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COMPRESSION CUTTING TEST FOR RUBBER

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ABSTRACT

This paper describes a study of the compression cutting test, also referred to as the shear test, for rubber. The test consists of compressing a sample of rubber to failure between a flat plate or anvil and a cutting tool, and recording the relation between the thickness of the sample and the load up to failure. Data are presented on (1) different tools used for the test, (2) conditions affecting the results, and (3) a comparison of the compression cutting tests with other common tests. Advantages and disadvantages of the compression cutting test are discussed. The conclusion is reached that it is valuable as a supplement to, rather than as a substitute for, the tensile test.

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I. INTRODUCTION

Compression tests for insulated wire were described by Hippensteel in 1926.¹ Later Ingmanson and Gray² and Somerville³ described a machine for making compression cutting and shear tests as applied not only to insulation for wire but to rubber in general. The test consists of compressing a sample between a flat plate or anvil and a cutting tool. The relation between the thickness under the cutting tool and the load is recorded graphically. The test has a strong appeal because it is much simpler to make than tensile-strength tests and data have been presented indicating that it may be a satisfactory substitute for the tensile test. The work described in the present paper was carried on in order to obtain information concerning the test with a view to employing it in specifications.

¹ Ind. Eng. Chem., vol. 18, pp. 409-411, 1926.² India Rubber World, vol. 82, no. 4, pp. 53-56, July 1, 1930.³ Inst. Rubber Ind., Trans., vol. 6, no. 2, pp. 150-159, 1930.

II. DESCRIPTION OF MACHINE AND NATURE OF TEST

The machine used for the tests was the same as used by Ingmanson and Gray, and by Somerville. (See fig. 1.) It consists essentially of a means for compressing rubber samples between a cutting tool and a steel anvil and measuring the load and thickness under the tool. The tool is fixed at the top of the machine and the anvil carrying the sample is forced up against it as indicated. The load is applied through a heavy coil spring, the compression of which is used to measure the load. The lower end of this spring travels at a speed of 1.5 inches per minute. The compression of the spring (i.e., the load), together with the distance between the tool and the anvil (i.e., the thickness of the

FIGURE 1.—Machine for compression cutting tests.

specimen), are recorded mechanically on a chart as a load-thickness curve. The maximum capacity of the machine is 2,000 pounds.

Cutting does not take place gradually as is the case with many materials. Instead, the rubber is compressed to a fraction of the original thickness before any cutting occurs. When cutting does start, it takes place suddenly and, due to the design of the machine, the specimen is cut completely through.

The property of a rubber compound measured by the test is not a simple one. The rubber is first crowded away from each side of the cutting tool, thus introducing stresses at an angle to the section being cut. The top surface of the sample is put in tension as indicated by the deformation of the surface, and frictional resistance between the rubber and the tool and anvil introduces stresses. The test is often referred to as shear, but in the present paper the expression "compression cutting", or simply cutting, is used as being a truer descrip-

tion. The test may be classed as a performance test in that it represents a condition which rubber may be called upon to resist in service. A relatively small quantity of material is required for test purposes, specimens are ordinarily easy to prepare, and small differences in the thickness of specimens have relatively little effect on the cutting load. Test specimens of insulation from wires and cables consist simply of longitudinal sections of the insulation about 1 inch long. Rubber in sheet form may be conveniently tested, a piece 1 by 2 inches sufficing for 6 or 8 tests.

III. COMPRESSION CUTTING TOOLS

A variety of ways of cutting have been tried out with the machine. When insulated wire containing a solid conductor is tested, it is satisfactory to compress the wire between two flat anvils. In this case, cutting takes place between the conductor and the anvils. However, this method cannot be used for a cable having a stranded conductor, nor is it applicable to the testing of sheet rubber. For tests of insulation from a stranded conductor, the insulation may be split longitudinally and the test made on a portion of the insulation between a flat anvil and a mandrel equivalent to the original wire size. For simplicity, however, there is an advantage in one tool for all tests, i.e., all sizes of wire, sheet rubber, etc.

A 90° steel wedge with the edge flattened to a width of 0.008 inch has been used elsewhere and was tried out for our work. (See fig. 2.) Questions arose, however, as to the necessary limits for the width of the flattened edge and how to define the sharpness of the two edges resulting from the flattening process. A series of wedges was made as nearly identical as possible except for the width of the flattened edges. These varied from 0.0008 to 0.0098 inch. Cutting tests were then made on five different compounds. The results are shown in figure 2. Duplicate tests were made with the samples dry and when lubricated with a mixture of glycerine and graphite. In both cases the relation between the width of the cutting edge and the cutting load is very nearly linear. A change in width of the cutting edge does not affect all compounds the same. The average for the dry tests with wedges in the region of 0.008-inch width is about 100 pounds difference in cutting load per 0.001-inch difference in width. With the lubricated samples it is about 85 pounds instead of 100 pounds.

An examination of wedges with a microscope after 40 or 50 tests showed considerable scratching of the surfaces, and a decided dulling, apparently due to high concentration of load on the edges of the flattened portion during a test. Attempts which were made to construct duplicate wedges indicated that considerable difficulty would be experienced in making them with equal cutting characteristics.

On the basis of these tests the 90° wedge was abandoned and a tool was made with an edge which can be more easily defined and renewed. This tool consists of an acute-angle wedge grooved along its edge to hold a piece of 1-millimeter drill rod. The tool and the corresponding anvil are shown in figure 3. Experience has shown that the tool can be easily duplicated and that by renewing the drill rod when there is an appreciable wear, a constant cutting edge is maintained. From the standpoint of cutting, the tool is equivalent to the mandrels used by Ingmanson and Gray. No precise data

have been obtained on the life of the cutting edge, but with ordinary grades of rubber, 100 tests per edge seem to be feasible. Stops are provided on each side of the cutting tool. These are set for a clearance of 0.002 inch between the tool and the anvil so as to avoid damage to the edge.

FIGURE 2.—Relation of width of edge face to the compression cutting load.

Five different compounds were tested as follows:

K—Pure gum, ultra accelerator.

L—Tread stock, 30 parts carbon.

M—Superaging compound 80 percent rubber by volume.

N—Tread stock, 50 parts carbon.

P—Loaded stock, 100 parts soft carbon.

In upper set samples were lubricated with glycerine and graphite. In lower set they were tested dry.

IV. CONDITIONS AFFECTING TEST

1. ADJUSTMENT OF TOOL

Care must be taken to insure that the tool and anvil face are parallel as otherwise low cutting loads result. The necessary limits for parallelism will depend upon the type of rubber tested and on its thickness. Tests show that for ordinary purposes the tool and the anvil should not be out of parallel by more than 0.001 inch. The thinner the sample and the more compressible the rubber, the greater will be the influence of any departure from parallelism.

FIGURE 3.—*Tool and anvil used in compression cutting tests.*

Stops are set for .002" clearance between tool and anvil so as to avoid damage to edge.

2. LUBRICATION

As has been observed by previous investigators, if the surfaces of the specimen are lubricated, or if the compound tested contains a lubricant which blooms or exudes on the surface, the cutting load is lower than would otherwise be the case. Tests which were made on two compounds to show the influence of surface lubricants are shown in figure 4. When alcohol and water were employed, a container was constructed around the anvil, and tests were made with the sample completely submerged. In the other cases the tool and the anvil and both sides of the sample were coated with the lubricant.

The pure gum compound is more sensitive to surface lubrication than the tread stock. It also appears that the surface of the pure gum rubber may have been attacked by the vaseline during the 3 or 4 minutes necessary to make the tests, thus lowering the cutting load. The tread stock, being more resistant to a lubricant such as vaseline, showed the same cutting load with vaseline as with castor oil which does not affect rubber. The high sensitivity of pure gum to surface lubrication is also illustrated by the wedge tests in figure 2 where "K" acts very differently in the dry and in the lubricated conditions.

It is general practice in some laboratories to test all samples under water—a method well adapted to tests at different temperatures. In the present work all tests were made dry, the only precaution being to dust samples lightly with talc. This dusting appears to leave the surfaces of all samples in a similar condition. With many compounds, particularly if there is a slight bloom, the talc has little or no effect. With nonblooming stocks having very clean surfaces, the use of talc reduces the cutting load somewhat and seems to increase the consistency of a series of tests.

FIGURE 4.—Influence of surface lubricants on the compression cutting load.

Sheet rubber samples of pure gum rubber 0.087 inch thick and tread rubber 0.075 inch thick were tested with the substances indicated as surface lubricants. Each point shown is the average of 5 or more tests.

3. DIMENSIONS OF TEST SPECIMEN

The dimension of the test specimen in the direction of the cut should be slightly greater than 1 inch (the anvil is exactly 1 inch wide). The other dimensions may be dependent upon the material to be tested and of any convenient magnitude. With the renewable edge tool this design proved to be more practical than the older design in which the

cutting face was made an exact length, the method used with the wedge and other tools.

The thickness of the sample will affect the cutting load, but, as indicated previously, not in direct proportion to the thickness. Data on the effect of thickness are shown in figure 5. Tests were made on eight rubber compounds, subsequently described, each compound being cured in sheets of four thicknesses. Results reported by Somerville, and by Ingmanson and Gray are indicated in the figure by broken lines. There is some variation in the effect of thickness of different types of rubber on the cutting load, but as an average the load increases 25 to 35 percent for an increase of 100 percent in thickness.

FIGURE 5.—Influence of thickness of sample on the compression cutting load.

Eight different compounds were tested (see table 1) with the tool shown in figure 3. Each point on the curve is the average of from 4 to 8 tests.

- A. 30-percent insulation.
- B. 40-percent insulation.
- C. Low quality insulation.
- D. 40 parts gas black stock.
- E. 40 parts thermatomic carbon stock.
- F. Pure gum plus 10 volumes kalite.
- G. Pure gum, ultra accelerator.
- H. Pure gum.

Broken line "S" shows results reported by Somerville with a wedge tool.

Dot-dash line "I" shows results reported by Ingmanson and Gray with a mandrel.

4. TEMPERATURE

Somerville has reported some data on the effect of temperature, which indicates that the compression cutting load and the tensile strength are affected similarly. In the present work all tests were made at a constant temperature of 75 F, and no data are presented on the effect of temperature.

V. COMPRESSION CUTTING TESTS OF TYPICAL COMPOUNDS

For a study of the compression cutting test as a means of classifying different types of rubber the eight compounds shown in table 1 were prepared in the form of sheets, several cures of each compound being made. The results of tests on these compounds are shown in figure 6.

TABLE 1.—Composition of compounds tested

Ingredient	Composition (parts by weight) of compounds—							
	A ¹	B ²	C ³	D	E	F	G	H
Rubber.....	100	100	250	100	100	100	100	100
Sulphur.....	4.6	4.0	11.72	3	3	2	2	3
Zinc oxide.....	37.0	32.6	15.60	5	5	2	2	2
Whiting.....	176.0	104.4	594.0					
Kalite no. 3 ⁴						26.0		
Tetramethylthiuramdisulphide.....						.25	.25	
"Micronex" (carbon black).....				40				
"Thermatomic" (carbon black).....					40			
Stearic acid.....			3.91	4	4			
V.G.B. (antioxidant).....	.5	.5		1	1			
Mercaptobenzothiazole.....			3.13	.8	.8			
Mineral rubber.....			235.0	5	5			
Tetramethylthiurammonosulphide.....	.4	.3						
Paraffin.....		5.5						
Ozokerite.....	4.1							
Litharge.....	8.2							
Reclaimed rubber.....			250.0					
Clay.....			235.0					
Diphenylguanidine.....								.75

¹ 30 percent insulation. ² 40 percent insulation. ³ Code wire. ⁴ Specially processed calcium carbonate.

The accelerated pure-gum compounds G and H give the highest cutting loads. Ten or fifteen percent below the pure-gum compounds are D, E, and F, all containing fillers and consisting, respectively, of 40 parts of reinforcing carbon black, 40 parts of nonreinforcing carbon black, and 26 parts of kalite, a specially processed calcium carbonate. D, the tread type of compound, has a slightly higher cutting load than the other two compounds.

B and A are respectively 40 and 30 percent rubber insulation compounds. The cutting load of B is lowered by its paraffin content. Compound C is low in rubber and high in asphaltic materials and other ingredients and shows a low cutting load. Cure affects the cutting load in much the same way that it affects tensile strength.

The cutting load itself is not particularly sensitive in distinguishing among different types of compounds as evidenced by the relatively small differences among the five highest compounds that differ very materially in composition. It would appear that in order to distinguish among them some other factor should be taken into consideration, such as the thickness under the tool at the time of cutting or the rate of decrease in thickness with load. This conclusion is in line with tensile tests where elongation and stiffness, together with tensile strength, are used in attempting to define a compound.

Although the design of this machine is such that the thickness under the tool during compression is indicated graphically, the precision of the measurement for highly compressible rubber, particularly if thin, is not very great. However, several measurements of thickness under the tool at the instant of cutting were determined as

closely as possible. These showed that a pure-gum compound will decrease to about 8 percent of its original thickness, and a carbon black compound to about 12 percent of its original thickness before cutting takes place. If the surfaces are lubricated, these percentages will be about 6 and 10 percent, respectively. Other types of compounds, containing other ingredients, showed thicknesses at the time of cutting in about the same range. It appears that the thickness at the time of cutting is largely a function of the amount of mineral filler

FIGURE 6.—Compression cutting loads of various types of rubber compounds vulcanized for different periods of time.

All samples in sheet form approximately 0.065 inch thick. A, 30 percent insulation; B, 40 percent insulation; C, low quality insulation; D, 40 parts gas black stock; E, 40 parts thermatomic carbon stock; F, pure-gum plus 10 volumes of kalic; G, pure-gum, ultra accelerator; H, pure-gum. A and B were vulcanized at 270 F; F and G were vulcanized at 275 F; C, D, E, and H were vulcanized at 288 F.

the machine with the foot extending through the top and resting on the anvil. The measurements, however, required a correction to take care of elastic deformation. A better plan would appear to be to redesign the head of the machine so as to permit precise gages accurate to 0.0001 inch to be mounted on each side of the tool and the anvil and very close to them.

and that for any particular compound it is a constant percentage of the original thickness.

The method of measuring the thickness under the tool afforded by the machine, however, is not sufficiently precise on account of the magnitude of possible errors in the recording mechanism and elastic deformations in the machine, in comparison with the high degree of precision required. For instance, a sample of pure-gum rubber, 0.040-inch thick, will have a thickness under the tool of about 0.003 inch at the time of cutting. To make this latter measurement within 10 percent would necessitate a precision of measurement of 0.0003 inch, whereas the elastic deformation in the machine may be of the order of 0.0015 inch. However, for relatively thick samples and those containing a considerable volume of loading material the thickness at the time of cutting, as indicated by the machine, is sufficiently accurate for practical purposes.

Some check measurements of thickness under the tool were made by mounting a dial gage on the top of

VI. COMPARISON WITH OTHER TESTS

With the compounds shown in table 1, a comparison was made between compression cutting tests (both dry and with a lubricant), and corresponding tensile, tensile-product, and tear tests. The results are shown in figure 7. The cutting load, either in the presence or absence of a lubricant, is not directly related to any of the other tests. There are certain agreements with tensile and tensile product, and at the same time certain discrepancies. For instance, samples G and D, pure-gum and tread compounds, respectively, are reversed in the cutting and the tensile tests; sample F is high in tensile product, and sample C is low as compared with the cutting tests.

The tear test is entirely out of line with the cutting test.

VII. THE COMPRESSION CUTTING TEST AS A MEASURE OF AGING

The change in tensile strength over a period of exposure to accelerated aging conditions is the usual measure of the aging properties of a rubber compound. Tests were made to ascertain the possibility of substituting the compression cutting test for the tensile test in measuring aging properties. The same 8 compounds shown in table 1 were used and the cutting loads and the corresponding

tensile strengths were determined after 0, 7, and 21 days in an oven at 70 C. The results are shown in figure 8.

As indicated by the figure, the changes in the cutting load follow in a general way the changes in tensile strength, but in practically every case they are less than for tensile strength. Taking an average for all 8 compounds, there is a drop in tensile strength of 38 percent and a drop in the cutting load of 25 percent over the 21-day period. This means that the cutting test is about 65 percent as responsive to differences as the tensile test.

FIGURE 7.—Comparison of tests by different methods.

Letters indicate compounds listed in table 1. Tests were made on the intermediate cures of all compounds except C and H. The shortest cures of these were tested. (See figure 6.) Tensile product is equal to the tensile strength multiplied by the elongation at break: A, 30 percent insulation; B, 40 percent insulation; C, low quality insulation; D, 40 parts gas black stock; E, 40 parts thermatomic carbon stock; F, pure-gum, plus 10 volumes kalite; G, pure-gum, ultra accelerator; H, pure-gum.

Stress-strain tests which were made on these compounds during aging show that A, C, D, and E stiffen and B, F, G, and H soften. Those which stiffen retain relatively high cutting loads, and those which soften show a considerable reduction in the cutting load.

VIII. APPLICATION OF COMPRESSION CUTTING TEST TO SPECIFICATIONS

Factors favoring the inclusion of a compression cutting requirement in specifications can be summed up briefly as follows: (1) The cutting test can be adapted to products from which it is difficult or inconvenient to obtain tensile test specimens; (2) the preparation of test specimens is simple—dimensional measurements need not be as precise as with many other tests; (3) it is more nearly an actual measure of performance for many products than tensile strength tests.

Factors unfavorable to a compression cutting requirement in specifications have largely to do with the technical details of making the

FIGURE 8.—Influence of aging in an oven on compression cutting and tensile strength.

Letters refer to compounds in table 1: A, 30 percent insulation; B, 40 percent insulation; C, low quality insulation; D, 40 parts carbon black stock; E, 40 parts thermatomic carbon stock; F, pure-gum plus 10 volumes kalite; G, pure-gum, ultra accelerator; H, pure-gum. Light lines show results of tensile tests. Heavy lines show results of compression cutting tests.

test. They may be stated briefly as follows: (1) Its use with thin samples, 0.006 to 0.020 inch in thickness, is open to question. The thickness of such samples at the time of cutting would be as little as 0.0005 to 0.0016 inch. For parallel cutting this requires tools and alinement of a degree of perfection that is perhaps beyond the range of practicability. In addition, the stops which protect the edge of the tool would probably have to be removed or adjusted within extremely close limits; (2) careful consideration must be given to the presence or absence of lubricants on the surface of the rubber. The use of a lubricant tends to make the cutting loads for different

types of compounds more nearly the same and reduces the sensitivity of the test; (3) as a criterion of aging in an oven, the cutting test is less responsive to differences than the tensile strength test.

IX. CONCLUSION

Compression cutting may be used to advantage in testing certain types of rubber products and in studying specific problems, but it is not the equivalent of the tensile test or any other common test used for rubber. From the data obtained in this study compression cutting appears to be valuable as a supplement to present tests for rubber goods.

WASHINGTON, January 8, 1934.