/shear test, an indentation test, an abrasion test, and an impact test. The compression/shear test is intended to be conducted both on the surface and bulk of the samples.

For each of the four tests, mechanical devices were constructed with modification of existing construction material test apparatus. A description of each device is given in the report. Preliminary laboratory tests, conducted on specially prepared spray-on materials having a range of friabilities, were performed. The test materials were mineral fibrous and cementitious. The results suggested that the devices could distinguish between degrees of friability of the test samples. For example, for the fibrous materials, the load required to damage the samples increased as the sample density increased.

Based on the results of the preliminary testing, it was suggested that further evaluation of the prototype test devices be made in Phase 2 of the study. This evaluation will include extensive laboratory testing including statistical analysis of the results, and evaluation of the precision of the proposed methods. Field testing of existing spray-applied asbestos-containing materials will be conducted. Recommendations will be made concerning quantitative values for each level of friability used in the GSA algorithm. The results of Phase 2 will be made available in a final report.

6. ACKNOWLEDGMENTS

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Table 1. Summary of Modes for Fiber Release and Dispersion[a]

Mode	Characteristic	Factors Affecting Mode
Fallout	constant release over time due to weak bonds; normally a slow process; rate may increase with age	vibration people movement cohesive/adhesive strength application quality degree of deterioration environment (humidity, sun) substrate (smooth vs. rough)
Impact	direct contact that knocks fibers loose; amount of fibers released can vary with impact and material	intensity of impact application quality cohesive/adhesive strength degree of deterioration
Resuspension	secondary dispersal or reentrainment of fibers which have previously been released by fallout or impact; amount of fibers released may depend on the level of activity	building activities, e.g.: - foot traffic - maintenance - sweeping - dusting - air circulation systems

a. This table was summarized from the discussion in Reference [4].

Table 2. Summary of the EPA Algorithm for Exposure Assessment[a,b]

Factor	Range or Extent	Score
1. Material condition (deterioration/ damage)	None	0
	Moderate, small areas	2
	Widespread, severe, pieces dislodged	5
2. Water damaged	None	0
	Minor	1
	Moderate to Major	2
3. Exposed surface area	Not exposed, located above suspended ceiling; none visible without removing panels or ceiling sections	0
	10% or less of the material is exposed	1
	10% to 100% of the material is exposed	4
4. Accessibility	Not accessible	0
	Low, rarely accessible	1
	Moderate to high, access may be frequent	4
5. Activity and movement	None or low, libraries, most classrooms[c]	0
	Moderate, some classrooms, corridors	1
	High, some corridors and cafeterias, all gymnasiums	2
6. Air plenum or direct air streams	None	0
	Present	1
7. Friability	Not friable	0
	Low friability, difficult but possible to damage by hand	1
	Moderate friability, fairly easy to dislodge and crush	2
	Highly friable, fluffy, spongy, flaking, pieces hanging, falls apart when touched	3
8. Asbestos content (total % present)	Trace to 1%	0
	1% to 50%	2
	50% to 100%	3

a. This table was developed by EPA and was taken from Reference 4. It is noted that EPA no longer uses an algorithm for assessing condition of asbestos-containing materials [6].
b. In using the algorithm to obtain a numerical indication of the potential for asbestos exposure, the sum of the numerical ratings for the first six factors is taken. That sum is, in turn, multiplied by the ratings obtained for factors 7 and 8.
c. These types of rooms are specifically mentioned, since a prime use of the EPA algorithm was the condition assessment of schools.

Table 3. Descriptors of Levels of Friability from the EPA Algorithm, As Published in 1982[a]

Friability Level	Descriptor
Not Friable	Material that is hard and crusty. Cannot be damaged by hand. Sharp tools required to penetrate the material.
Low Friability	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.
Moderate Friability	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.
High Friability	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.

a. This table was taken from Reference 4. It is noted that EPA no longer uses an algorithm for assessing condition of asbestos containing materials [8].

Table 4. Descriptors of Levels of Friability from the GSA Algorithm[a]

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

a. This table is taken from Reference 3.

Table 5. Summary of Hand Actions and Related Mechanical Tests

Level of Friability	Hand Action Specified in Algorithm	Hand Action Implied in Algorithm	Mechanical Test Associated With Hand Action
Not Friable	None	Impact	Impact
Low Friability	Impact	---[a]	Impact
	Rubbing	---	Abrasion
Moderate Friability	Indentation	---	Indentation
	Rubbing	---	Abrasion
	---	Pinching/Squeezing	Compression/Shear
	---	Pushing	Shear
	---	Pulling	Tension
	---	Scratching	Abrasion
High Friability	---	Pinching/Squeezing	Compression
	---	Pushing	Shear
	---	Pulling	Tension
	---	Scratching	Abrasion

a. No hand actions other than those given in the algorithm descriptors were considered needed for this level of friability.

Table 6. Spray-Applied Fireproofing Materials Used in Preliminary Tests

Sample No.	Material Type	Average 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. Average values to which the materials were manufactured.
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 water on the job site, forms a slurry for spray application.

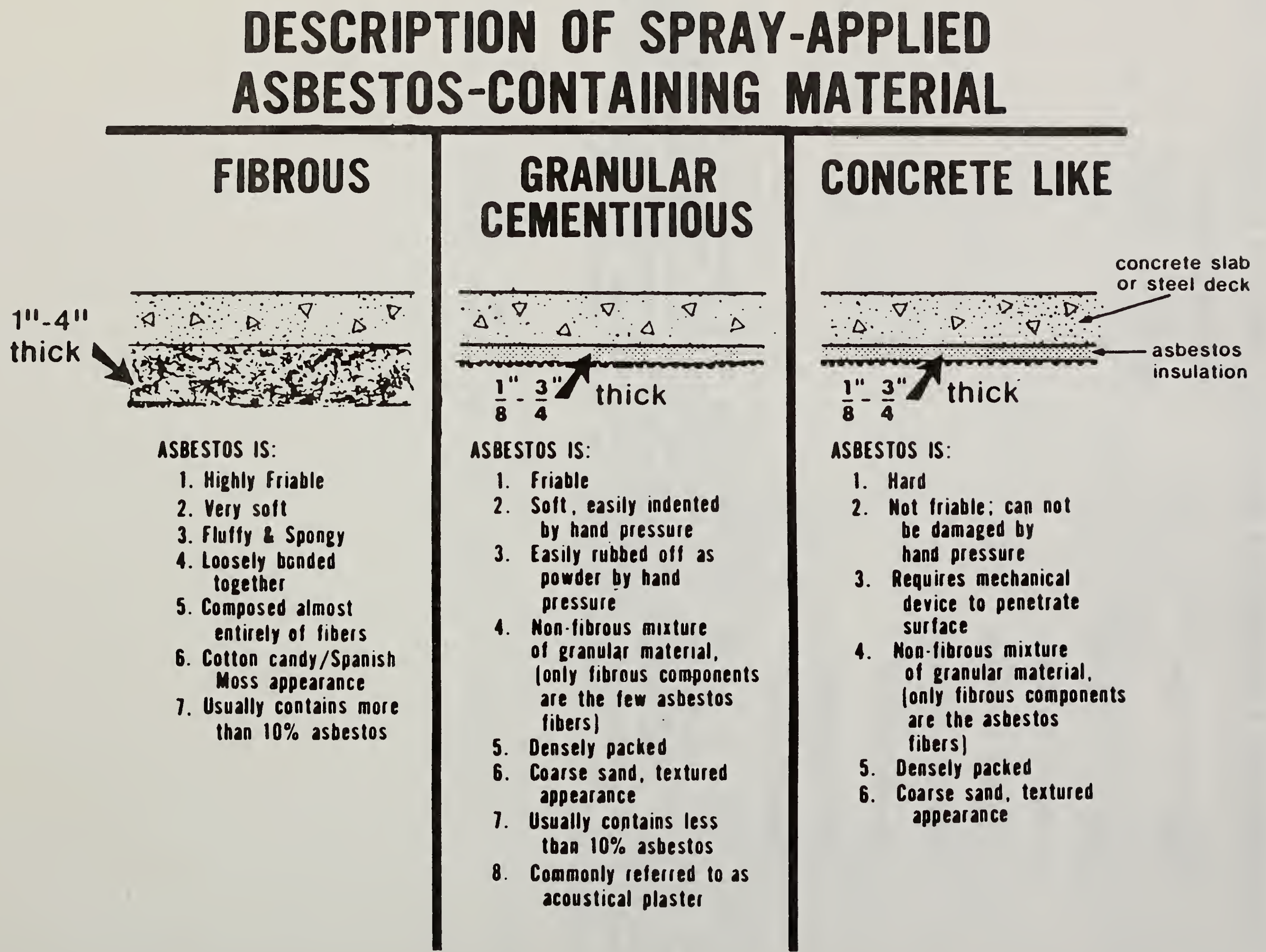

Figure 1. Types of Spray-Applied Materials, as given in Reference 4.

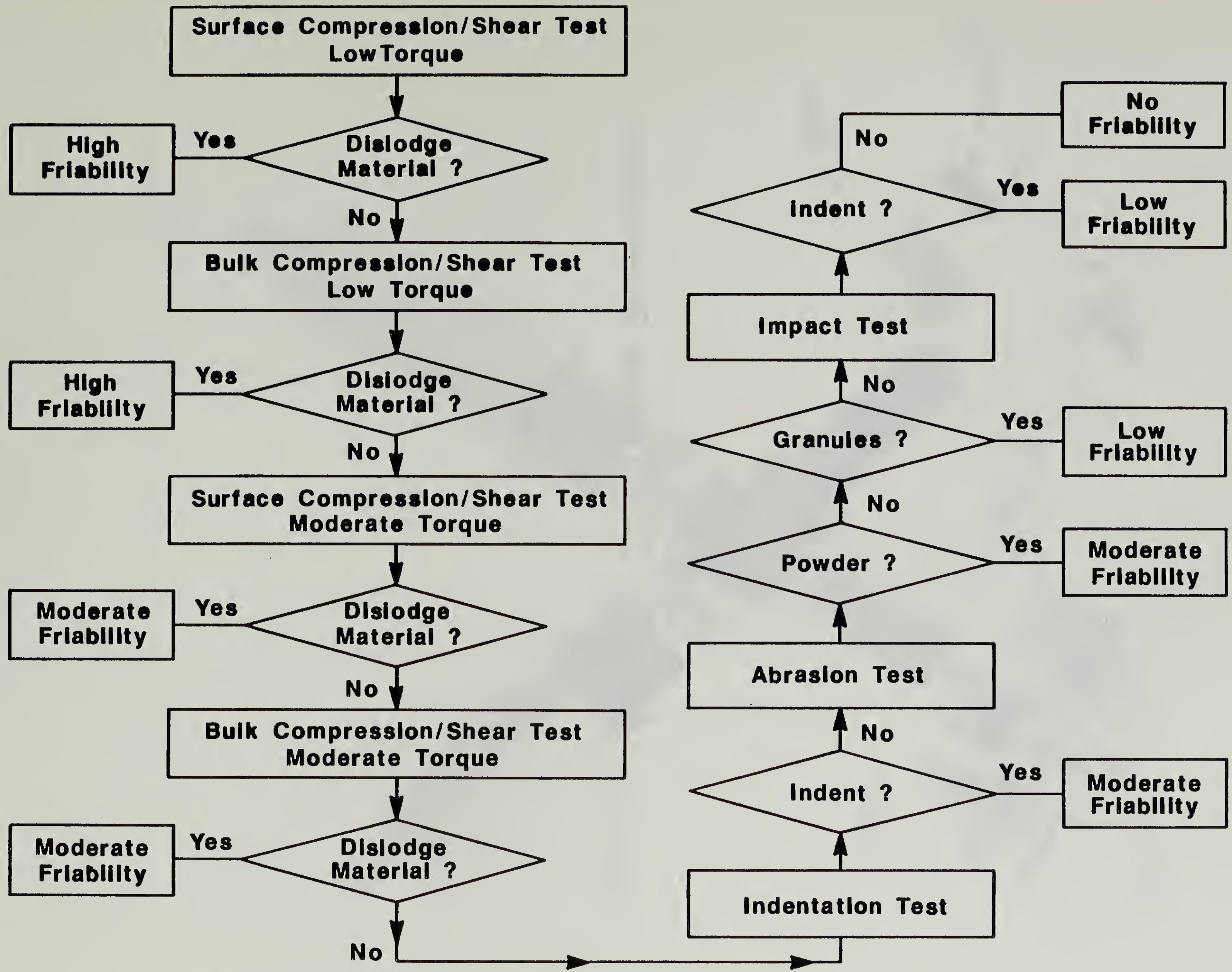

Figure 2. Flow Diagram Indicating the Sequence of Conducting Friability Tests

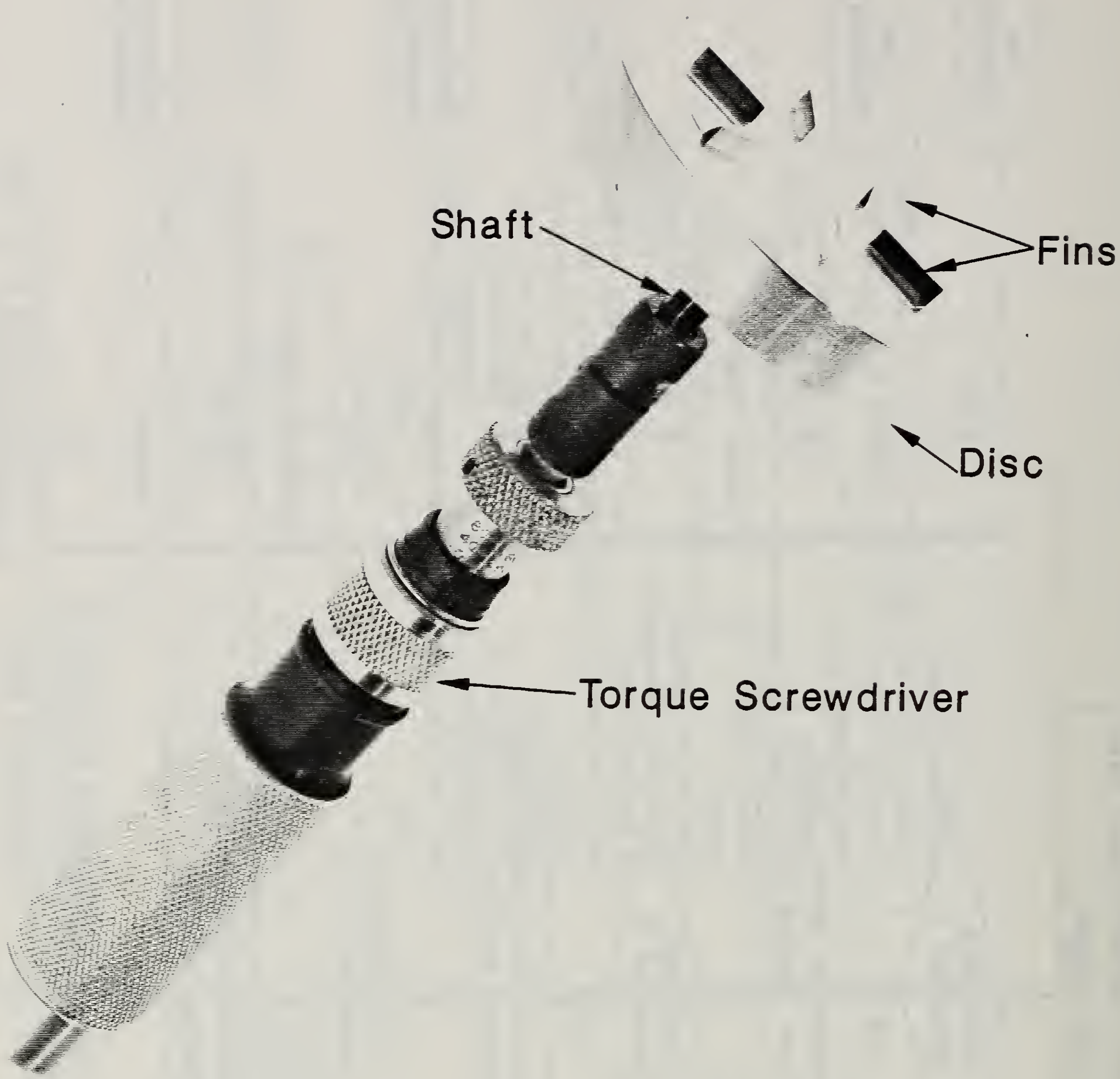

Figure 3. Prototype Device for Conducting Surface Compression/ Shear Tests

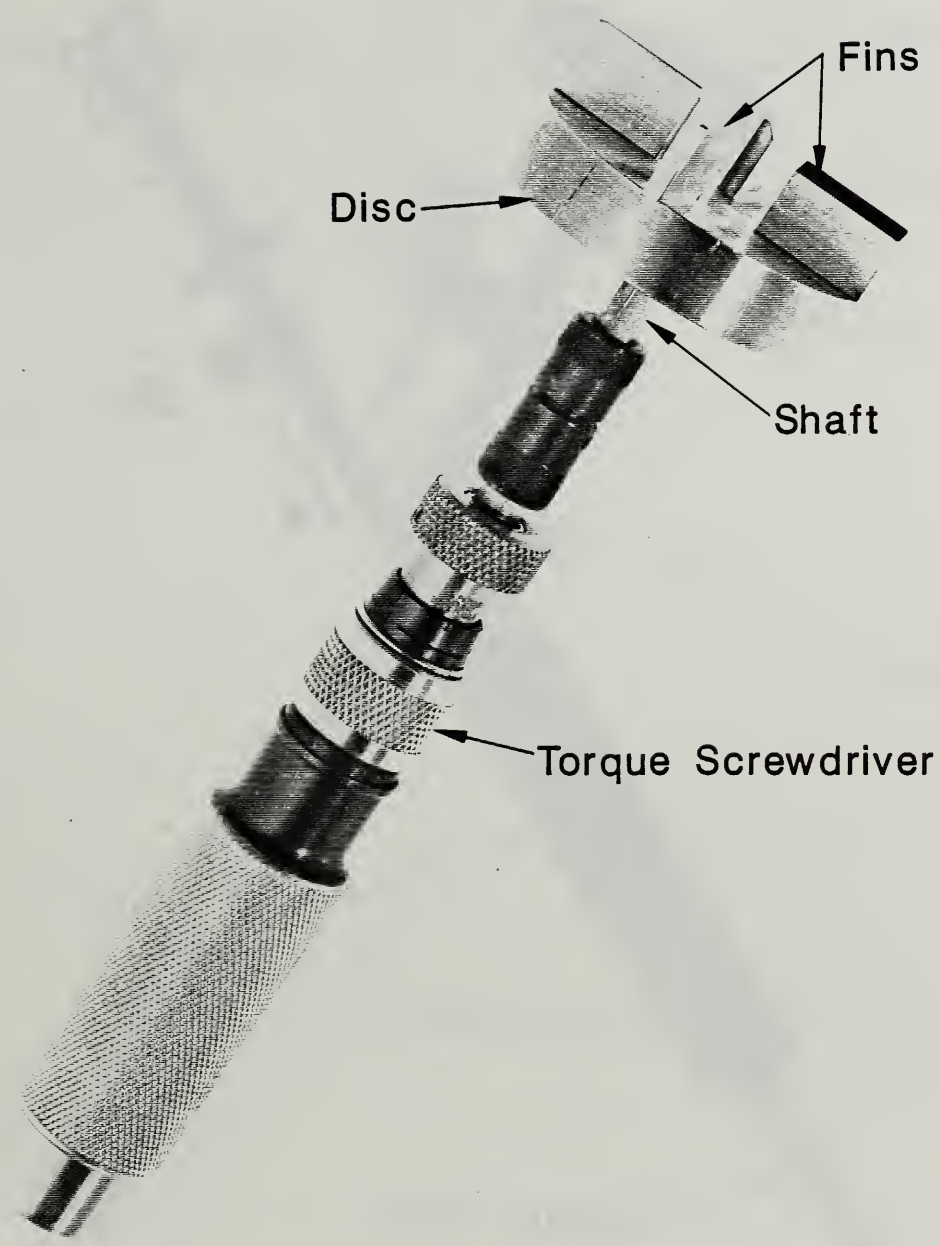

Figure 4. Prototype Device for Conducting Bulk Compression/ Shear Tests

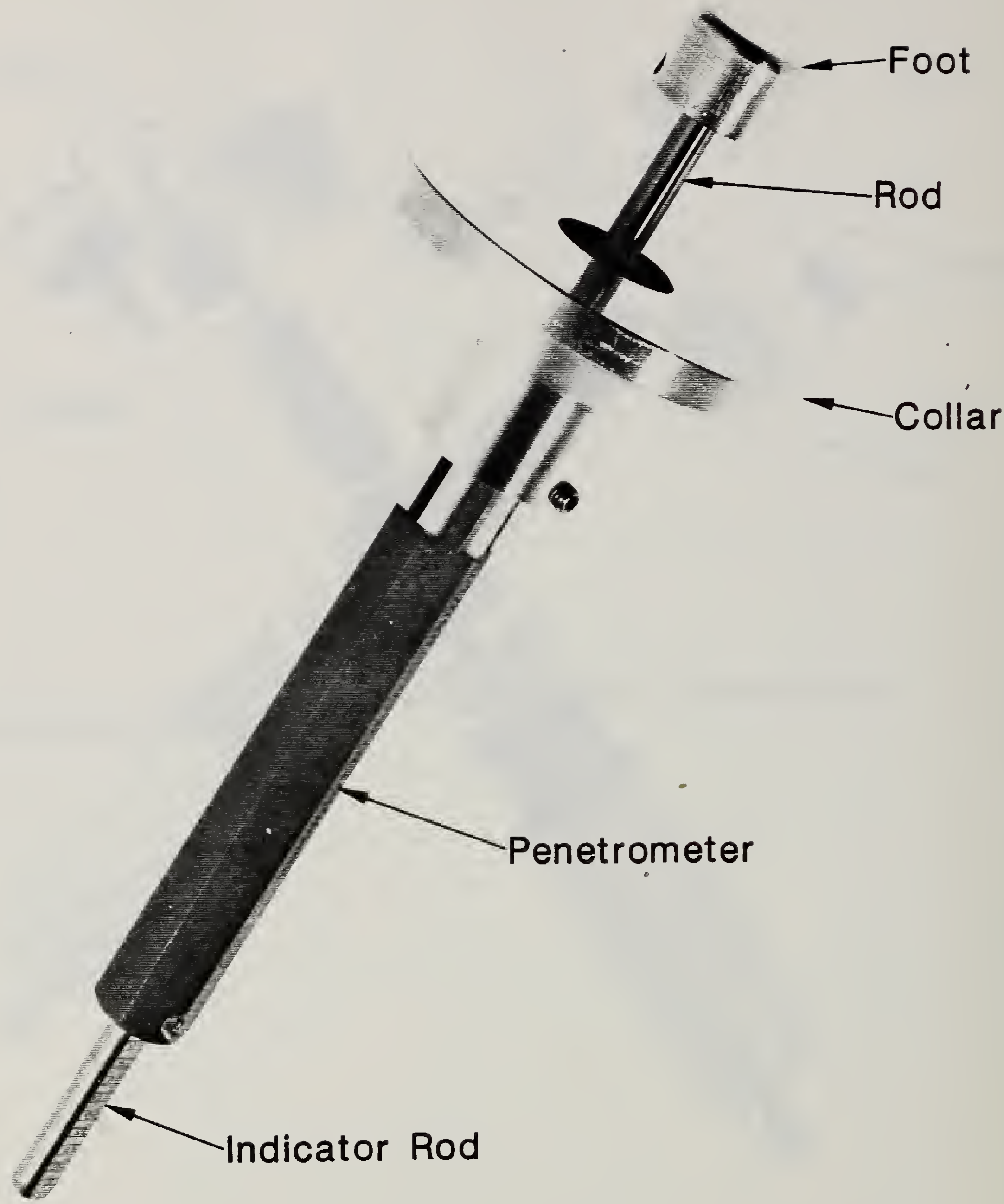

Figure 5. Prototype Device for Conducting Indentation Tests

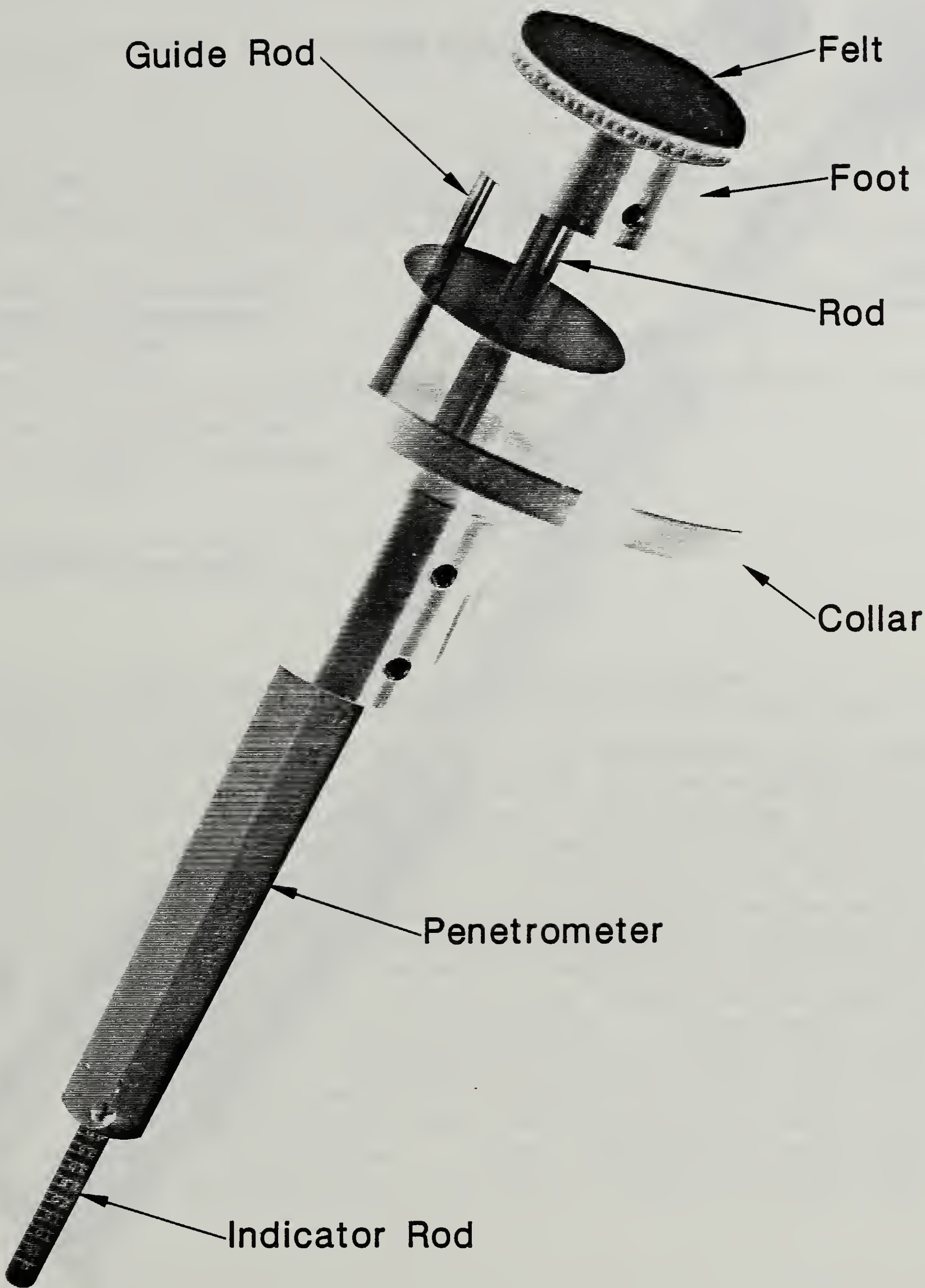

Figure 6. Prototype Device for Conducting Abrasion Tests

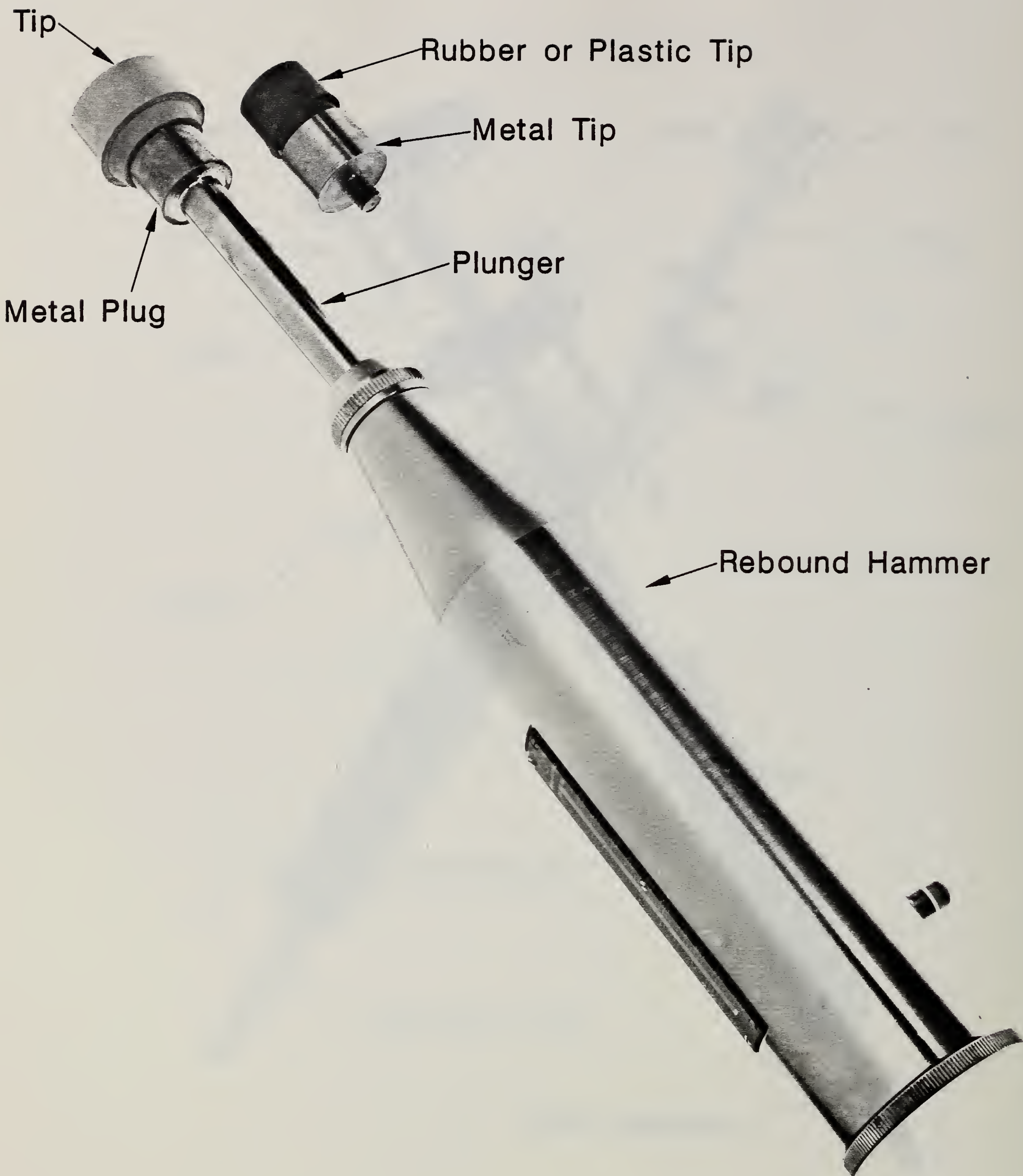

Figure 7. Prototype Device for Conducting Impact Tests

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11. 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 investigation was Phase 1 of a two part study to develop a test method that can be used in the field to measure the friability of spray-applied fireproofing and insulating materials containing asbestos fibers. The objective of the first phase was to establish the technical basis for development of a test method to measure friability quantitatively. The test method is intended for use in lieu of current field procedures which involve evaluation by hand pressure and are subjective. A flow chart was prepared outlining a systematic sequence for conducting the field assessments. Four test methods were selected; compression/shear, indentation, abrasion, and impact. For each of the four tests, mechanical devices were devised by modification of existing material test apparatus. A description of the test devices is given in the report. Preliminary laboratory tests, conducted on specially prepared spray-on (non-asbestos) materials having a range of friability, were performed. The results suggested that the devices could distinguish differences in friability between the test samples. Further evaluation of the prototype test devices will be made in the laboratory and field in Phase 2 of the study.

12. 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; thermal insulations

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