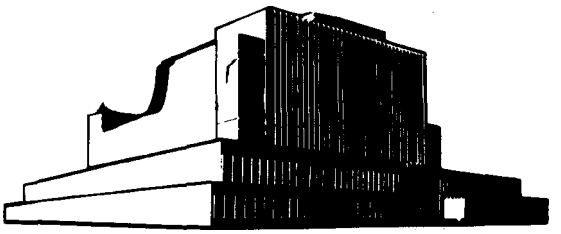

U.S. Forest Service Research Note

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In Cooperation with the University of Wisconsin

EFFECT OF NUMBER OF PLIES ON THE TEAR RESISTANCE OF PAPER

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EFFECT OF NUMBER OF PLIES ON THE TEAR RESISTANCE OF PAPER

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Summary

Tear tests made on low-finish bond paper and a 42-pound linerboard showed that the tear resistance, the degree of spreading of the plies, and the deviation from a straight line of failure increased with the increase in the number of plies tested. Tests on plies of aluminum foil indicated this degree of variation due to multiplicity of plies lay not in the tester but in the type of material being tested. With foil, no increase in tear resistance per ply accompanied the increase in the number of plies tested. But when the aluminum foil plies were separated by bulking and tested, results indicated that the bulking caused an increase in average tear resistance as the number of plies increased. Many of the failures of this group deviated beyond the limits allowed in TAPPI Standard T 414 m-49. Measurements of the deviation from a straight line of failure for the 50-pound bag paper showed a direct correlation between increase in average tear and the amount of deviation from a straight line of failure.

Introduction

In obtaining tear test values for paper the use of more than one ply can result in substantial increases in tear test values when the papers are tested according

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[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

to TAPPI Standard T 414 m-49. A number of tests were made on paper and aluminum foil in an effort to define those factors that account for the variation due to the number of plies simultaneously tested. Inconsistencies in tear test results, when the number of plies tested was varied, led to the initiation of this study. An examination of the literature shows that average tearing resistance increases as the number of plies used in the test increases.[2,3,4,5] According to TAPPI Standard T 414 m-49, the number of plies tested should be varied to give a scale reading of from 20 to 60. This limits the working range of the tester. If the cause of test value variation due to multiplicity of plies could be determined and compensated for, the working range of the tester could be expanded. To accomplish this task it was necessary to find a material that could be torn like paper but was of such uniform formation that test variability would be small, Aluminum foil was thought to be such a mate rial.

Materials

Materials used in this study included three papers and two aluminum foils as follows: A low-finish bond paper, a 42-pound linerboard (pounds per 1,000 square feet), a 50-pound bag paper (pounds per 3,000 square feet), a 2-mil aluminum foil, and a 3-mil aluminum foil. Several series of tests were run. A series is defined as all of the tests necessary to run one material through all possible ply multiples within the capacity of the tester. A commercial bond paper of low tearing strength was selected so that a large number of plies could be tested. Two papers of similar densities but of differing thickness were chosen in an attempt to illustrate the degree to which the test value variation due to multiplicity of plies can vary with thickness. Both the 42-pound linerboard (pounds per 1,000 square feet) and the 50-pound bag paper (pounds per 3,000 square feet) were produced on the Forest Products Laboratory' s experimental paper machine. The aluminum foil was a commercial moisture vapor barrier. Two thicknesses of foil were used to discover if the variation due to number of plies tested was due to the material tested or the tester.

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[2] Houston, Paul L. A Supplementary Study of Commercial Instruments for Determining the Tearing Strength of Paper. Paper Trade Journal,LXXIV (10): 43-46. 1922.

[3] Institute of Paper Chemistry. Instrumentation Studies XLVI: Tearing Strength of Paper. Paper Trade Journal, 118(5): 13-16, 18. 1944.

[4] Technical Association of the Pulp and Paper Industry. Internal Tearing Strength of Paper. TAPPI Standard T 414 m-49. 1949.

[5] Winterbottom, Marion, and Minor, Jessie E. The Test for Tearing Resistance. The Paper Industry 18: pp. 928-930. February 1937.

Test Procedure

Except as noted, all tests were made in accordance with TAPPI Standard T 414 m-49. Specimens 2-1/2 by 3 inches were cut on a shear-type paper cutter. The paper cut easily, but great care was taken in cutting the foil so as to preserve a wrinkle-free surface.

Every specimen was carefully calipered and those specimens that were not of the same thickness as the rest in the series were rejected. After being calipered, the specimens were arranged in groups containing the prescribed number of plies to be tested. These individual groups were recalipered to determine their combined thickness. With each material, an increasing number of plies was tested until the capacity of the test machine was reached. Five test replications were made for each test condition. The machine direction was used for the paper tests except where specifically noted. Seven series of tests were made, and all tests were performed by one operator. The first four series--the bond paper, the 42-pound linerboard (pounds per 1,000 square feet), the 2-mil aluminum foil, and the 3-mil aluminum foil--were tested according to the TAPPI Standard. This procedure was altered somewhat for the fifth and sixth series of tests.

The fifth series of tests was run using 2-mil aluminum foil. The test procedure was changed by placing a 3-mil foil separator, cut exactly to the jaw size, between each ply during each test. The separator was used to increase the bulk of the pack of specimens without changing the physical properties of the material. It was believed that the bulking would cause an increase in average tear value. Previous to this method of bulking, attempts were made to emboss the foil but this resulted in weakening the individual plies by deforming their surfaces.

In the sixth series of tests only four plies were used for each test, but the thickness of the foil separators between the plies was progressively increased from 0 to 20 mils.

For the seventh series, tests were made in both the machine direction and cross-machine direction, using the 50-pound bag paper (pounds per 3,000 square feet). The specimens were marked and saved after testing. This was done so that each specimen could be measured to determine the amount the line of failure deviated from a straight line projection of the initial slit (fig. 1). Line of failure deviations of each specimen were measured to the closest hundredth of an inch.

Results and Discussion

In general, it was found that an increase in the number of plies resulted in an increase in the average tear. The variation due to increasing the number of plies was not constant. Data are presented in tables 1 and 2.

Using bond paper and increasing the number of plies from 1 to 14 resulted in an increase in tear resistance of 30 percent (fig. 2). The largest increase in the average tear with an increase in the number of plies tested occurred with only five plies of the 42-pound linerboard. This increase in variation amounted to 36 percent (fig. 2). Tear values for the 50-pound bag paper proved to be the least affected by multiplicity of plies. The change in average tear value for the bag papers was 10 percent in the machine direction and 27 percent in the cross-machine direction (fig. 3).

A comparison of tear values for papers of similar density shows that as thickness is increased the variation due to multiplicity of plies is increased.

It was observed that in all the papers there was a tendency for the individual plies to separate at the top when pressure was applied as the plies were secured in the clamps. This tendency was more noticeable as the number of plies was increased. Tear failures of the paper specimens were usually within the limits allowable by TAPPI. As the number of plies increased, there was a tendency for the line of failure to deviate from a straight line projection of the initial slit. The deviation was most prevalent with tear specimens of the 50-pound bag paper when tested in the cross-machine direction (fig. 4).

Average tear values of aluminum foil without separators were not affected by increasing the number of plies (fig. 4). The plies showed little tendency to separate when clamped in the jaws. Only when the number of plies approached limits of the capacity of the tester was there any separation of plies and deviation of the line of failure. The tests on the bulked foil revealed a different trend. With the 3-mil separators in place, there was a marked tendency for the plies to separate when clamped into the jaws. This resulted in increased tear values throughout most of the range of plies tested. Irregular failures in this series were first encountered at the 5-ply stage and when the 7-ply stage was reached, all failures were of an irregular nature. Testing was continued through the 10-ply stage. The average tear value increased as the number of plies increased, reading 40 percent with 10 plies (fig. 5).

The series of tests using a constant number of plies and progressively thicker foil separators indicated that if the line of tear failure was within the limits

Table 1.--Effect of the number of plies tested upon average tear value

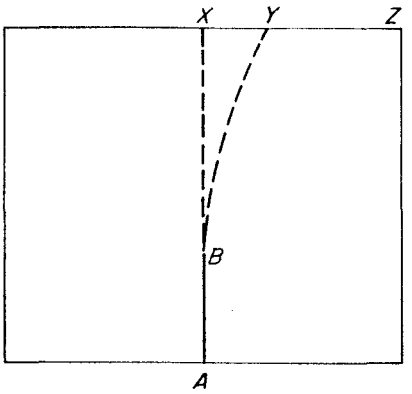
Number of plies	Average tearing resistance						
	Low-finish bond	42-lb. linerboard (Lb. per 1,000 sq. ft.)	50-lb. bag paper (Lb. per 3,000 sq. ft.)		2-mil aluminum foil	3-mil aluminum foil	Separated 2-mil aluminum foil
			Machine direction	Cross direction			
	G.	G.	G.	G.	G.	G.	G.
1	70.4	115.2	64.0	73.6	83.2	160.0	88.0
2	72.0	126.4	64.0	75.2	84.8	161.6	92.7
3	70.4	133.2	65.0	75.7	84.2	161.0	103.8
4	76.0	139.2	65.6	78.4	84.8	161.6	87.6
5	77.4	156.2	67.2	79.4	84.4	163.0	98.2
6	74.8	.....	66.8	86.0	84.4	.....	98.7
7	78.4	.....	68.4	84.8	84.8	.....	102.4
8	81.2	.....	69.2	86.8	84.4	.....	113.6
9	84.6	.....	70.5	89.7	84.4	.....	121.9
10	88.0	.....	68.8	93.4	84.8	.....	.....
11	88.2	.....	.....	.....	85.2	.....	.....
12	88.8	.....	.....	.....	84.3	.....	.....
13	89.5	.....	.....	.....	.....	.....	.....
14	91.9	.....	.....	.....	.....	.....	.....

described by TAPPI there would be no increase in average tear value due to bulking (fig. 6). As bulking was increased, however, the incidence of irregular failure increased.

Measurements of the deviation from a straight line of failure for the 50-pound bag paper showed a direct correlation between increases in average tear and the amount of deviation from a straight line of failure (figs. 7 and 8).

Table 2.--Effect of ply separation on average tearing resistance

Number of plies	Separation between plies	Average tearing resistance
	Mils	Grams
4	0	80.0
4	4	78.4
4	8	81.6
4	12	80.8
4	16	80.8
4	20	81.6



AB= INITIAL SLIT
BX= STRAIGHT LINE PROJECTION Of INITIAL SLIT
BY= LINE OF FAILURE
XY= DEVIATION OF LINE OF FAILURE FROM BX

Figure 1. --Diagram showing typical deviation of the line of failure of a tear specimen.

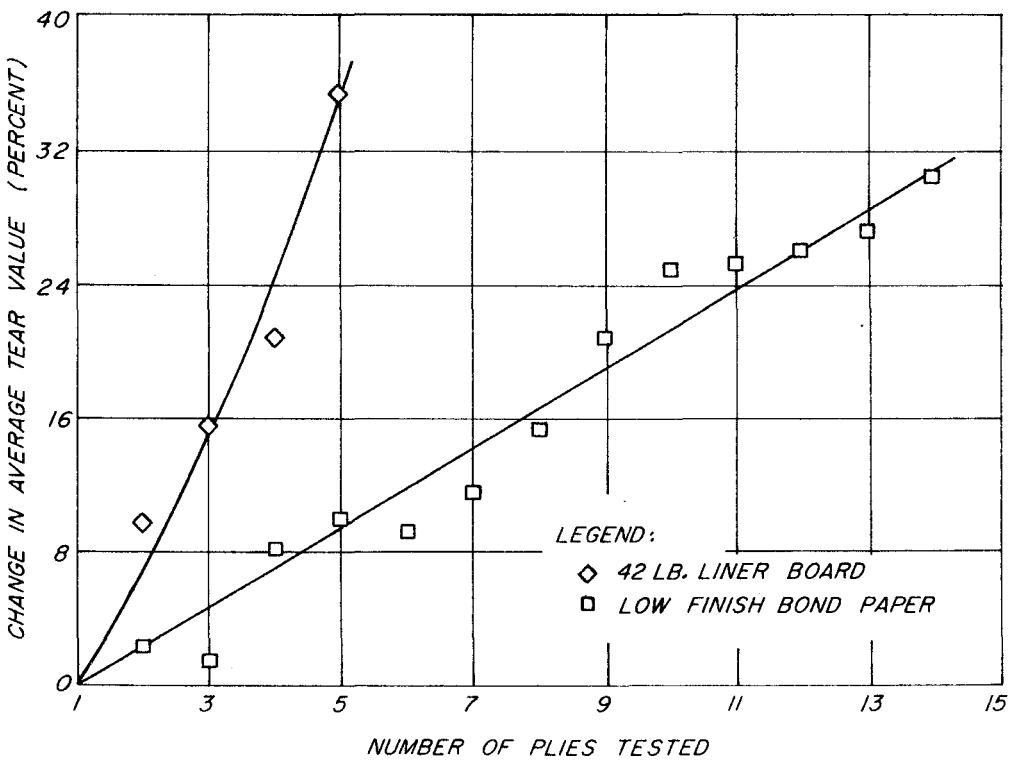


Figure 2. --Change in average tear value increases as the number of plies tested is increased for the low finish bond paper and the 42-pound linerboard.

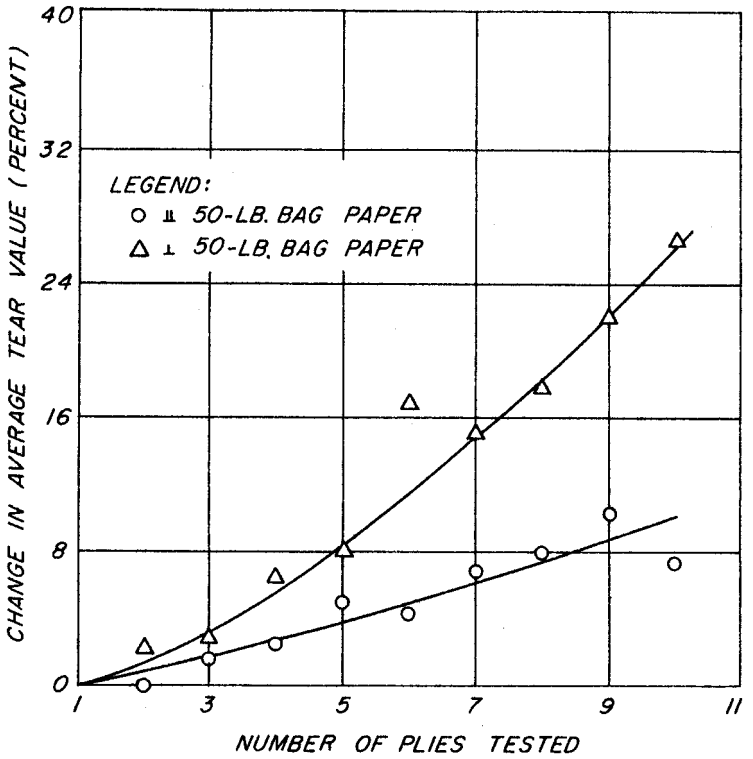


Figure 3. --Change in average tear value increases as the number of plies tested is increased for the two test directions of the 50-pound bag paper.

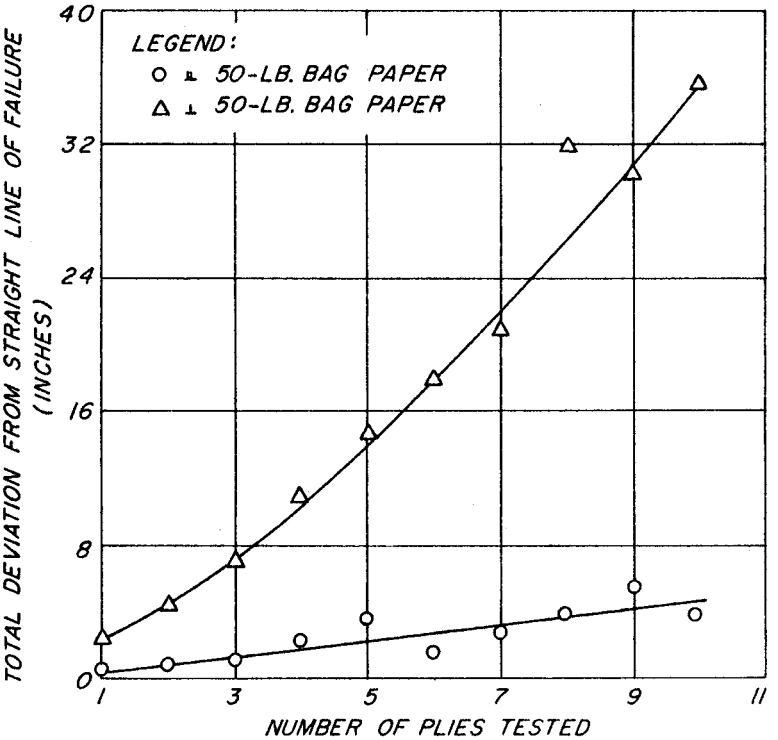


Figure 4. --Deviation from straight line of failure increases as the number of plies tested is increased for the two test directions of the 50-pound bag paper.

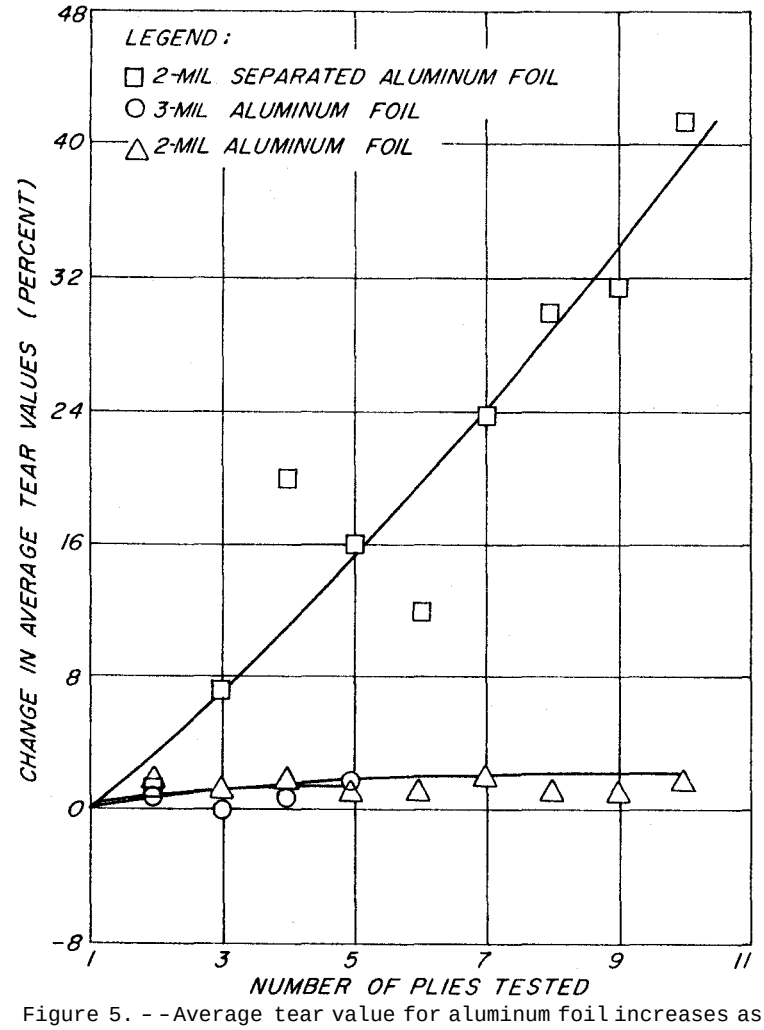


Figure 5. - -Average tear value for aluminum foil increases as the number of plies tested is increased.

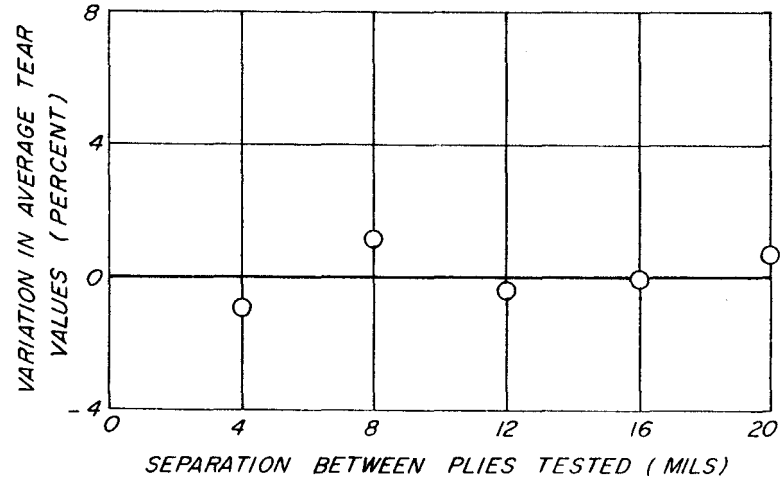


Figure 6. - -No increase in average tear value occurs when separation between plies tested is increased for 2-mil aluminum foil.

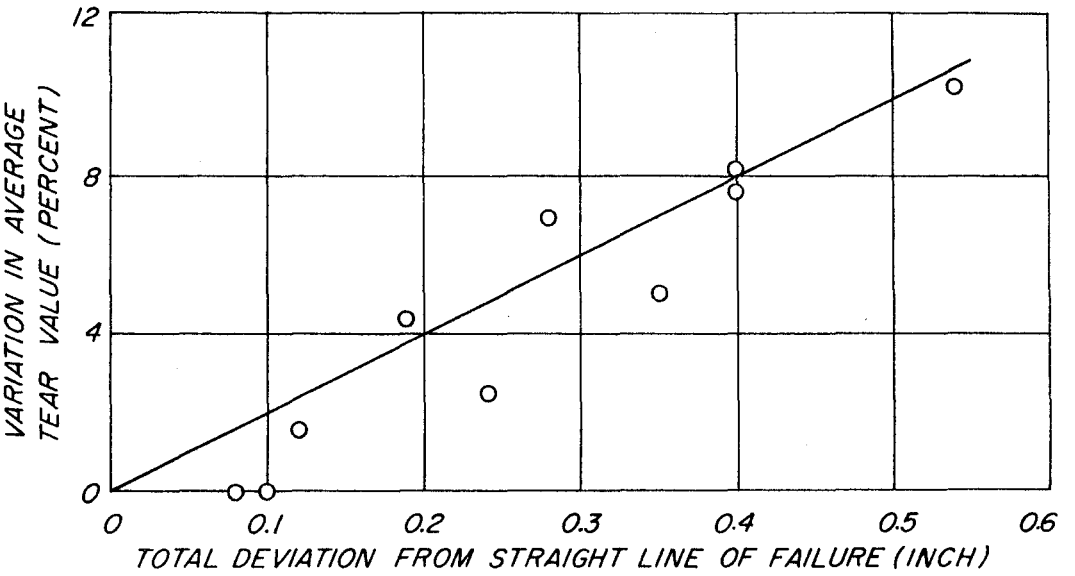


Figure 7. --Average tear value increases as the deviation from a straight line of failure increases for the machine direction tests of the 50-pound bag paper.

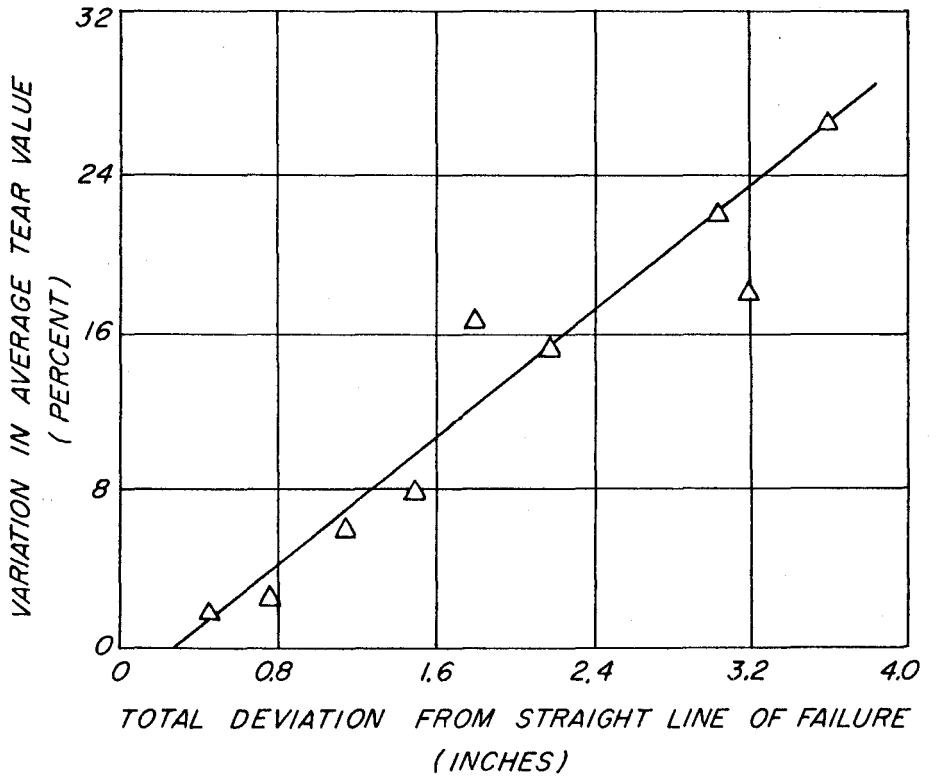


Figure 8. --Average tear value increases as the deviation from a straight line of failure increases for the cross-machine direction tests of the 50-pound bag paper.