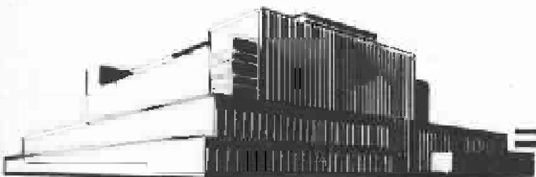
EFFECT OF PHENOLIC RESINS ON PHYSICAL PROPERTIES OF KRAFT PAPER

Information Reviewed and Reaffirmed

March 1956

No. 1750

YOUR FILE COPY
DO NOT REMOVE FROM FILE



FOREST PRODUCTS LABORATORY
MADISON 5, WISCONSIN

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

In Cooperation with the University of Wisconsin

EFFECT OF PHENOLIC RESINS ON PHYSICAL PROPERTIES OF KRAFT PAPER[1]

By

PARKER K. BAIRD, Chemist
ROBERT J. SEIDL, Chemical Engineer
and
DONALD J. FAHEY, Technologist

Forest Products Laboratory,[2] Forest Service
U. S. Department of Agriculture

Summary

The physical properties of phenolic-resin-treated kraft paper were determined to note the effects of various amounts and types of resins and thicknesses of paper on the tensile strengths in the dry and wet conditions, and on air resistance, stretch, density, dimensional swelling, equilibrium moisture content, and water-vapor-transmission rate.

Impregnation of the paper with a water-soluble phenolic resin increased the thickness of the paper appreciably above the original thickness of the paper. This also caused a greater percentage increase in the tensile strength in the dry condition in the cross than in the machine direction. In most cases, the strength of the treated paper in the wet condition, equivalent to prolonged exposure to high humidities, was greater than the strength of the untreated paper in the dry condition. Paper with about 15 percent resin retained, after soaking, at least 80 percent of its tensile strength when dry.

---

[1] To be presented at the Fall Meeting of the Technical Association of the Pulp and Paper Industry, Portland, Oreg., Sept. 11-15, 1949.

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

The dimensional swelling of the untreated and of the treated 9-mil paper in the cross-machine direction was more than twice that in the machine direction. A paper with 14 percent of water-soluble phenolic resin expanded approximately one-half as much in both length and width as did untreated paper, and paper with 18 and 24 percent of resin expanded still less. Twenty-four percent of resin appeared to be the approximate practical limit in regard to dimensional stability since higher resin contents, up to 33 percent, did not result in significant additional improvement.

Increasing the water-soluble-phenolic-resin content of the kraft paper decreased its rate of moisture adsorption and its equilibrium moisture content. Impregnation with an alcohol-soluble phenolic resin did not alter the actual equilibrium moisture content of the fiber substance.

Introduction

The need for papers with superior properties to meet the increased diversification of paper uses have stimulated the development of treated papers in which the inherent deficiencies are overcome or special requirements are met by the addition of chemicals or resins. Phenolic resins are among the most common materials selected to modify the properties of paper used for plastics or special products. Previous work on the impregnation of paper with phenolic resin has shown a considerable variation in the properties obtainable according to the type of resin and method of its addition. These effects are evident, particularly in such properties as equilibrium moisture content, dimensional stability, wet strength, and resistance to attack by fungi. In addition to the resin itself, among the most important factors in the impregnation of cellulose fibers is the type of solvent used as a carrier for the resin. For example, thorough penetration of the fiber wall with resin probably can be obtained only through the use of solvents that can swell cellulose. Complete penetration may be undesirable in many cases.

This report discusses briefly the effects of impregnation of kraft paper, primarily with water-soluble phenolic resin in various amounts up to about 35 percent resin. The papers were impregnated under conditions believed to give a good degree of resin penetration into both the fiber and the sheet structures. Some data are also reported on papers treated with alcohol-soluble phenolic resin under conditions believed to give good penetration of the sheet but poor penetration of the fiber. The resin in the impregnated papers was cured without pressure before evaluation. An analysis was made of specific effects observed, particularly on the effect of resin on the moisture sensitivity of the fiber and sheet. No attempt is made in this report to translate these effects in terms of possible uses to improve paper plastics, stabilize paper against dimensional change, or to suggest other applications.

Preparation of Test Material

In this report, the term "resin content" refers to the difference in weight of the untreated paper and the treated, cured papers, both dried at 105° C. It is expressed as a percentage of the weight of the latter. It was recognized that this is at variance with the way of expressing resin content usually used industrially. Various values for resin content can be obtained according to what value is used as the basis; for example, weight of the untreated paper, weight of the cured treated paper, or weight of the treated paper as it emerges from the impregnator drying tower.

The 9-mil and 14-mil kraft paper used in this study was made on the Forest Products Laboratory experimental paper machine from a commercial northern pine sulfate pulp. These papers were impregnated with a water-soluble phenolic resin to give resin contents of approximately 14, 18, 24, 27, and 33 percent for 9-mil paper and of 8, 12, 15, and 19 percent for 14-mil paper, based on the weight of treated paper after oven-drying the cured sheets. Also, a commercially made 4.5-mil kraft paper was impregnated with approximately 18 percent each of water-soluble phenolic resin and alcohol-soluble phenolic resin. The resin in all impregnated papers was cured by heating in a hot press without pressure for 6 minutes at 325° F. Untreated 9- and 14-mil papers, for use as controls in moisture-adsoprtion and dimensional-stability tests, were given a similar heat treatment.

Testing Procedure

Air resistance (a measure of porosity), density, thickness, and stretch tests made on the paper conformed with the TAPPI Standard Methods of Tests. Stretch values were obtained on specimens 1 inch wide. Stiffness values were obtained on the various resin-treated papers with the Askania stiffness tester.

The relative water-vapor-transmission rate was determined with a water-vapor-transmission cabinet. The exposure conditions were 100° F. and 92 percent relative humidity on the outside of a sealed dish containing calcium chloride.

The tensile strength of both treated and untreated paper was measured on a standard Schopper tensile-testing machine. The paper strips were 1 inch wide and 6 inches long. The initial distance between the jaws of the machine was 4 inches. The stressing jaw moved at the rate of 12 inches per minute. Specimens were tested with the machine direction of the sheet both parallel and perpendicular to the direction of the applied load. The tests were made on strips conditioned at 50 percent relative humidity and 75° F., and after soaking in water at 75° F.

For dimensional-stability and moisture-adsorption determinations, four specimens approximately 5-3/4 inches square were cut from the 9-mil treated papers. Specimens were also cut from the untreated 4.5-mil kraft paper and paper treated with water-soluble and with alcohol-soluble phenolic resins. Specimens were exposed at about 30 percent relative humidity for 2 weeks. Dimensional measurements in both the machine and cross-machine direction were made at this condition with a gage reading accurately to 0.001 inch. Weight measurements were also made at this condition with an analytical balance. Specimens were then exposed to each of the humidity conditions of about 50, 65, 80, and 90 percent for a period of 1 week. Measurements were made while the paper was at each of these conditions. The specimens were then ovendried for calculation of data.

To determine the effect of resin content on the rate of moisture absorption, three specimens approximately 5-3/4 inches square of each resin content of the 9-mil overlay paper were exposed to 33 percent relative humidity for more than 3 weeks. Weight determinations were made during this period. Specimens were then exposed to 90 percent relative humidity, and measurements were made every minute for the first 15 minutes of exposure and then at frequent intervals until weight equilibrium was obtained.

Discussion of Results

A discussion of the relationships between resin content as previously defined and certain physical properties of the various papers follow. It is emphasized that the resin in all the treated papers was cured prior to testing.

Thickness

An increase in paper thickness was found to accompany an increase in resin content. This increase was at an approximately uniform rate within the range of resin contents studied. The nominal 9-mil paper when treated with 14 percent of water-soluble phenolic resin diluted with a 50-50 mixture of water and alcohol had a thickness of 10.4 mils after cure of the resin, or an increase in thickness of 17 percent based on the thickness of untreated paper. The corresponding increase in thickness for papers containing 18, 24, 27, and 33 percent resin was 24, 26, 31, and 37 percent, respectively.

The increase in thickness upon resin impregnation cannot be attributed to the resin alone. Soaking the 9-mil paper in water caused an increase in thickness of 10 percent based on an equilibrium condition with 50 percent relative humidity. Soaking the paper in a 50-50 mixture of water and alcohol increased the thickness 7 percent while soaking it in alcohol alone increased its thickness only 2.4 percent. Increase in thickness of untreated paper upon wetting and subsequent drying is probably caused by strain relaxation. In addition, the increase in thickness upon resin impregnation and drying is influenced by (1) deposition of resin in the fiber wall, which maintains the fiber in a partially expanded condition; and (2) fiber dispersion caused by swelling forces or resin between fibers. Thus, the change in thickness of the paper was dependent on the solvent used as the impregnating medium as well as on the amount of resin added.

Density

The densities of the untreated 9- and 14-mil papers were 0.60 and 0.65 gram per cubic centimeter, respectively. The gain in weight of the paper due to resin impregnation was commensurate with increase in thickness, so that no significant change in density was obtained with increases in resin content.

Air Resistance

Air resistance of paper as determined by the Gurley densometer is expressed in terms of the time in seconds required for 100 cubic centimeters of air to flow through a given area of paper. The reciprocal of this value is considered to be proportional to the porosity of the paper. The porosity is considered to be one measure of the structure of paper that influences resin absorption.

Air resistance values of 79 and 132 seconds per 100 cubic centimeters were obtained on the untreated 9- and 14-mil papers (table 1). An increase in resin content of 14-mil paper caused a decrease in this value indicating an increase in the porosity. The 14-mil papers containing 8, 12, or 19 percent of resin had values of 94, 83, and 66 seconds, respectively. The decrease in air resistance with increasing resin content of 9-mil paper, however, occurred only for the lowest resin content used, namely 14 percent. This increase in porosity may have been due to the resultant expanded thickness and increase in the pore fraction of the paper.

Water-Vapor Transmission

Although it was recognized that low-resin-content papers were not highly resistant to the passage of water vapor, it was thought such resistance would be of interest in measuring the effect of the impregnation and the subsequent swelling on the rate of water-vapor transmission through the sheet. The water-vapor transmission rate of the untreated 9-mil paper was over 200 grams per 100 square inches per 24 hours. Similar papers containing 14 to 33 percent resin had transmission rates of about 150 grams per 100 square inches per 24 hours and showed no significant differences within this range of resin contents.

Tensile Strength

It should be emphasized that the analysis of tensile strength was based on pounds per inch of width. It was recognized that strength analyses based on pounds per square inch would be considerably different. Tensile-strength tests obtained on the various papers showed the effectiveness of resin impregnation in increasing the strength of the paper, especially that of specimens tested in the wet condition. Figure 1 and table 1 show the effects of resin impregnation on the tensile strengths of 14-mil paper in both the machine and cross-machine directions. A greater proportional increase in dry strength was obtained in the cross-machine direction than in the machine direction by the addition of resin. For example, the 14-mil paper treated with 15 percent of resin had a dry strength in the cross-machine direction of about 18 percent more than the untreated paper, while the corresponding increase in the machine direction was only 5 percent.

The disproportionate increase in cross-machine dry tensile strength may be partially attributable to an improved bonding or to the greater number of contact points caused by the presence of resin between parallel fibers perpendicular to the cross-machine direction. Contact may have been further enhanced by the greater swelling in diameter of fibers that occurred upon resin impregnation. Furthermore, it appeared that resin impregnation was more effective in increasing the dry tensile strength in both directions of 9-mil than of 14-mil paper. The dry strength of both untreated papers in the machine direction was 1.8 times as great as that in the cross-machine direction. This ratio was reduced slightly in the treated papers.

The untreated 9- and 14-mil papers lost approximately 95 percent of their strength after soaking 48 hours in water. These papers, when impregnated with about 15 percent of resin, lost only about 20 percent of their tensile strength in the machine direction after soaking. The corresponding loss in the cross-machine direction was only about 10 percent. The papers containing higher resin contents retained even a higher proportion of their original strength.

Tensile strengths of both the treated and untreated papers were tested by an engineering method in addition to the method previously described. This engineering method involved a slower rate of loading than the TAPPI method. Results of tests showed higher ultimate tensile strength for the treated papers loaded at the slower rate, but there was no significant difference for the untreated papers. Also, increases in resin content had a greater effect on the tensile strength of the paper, especially when tested dry by the engineering method.

Stretch

Stretch (the elongation at failure in tension) determined on the untreated and treated 9-mil paper in the cross-machine direction for both the dry and the wet condition is shown in table 1. The paper treated with 14 percent of water-soluble phenolic resin stretched in the dry condition about 50 percent as much as the untreated paper. Paper treated with 18 and 33 percent resin yielded stretch values of 40 and 25 percent of that of the untreated paper. The stretch of the paper in the wet condition was approximately twice as much as in the dry condition for resin contents up to about 24 percent. The reduction in stretch incident to resin impregnation may be an indication of the embrittlement characteristic of papers impregnated with water-soluble phenolic resins.

Stiffness

The stiffness (table 1) of the paper in both the machine and the cross-machine direction as determined by the Askania stiffness tester increased with increasing resin content. The stiffness in the machine direction was approximately 1-1/2 times that in the cross-machine direction. The 14-mil paper also had a stiffness at least 1-1/2 times as great as that of the 9-mil paper. The data on stiffness are useful for comparative purposes only, since the results are not expressed in the engineering units usually employed. The increase in stiffness is no doubt due to the swelling effect of the solution, which caused an increase in thickness of the paper as well as a stiffening of the fibers themselves.

Dimensional Stability

Paper, like wood, expands with increase in moisture content more in the cross-grain direction than in the grain direction. The expansion of the untreated and treated paper as shown in table 2 was between 2 and 3 times greater in the cross-machine than in the machine direction. Resin impregnation was effective in reducing the swelling in both the machine and cross-machine directions of the paper.

The effect of resin content on the dimensional swelling in the cross-machine direction of the 9-mil paper is shown in figure 2. Paper treated with 14 percent of resin had a dimensional swelling about one-half as much as untreated paper (not heat treated) after exposure to various relative humidities. Under the same conditions a paper containing 18 percent of resin swelled only about 40 percent as much as untreated paper. A further reduction in dimensional growth was obtained with the use of 24 percent of resin, but 27 and 33 percent of resin caused only a slight additional reduction. Increases in resin content reduced the dimensional swelling in the machine direction in approximately the same proportion as obtained in the cross-machine direction (fig. 2).

Samples of untreated paper were exposed to the same heat treatment that was used for curing the resin in the treated papers. This treatment reduced the swelling of the paper slightly. As an example, the paper subjected to the heat had a dimensional change in the cross-machine direction of 1.4 percent for a change in exposure from 82 percent relative humidity to an ovendry condition, as compared to 1.5 percent for paper not subjected to the heat.

Equilibrium Moisture Content

To determine the rate of moisture adsorption and the effect of water-soluble-resin content on the rate of adsorption for a humidity change of from 33 to 90 percent relative humidity, samples of untreated and treated papers were conditioned to equilibrium in 33 percent relative humidity and were then exposed to 90 percent relative humidity. Weight measurements were made every minute for the first 15 minutes after exposure and at frequent intervals thereafter. The greatest change in moisture content occurred in the first few minutes, as shown in figure 3. The rate of change was greater for the untreated paper than for the treated paper, and increasing resin content decreased the rate of adsorption. It appeared from these tests that the equilibrium moisture content was substantially obtained in the first hour of exposure. Weight measurements made at weekly intervals up to 55 days showed no significant changes.

The addition of a water-soluble phenolic resin resulted in a decrease in the equilibrium moisture content of the kraft paper. This fact is clearly evident when changes are calculated on the basis of dry fiber instead of on the basis of fiber plus resin as shown in table 3. If the resin had no effect on the sensitivity of the fiber for moisture, the equilibrium moisture content of the fiber substance would be unchanged by the addition of the relatively nonhygroscopic resin, but its addition could reduce the apparent equilibrium moisture content of the mixture. That the resin did affect the hygroscopicity of the fiber substance is shown in figures 3, 4, and 5.

The equilibrium moisture content, which affects the dimensional stability of impregnated papers, may be influenced by the deposition of resin in the fiber cell wall, mechanical restraint of fiber and sheet dimensions, and chemical action between resin and fiber. If the quantity of resin deposited in the fiber cell wall were known, it would then be theoretically possible to calculate its effect upon the equilibrium moisture content by using the volume of resin deposited and the equivalent volume of water displaced.

Figure 6 shows the relationships between dimensional change of the sheet and equilibrium moisture content based on the fiber alone in the humidity range from 33 percent to 90 percent. If dimensional stability were dependent only upon equilibrium moisture content, all points on the figure would be expected to be along a single line; but the fact that a family of curves resulted from these data is evidence that the resin has a contributory effect on stability beyond that due to equilibrium moisture content. For example, paper containing 14 percent resin having an equilibrium moisture content of 11.7 (82 percent relative humidity) based on ovendry fiber had a dimensional growth of 0.85 percent in the cross-machine direction as compared to 0.71 percent obtained from a sheet having the same equilibrium moisture content (90 percent relative humidity) but containing 18 percent resin.

Water-Soluble and Alcohol-Soluble Resins

The characteristics imparted to cellulose fiber sheets by water-soluble and alcohol-soluble phenolic resins were known to be greatly different. To determine the extent of the differences 4.5-mil kraft paper was impregnated with each of the two types to a resin content of 18 percent based on the ovendry weight of the treated paper after cure of the resin. The differences between the two papers are shown in tables 4 and 5.

A comparison of the use of water-soluble-resin and alcohol-soluble-resin saturants indicated that the tensile strength in the wet condition of the paper impregnated with a water-soluble resin was greater than that obtained from a paper containing an equal amount of alcohol-soluble resin, especially in the cross-machine direction. The tensile properties of these papers when dry indicated the opposite to be true. The type of tension failure for wet specimens representing each resin is shown in figure 7. The fibrous nature of the paper break in the case of the alcohol-soluble resin is no doubt due in part to the less thorough impregnation of the fibers because of the larger molecular size of the resin, and to its nonaqueous diluent. There was no obvious difference, however, between the two resins in the type of tension failure for the dry specimens. It is interesting to note the relative swelling in thickness due to impregnation. For instance, passing the paper through a water-soluble resin increased the thickness from 4.3 to 6.0 mils, while the use of alcohol-soluble resin yielded a thickness value of 4.7 mils.

The equilibrium moisture content of paper containing the water-soluble resin was appreciably lower at all humidities than that of paper containing an equal amount of alcohol-soluble resin (table 5 and figure 5). The dimensional stability of the paper treated with water-soluble resin was much greater. The equilibrium moisture content of the paper treated with alcohol-soluble resin, when based on the ovendry weight of the fiber alone, was nearly as high as that obtained from untreated paper, and the dimensional swelling in the cross-machine direction was nearly as great as that of untreated paper. When water-soluble resin was used, the dimensional swelling in the cross-machine direction was reduced to less than one-half that of either untreated paper or paper with alcohol-soluble resin. A probable explanation is that the penetration of the fiber cell wall with the alcohol-soluble resin is not so great as that of the water-soluble resin. The latter tends to maintain the fiber in a swollen condition. Additional evidence that the penetration of the fiber itself with water-soluble resin is greater and that the equilibrium moisture content of the fiber itself is lower than that obtained with alcohol-soluble resin, is further indicated by results of tests made on these papers that showed the paper treated with water-soluble resin to be much more decay resistant. Higher moisture contents encourage the growth of fungi, while resins themselves are not especially inhibitive.

The relationships between dimensional stability and equilibrium moisture content have been emphasized because they are believed to be basic in the field of dimensional stability of paper and fiber products.

Conclusions

The following conclusions are drawn from the data obtained under the conditions described:

1. The thickness of kraft paper increased at an approximately uniform rate for a range of resin contents between 8 and 33 percent. Resultant density of the paper was not greatly affected by treatment with water-soluble phenolic resin, inasmuch as the swelling was compensated by the addition of resin.

2. Impregnation with phenolic resin resulted in an increase in tensile strength in pounds per inch of width in both the dry and the wet condition, particularly the latter. The resin caused a greater increase in cross-machine than in machine-direction tensile strength. The greatest proportional increase in wet strength was obtained with the first amount of resin.

3. Impregnation with a water-soluble phenolic resin reduced the swelling of the paper in all dimensions upon exposure to various humidity conditions. About 24 percent resin content appeared to have about the maximum restraining effect on swelling in proportion to resin content. The dimensional change in the cross-machine direction was more than twice that in the machine direction for the treated and untreated paper under various humidity conditions.

4. Increase in water-soluble resin content of kraft paper decreased the equilibrium moisture content at all humidities, as well as the rate of adsorption of moisture at 90 percent from conditions at 30 percent relative humidity. Impregnating the paper with alcohol-soluble resin did not alter the equilibrium moisture content of the fiber substance.

Table 1.--Physical tests on nominal 9- and 14-mil kraft papers containing various amounts of water-soluble phenolic resin

Resin content	Basis weight (24x36-500)	Thickness	Density	Air resistance (Gurley)	Tensile strength, Dry, Machine direction	Tensile strength, Dry, Cross direction	Tensile strength, Wet, Machine direction	Tensile strength, Wet, Cross direction	Stretch (Cross direction), Dry	Stretch (Cross direction), Wet	Stiffness (Askania), Machine direction	Stiffness (Askania), Cross direction
Percent	Pounds	Mils	Gm./c.c.	Seconds per 100 c.c.	Lb. per in. width	Lb. per in. width	Lb. per in. width	Lb. per in. width	Percent	Percent	Points	Points
					NOMINAL 9-MIL PAPER							
0	97	8.9	0.60	79	73.6	40.4	3.3	2.7	6.0	....	30	18
14.1	115	10.4	.61	54	77.2	46.7	62.6	42.4	2.9	5.9	42	25
18.1	119	11.0	.60	50	77.4	53.8	69.9	46.5	2.5	5.1	45	27
24.4	126	11.2	.62	50	78.5	59.6	73.8	50.1	2.1	3.8	55	29
27.2	130	11.6	.62	63	80.5	61.2	75.8	52.5	1.9	3.1	53	30
33.0	143	12.2	.65	50	83.8	61.8	82.8	55.4	1.5	2.3	55	31
					NOMINAL 14-MIL PAPER							
0	164	14.3	.65	132	107.8	60.0	4.6	3.4	....	....	57	39
7.7	179	15.8	.63	94	110.8	67.6	75.6	50.0	....	....	62	43
12.0	189	16.4	.64	83	113.0	69.6	86.7	60.6	....	....	66	43
15.2	199	16.9	.65	82	113.2	70.8	88.7	62.1	....	....	70	45
18.6	203	17.4	.65	66	114.4	73.6	95.3	68.4	....	....	71	46

Table 2.--Dimensional changes in 9-mil kraft paper containing various amounts of water-soluble phenolic resin under various moisture conditions

Resin content	Percentage of dimensional change[1]									
	Machine direction at relative humidity (percent) of:					Cross-machine direction at relative humidity (percent) of:				
	33	46	65	82	90	33	46	65	82	90
Percent										
0	0.48	0.51	0.56	0.61	0.64	0.84	0.96	1.14	1.53	1.81
[2]0	.45	.48	.52	.55	.57	.83	.93	1.08	1.42	1.72
14	.17	.18	.22	.30	.35	.41	.45	.56	.85	1.02
18	.11	.13	.14	.19	.23	.31	.33	.39	.59	.71
24	.09	.11	.13	.15	.16	.24	.27	.31	.47	.54
27	.07	.07	.08	.07	.12	.23	.25	.28	.41	.53
33	.09	.10	.14	.13	.18	.22	.26	.30	.41	.58

[1] Change in dimensions caused by subjecting material to the indicated relative humidity and then ovendrying. Percentage of change based on ovendry dimensions.

[2] Paper given the same heat treatment as the treated papers.

Table 3.--Equilibrium moisture content of 9-mil kraft paper containing various amounts of water-soluble phenolic resin at various relative humidities

Resin content	Percentage of moisture based on ovendry weight of fiber at relative humidity (percent) of:					Percentage of moisture based on ovendry weight of fiber plus resin at relative humidity (percent) of:				
	33	46	65	82	90	33	46	65	82	90
Percent										
0	6.0	7.3	8.7	14.4	18.4	......	......	......	......	......
[1]0	6.1	7.4	8.6	13.9	18.3	......	......	......	......	......
14	5.5	6.2	7.0	11.7	14.0	4.6	5.2	6.0	9.9	11.8
18	5.4	6.1	6.6	10.6	11.7	4.1	4.7	5.1	8.4	9.8
24	5.2	5.7	6.3	9.5	11.2	3.8	4.2	4.6	7.1	8.4
27	5.0	5.5	6.1	9.0	11.3	3.6	3.9	4.3	6.5	8.1
33	5.6	6.2	6.8	9.3	12.0	3.7	4.0	4.4	6.1	8.0

[1]Specimens given the same heat treatment as the treated papers.

Table 4.--Effect of alcohol-soluble and water-soluble phenolic resins on properties of 4.5-mil kraft paper

Resin used	Basis weight (24x36-500)	Thickness	Density	Tensile strength, Dry, Machine direction	Tensile strength, Dry, Cross direction	Tensile strength, Wet, Machine direction	Tensile strength, Wet, Cross direction	Dimensional change[1], Machine direction	Dimensional change[1], Cross direction
	Pounds	Mils	Gm./c.c.	Lb. per in. width	Lb. per in. width	Lb. per in. width	Lb. per in. width	Percent	Percent
None........	51.2	4.3	0.68	35	27	3	2	0.61	1.22
Alcohol-soluble type[2]......	62.5	4.7	.75	51	40	39	22	.41	1.08
Water-soluble type[2]......	63.5	6.0	.60	50	30	40	28	.21	.53

[1]Change in dimensions caused by ovendrying material containing moisture at equilibrium with 90 percent relative humidity. Percentage of change based on ovendry dimensions.

[2]Resin content 18 percent, based on weight of treated paper after ovendrying.

Table 5.--Effect of alcohol-soluble and water-soluble phenolic resins on the equilibrium moisture content of 4.5-mil kraft paper

Relative humidity	Percentage of equilibrium moisture content[1]: Of untreated paper	Of paper treated with: Alcohol-soluble resin[2]	Of paper treated with: Water-soluble resin[2]
Percent			
30	4.73	4.48	3.29
50	6.29	6.25	4.19
65	8.66	8.64	5.77
82	13.25	12.76	8.97
88.5	16.36	15.00	9.78

[1]Based on ovendry weight of fiber.

[2]Resin content of paper was 18 percent of weight of ovendry treated paper.

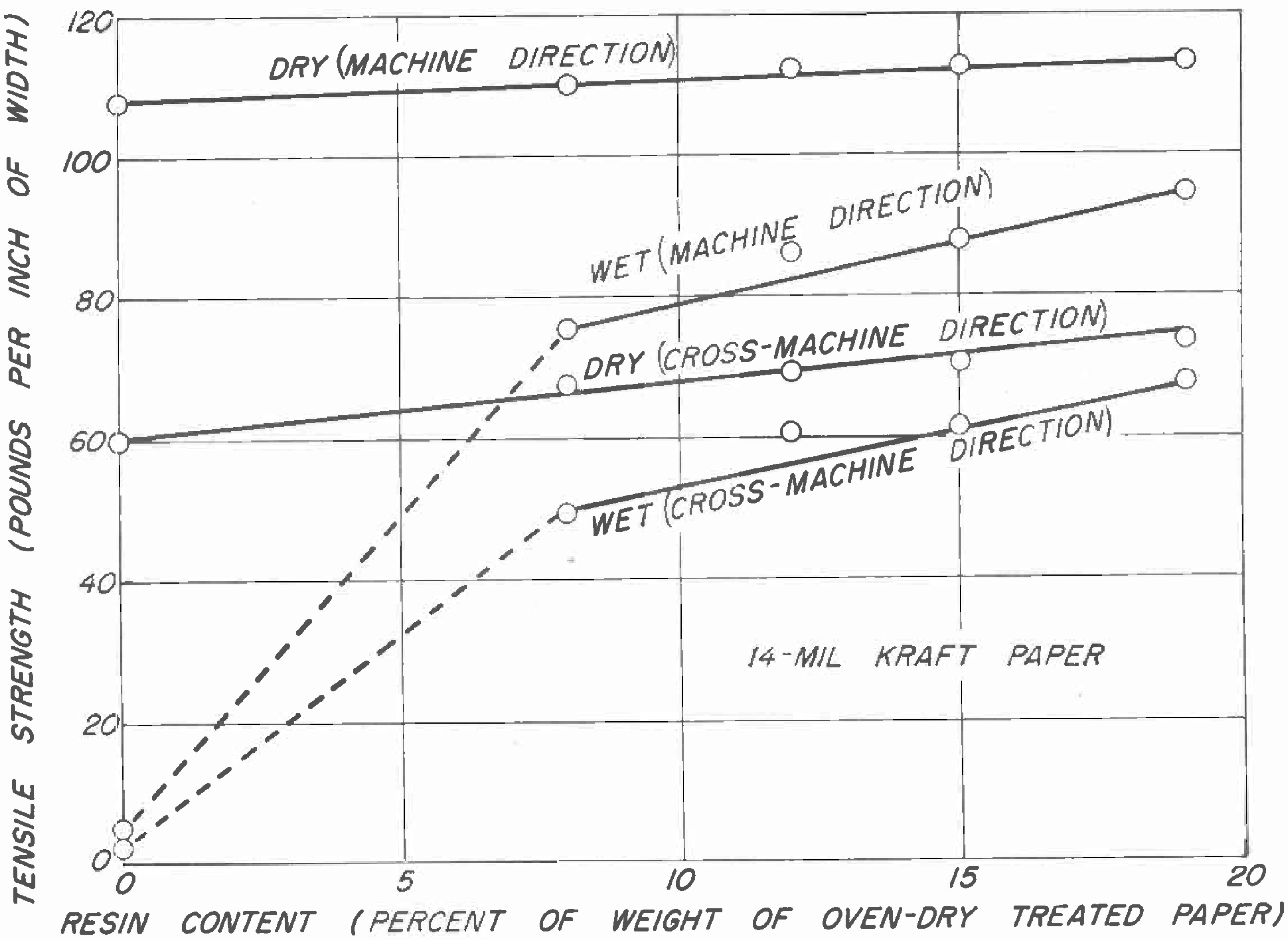


Figure 1. --Effect of resin content on dry and wet tensile strength.

Z M 83312 F

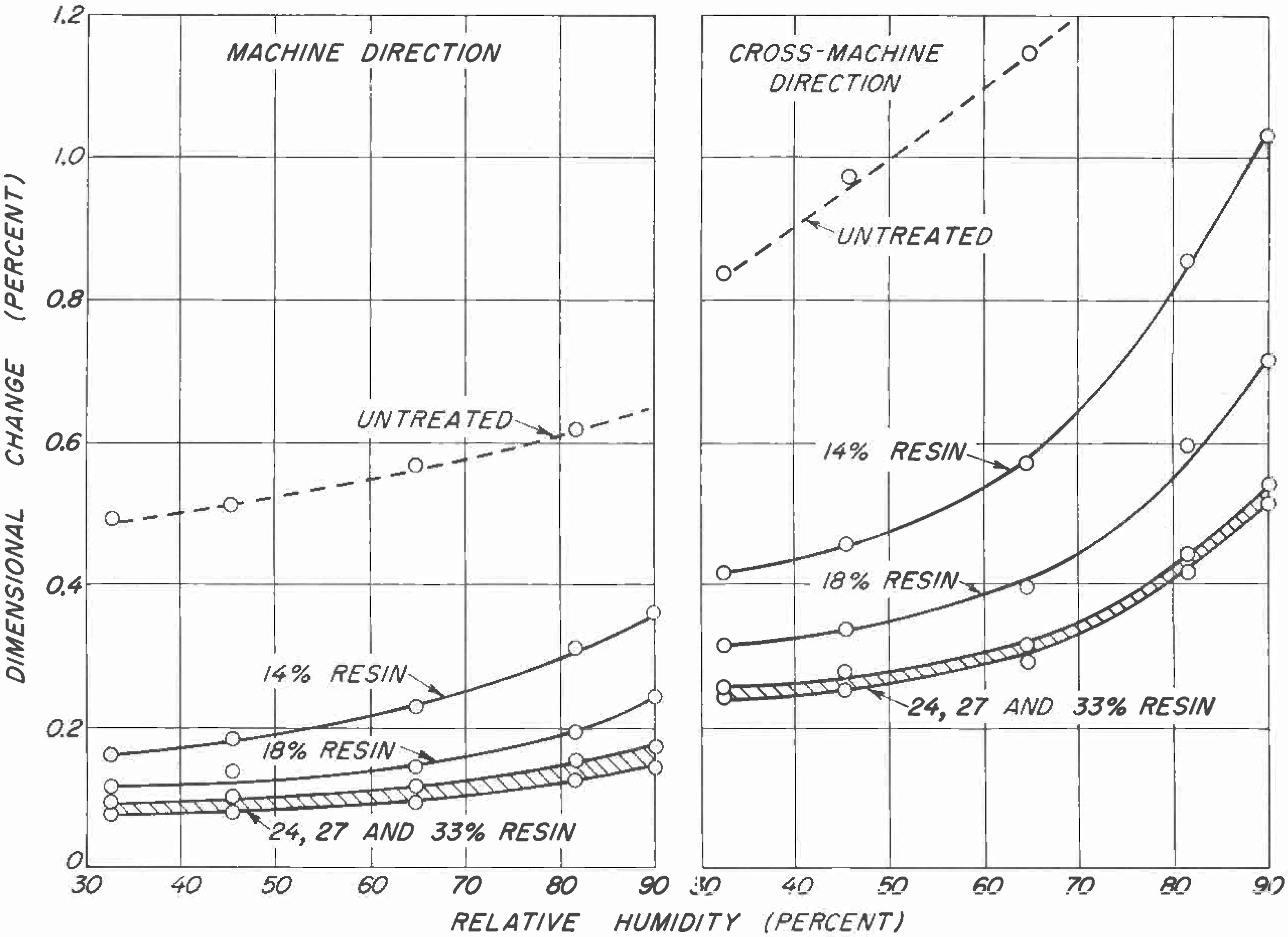


Figure 2. --Effect of resin content on the dimensional swelling of 9-mil kraft paper exposed to various relative humidities.

Z M 83313 F

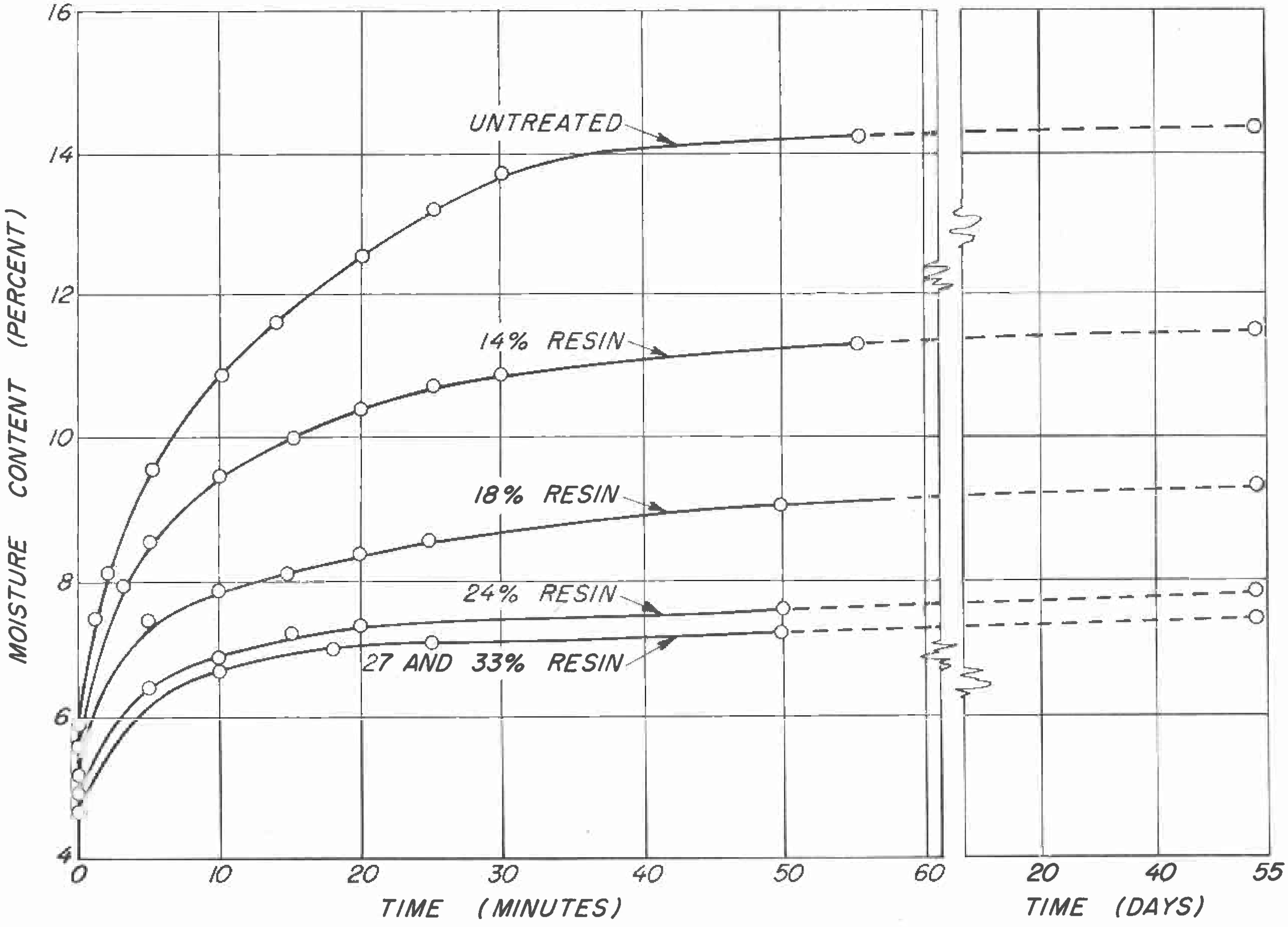


Figure 3. --Rate of adsorption of moisture by 9-mil kraft paper, containing various amounts of water-soluble phenolic resin, upon exposure to a relative humidity of 90 percent. Moisture content at zero time is the equilibrium content at 30 percent relative humidity. Calculations based on weight of sample at 30 percent relative humidity.

Z M 83314 F

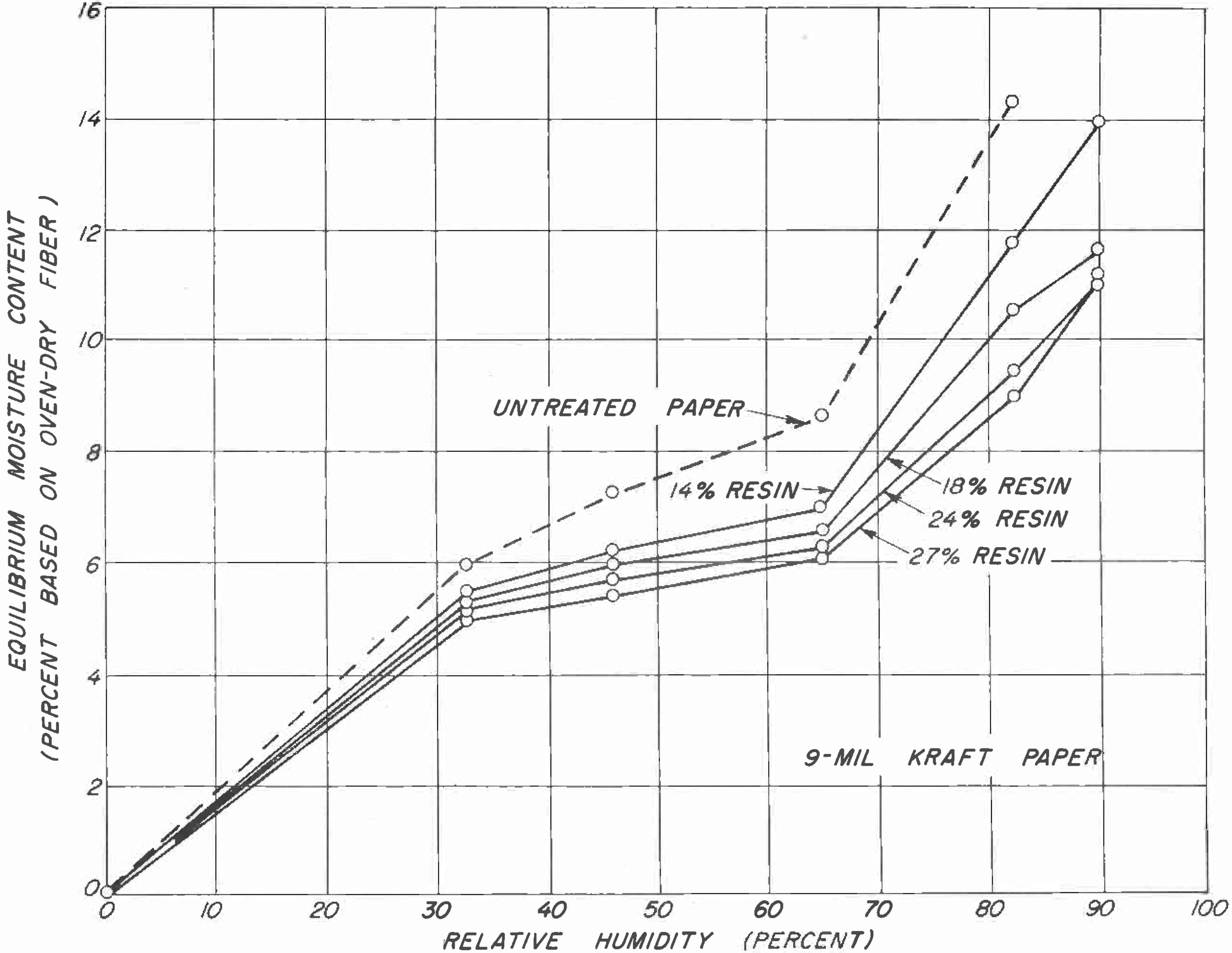


Figure 4. --Effect of water-soluble-phenolic-resin content on the equilibrium moisture content.

Z M 83315 F

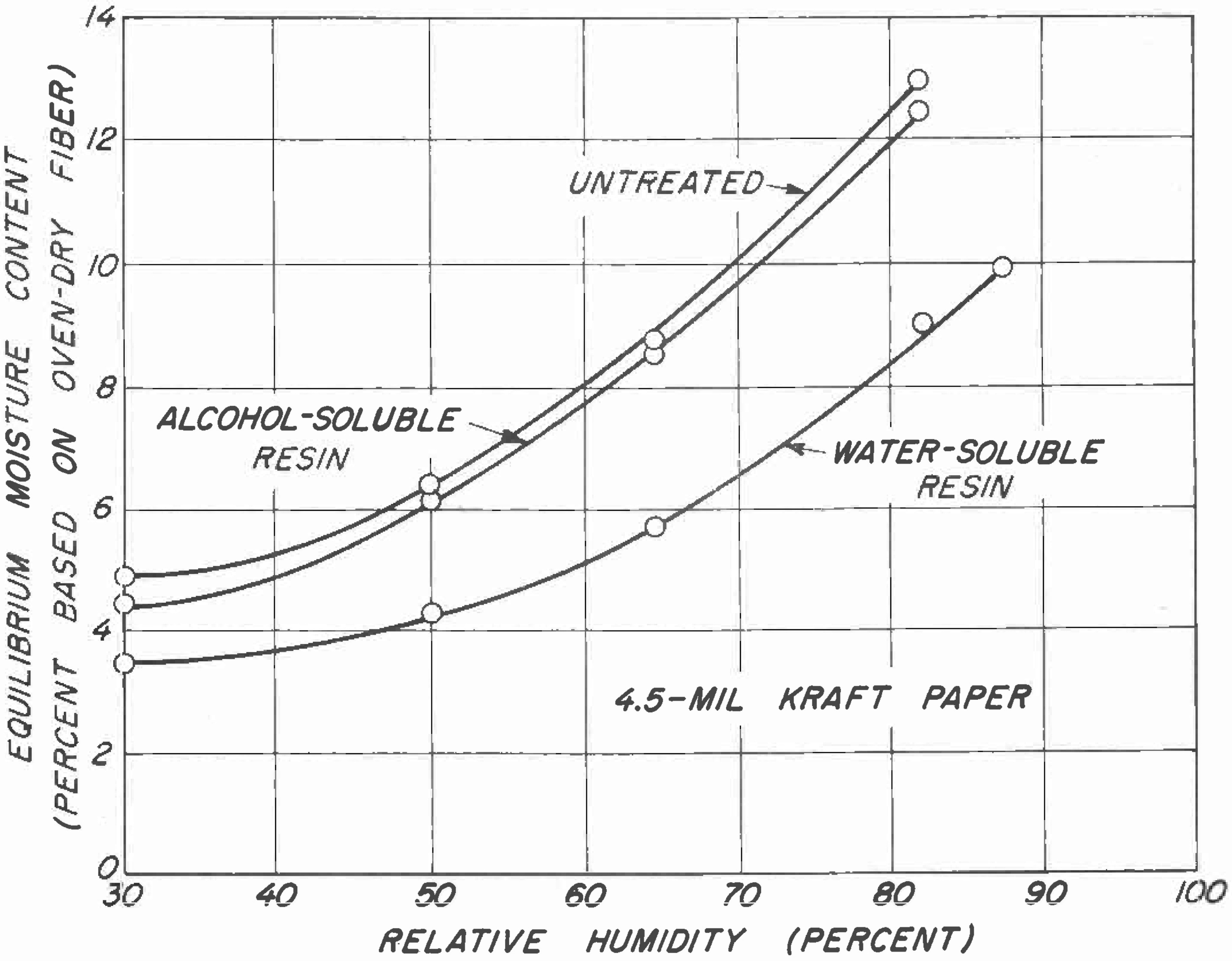


Figure 5. --Effect of alcohol-soluble and water-soluble phenolic resins on the equilibrium moisture content. Resin content about 18 percent based on ovendry weight of treated paper after cure of the resin.

Z M 83316 F

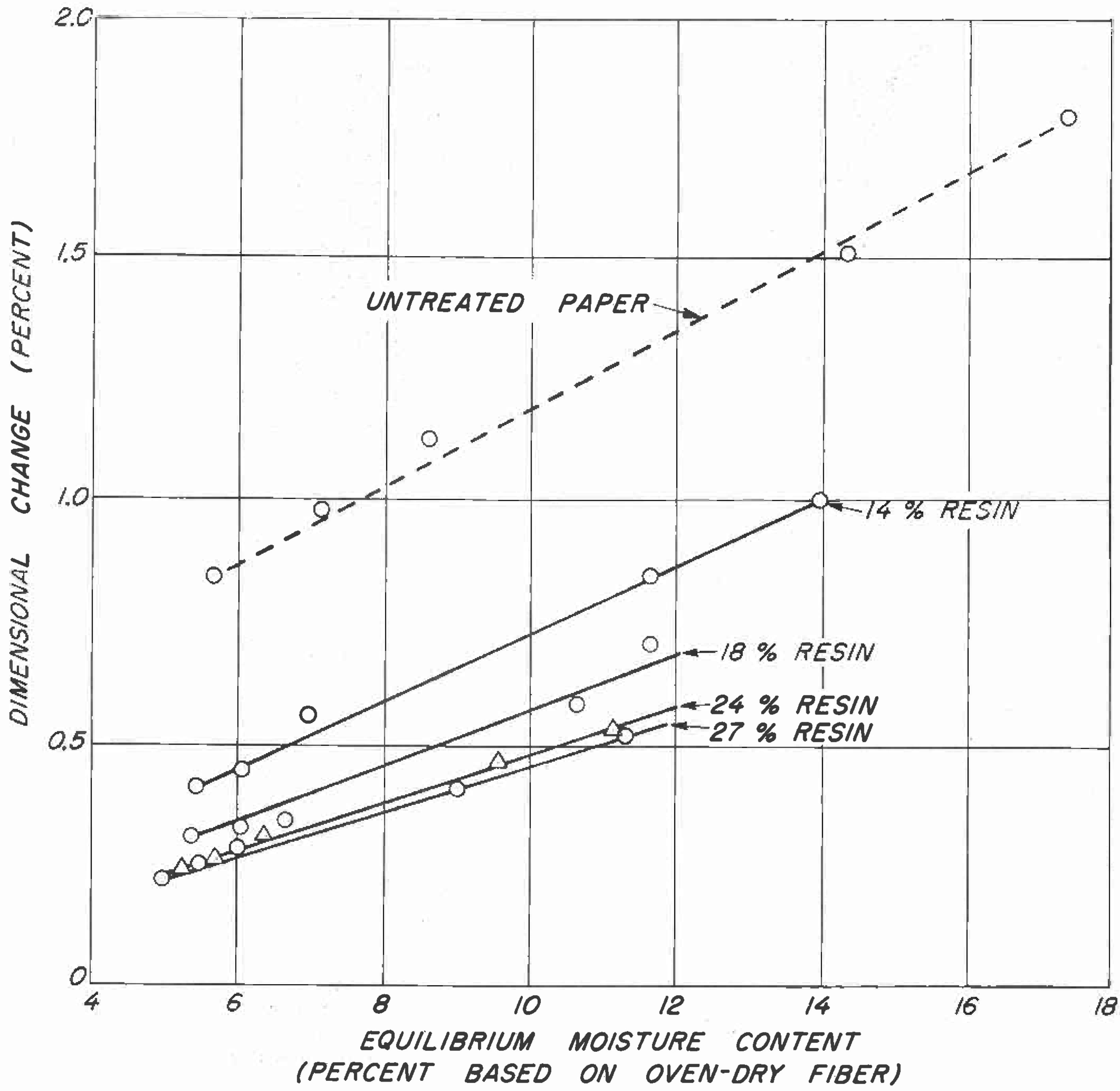


Figure 6.--Relation of the equilibrium moisture content of water-soluble-phenolic resin-impregnated 9-mil kraft paper to cross-machine dimensional change.

Z M 83317 F

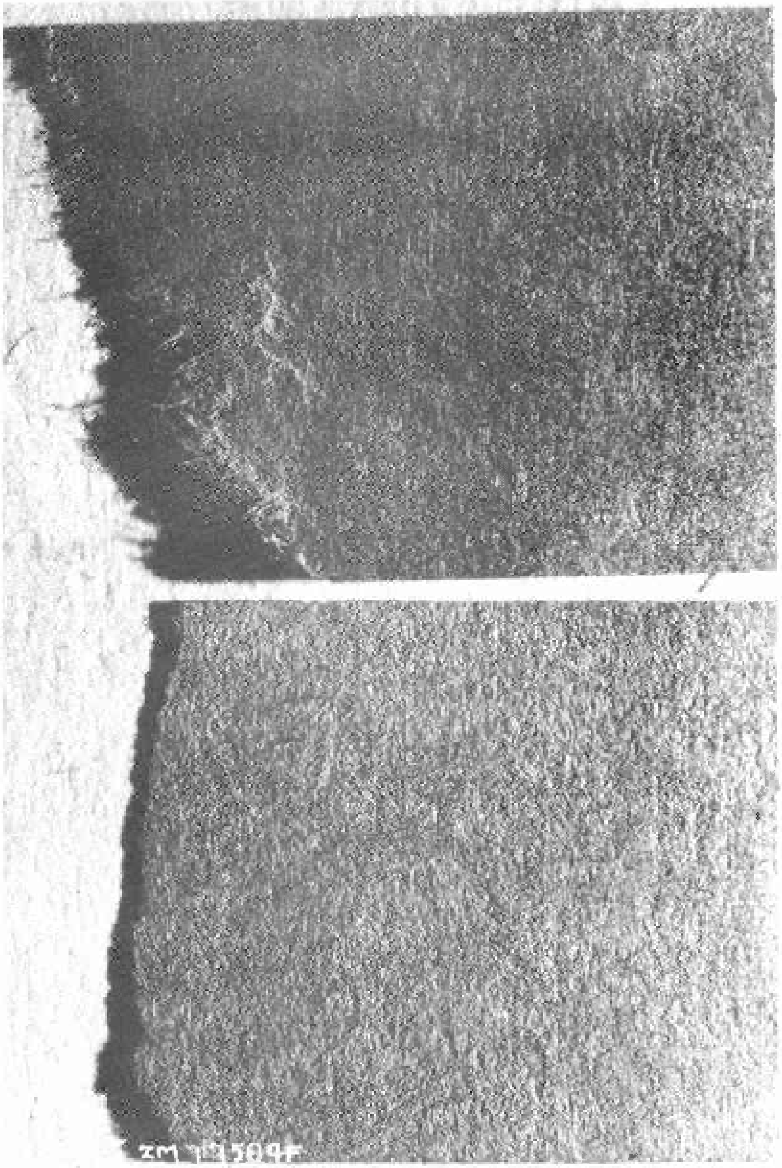


Figure 7. --Type of tension failure for samples of resin-treated paper tested when wet after soaking 48 hours in water. Top, alcohol-soluble-phenolic-resin paper; bottom, water-soluble-phenolic-resin paper.

Z M 77584 F