Carl Smith

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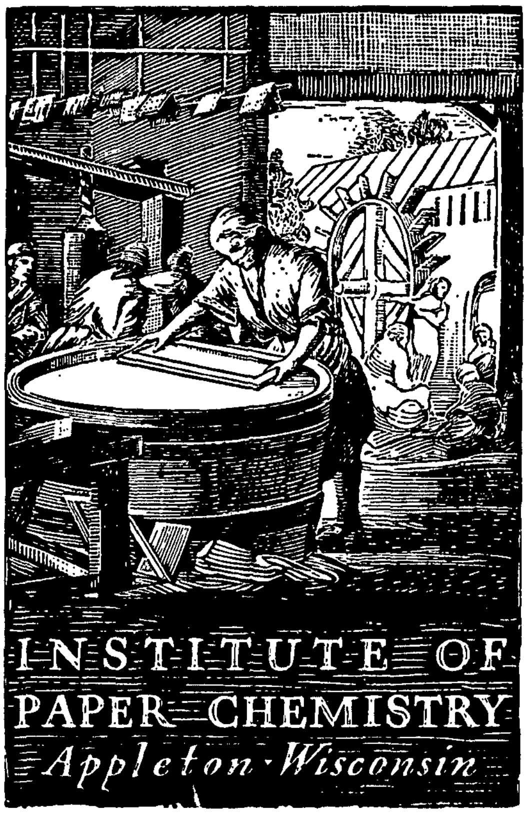

DEVELOPMENT OF A METHOD FOR EVALUATING THE RELATIVE ABRASIVENESS OF CORRUGATING MEDIUM

Project 2696-18

Report One

A Summary Report
to
FOURDRINIER KRAFT BOARD INSTITUTE, INC.

October 5, 1976

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

DEVELOPMENT OF A METHOD FOR EVALUATING THE RELATIVE ABRASIVENESS OF CORRUGATING MEDIUM

SUMMARY

This project was initiated for the purpose of developing a method for the evaluation of the relative abrasiveness of corrugating medium to a metal surface. The Institute was advised that it would not be necessary to correlate actual corrugating roll wear with the abrasion results obtained with the method.

For this purpose, a web abrasion test was developed. This involved drawing a given length of the medium web at controlled web tension over metal foil sheets attached to a fixed steel roll. The loss in weight of the foil sheet is taken as a measure of the abrasiveness of the medium. In order to determine what conditions would give measurable amounts of wear without consuming an excessive amount of medium (usually 2000 feet per test), trials were made with both steel and brass foils and at two web tension levels, namely 0.5 and 2.75 lb/inch. The lower tension level is near the minimum level frequently used in past corrugating studies at the Institute. Eight commercial mediums were evaluated at each test condition.

In addition, limited trials were carried out using a needle penetration method. This involved use of an electric sewing machine to penetrate a pad of medium a given number of times with a brass needle. The needle weight loss was taken as a measure of the abrasiveness of the medium.

The results obtained with the web abrasion test are summarized below:

1. The medium samples exhibited highly significant differences in abrasion characteristics. For example, when expressed in terms of estimated

corrugating roll life for an arbitrary degree of wear, the lives ranged from 357 to 2059 million square feet — a ratio of about 6. Thus, it appears that the method can be used to evaluate the relative abrasiveness of medium.

2. Increasing the web tension from 0.5 to 2.75 lb/inch significantly increased the wear and decreased the estimated corrugating roll life. The increased wear at high web tension is advantageous for wear measurement because the weight losses are greater for a given footage of medium. In addition, it indicates that operation of the corrugator at elevated medium web tensions can markedly increase wear, particularly if more abrasive mediums are being corrugated.

3. The average amounts of wear obtained with the brass foil were about 2.3 and 2.8 times greater than on steel at 0.5 and 2.75 lb/inch web tension, respectively. This is in the expected direction and the differences between brass and steel wear were highly significant.

4. The abrasion results in the brass were highly correlated with the abrasion results on steel. Also, abrasion results at high web tension were well related to the wear obtained at low web tension. Because the weight losses are greater at high web tension and/or on brass, these test conditions have advantages from a measurement standpoint.

INTRODUCTION

In recent years, a number of box plants have reported significant decreases in corrugating roll life due to wear. The need for more frequent replacement of the corrugating rolls increases the process costs and makes it more difficult to maintain product quality.

In the corrugating operation, the medium on the entrance side of the corrugating labyrinth travels at a faster rate than the peripheral speed of the top corrugating roll. The difference in speeds induces a frictional drag between the medium and the flute tips of the top corrugating roll. This results in wear of the fluted roll. Additional and presumably greater wear takes place in the corrugating labyrinth itself. Thus, the abrasive characteristics of the corrugating medium are of importance in determining roll wear. In this connection, a wider variety of fiber furnishes have been employed in the manufacture of medium — some of which could affect wear. This includes greater use of recycled fibers with their attendant nonfibrous contaminants, higher yield pulps and new types of cook, e.g., green liquor semichemical.

Accordingly, this project was initiated for the purpose of developing a method for the evaluation of the relative abrasiveness of corrugating medium on a metal surface. In the revised proposal (Proposal No. 2400, revised Nov. 20, 1975) the Institute was requested to focus attention on the development of a simple test which would differentiate between mediums. The Institute was advised that initially it would not be necessary to correlate actual corrugating roll wear with the abrasion results obtained with the candidate methods.

Two methods were investigated as follows:

1. Web abrasion test. This involves drawing a given length of the medium web under controlled tension over metal foil sheets attached to a fixed steel roll and determining the weight loss of the foil sheet due to abrasion.

2. Needle penetration method. This method involves the use of an electric sewing machine to penetrate a pad of medium a given number of times with a "calibrated" brass needle. The loss in weight of the needle is taken as a measure of the relative abrasiveness of the medium. The general technique was developed by Wink (1) a number of years ago in connection with certain paper abrasive problems.

MATERIALS

Ten corrugating medium rolls made by nine FKI member mills were selected for the study from rolls in the Institute stock. The roll numbers and company codes are shown below.

IPC Roll No.	Company Code	Basis Weight, lb/M ft^2
5609	A	27.3
5510	B	27.1
5537	C	27.3
5559	D	26.0
5561	B	25.2
5570	E	25.6
5576	F	26.9
5579	G	28.5
5604	H	27.7
5608	I	26.4

Based on the current classifications used in Project 2694-2, all the samples fall in the semichemical category.

TEST PROCEDURE

WEB ABRASION TEST

For this test, a given length of medium (usually 2000 lineal feet per determination) was drawn over specially prepared foil specimens at controlled web tension. The specially cleaned foil specimens were weighed before and after the abrasion process to determine the weight loss.

As an experimental convenience, the drive system and web tension measuring roll on the Institute's experimental corrugator were utilized. A schematic drawing of the web threading arrangement is shown in Fig. 1. As noted, the metal foil test specimens were taped to the surface of the fixed 5.5 inch diameter idler roll located just after the medium preheater. After the medium traversed the foil specimens, it passed over a strain gaged cantilever mounted idler roll which was used to measure the web tension.

Two types of metal foils were employed, namely 0.002 inch brass shim stock made by the McCord Corp. and 0.002 inch steel foil. The latter was obtained from the U.S. Steel Co. in connection with other experimental work in the past. In general, the steel surface would be expected to exhibit less wear than the brass, and the amount of wear on the steel surface should probably be more comparable to corrugating roll wear. However, at the outset it was not clear whether measureable amounts of wear would be obtained with the steel foil for the medium footage involved. Therefore, it was decided to evaluate wear with both the steel and brass surfaces because it was expected that greater measurement accuracy could be obtained with the softer brass surface.

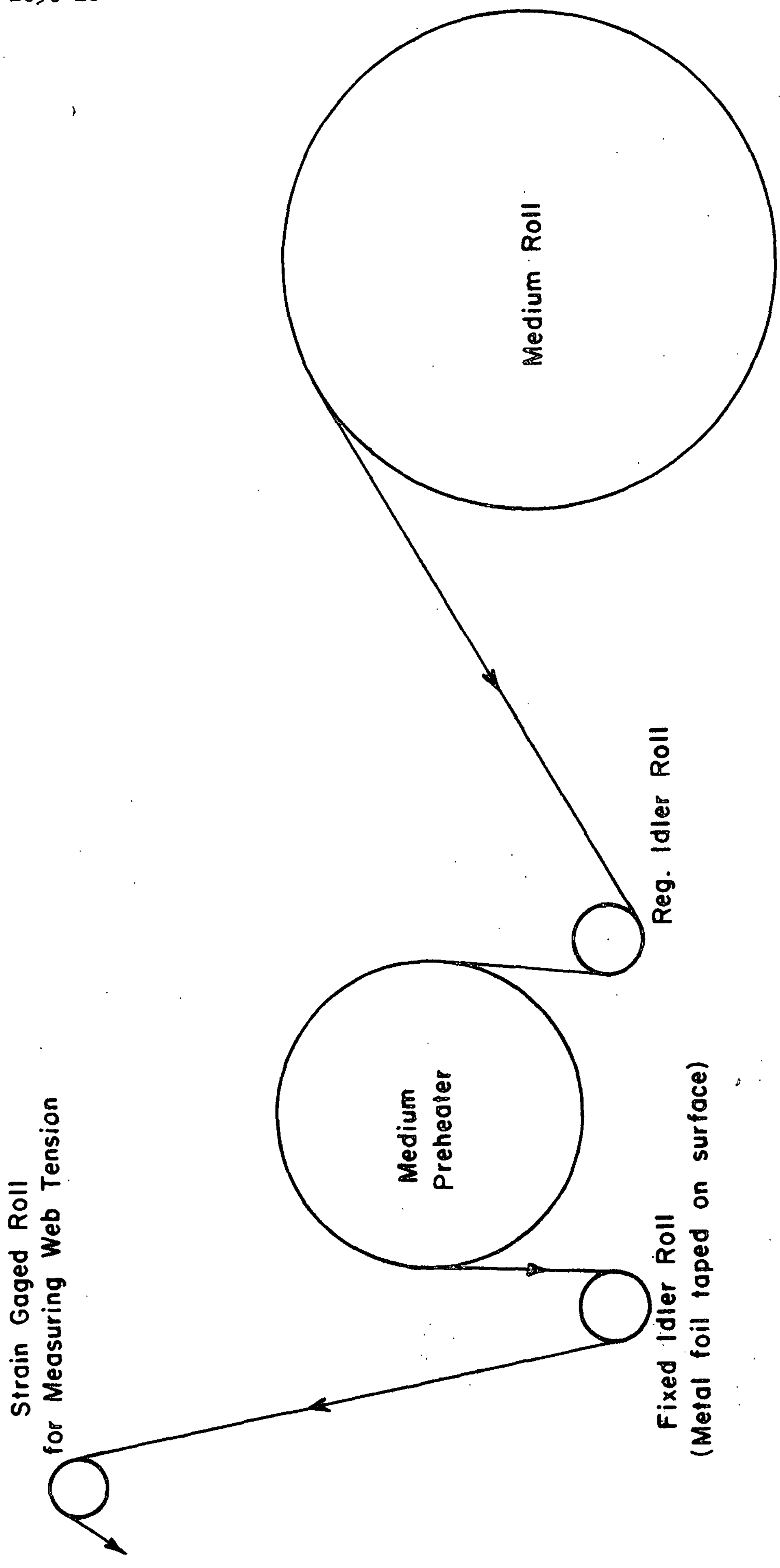
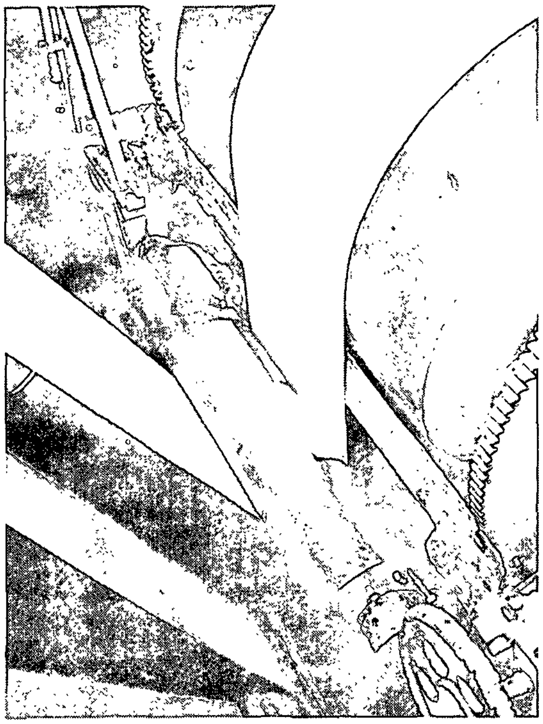


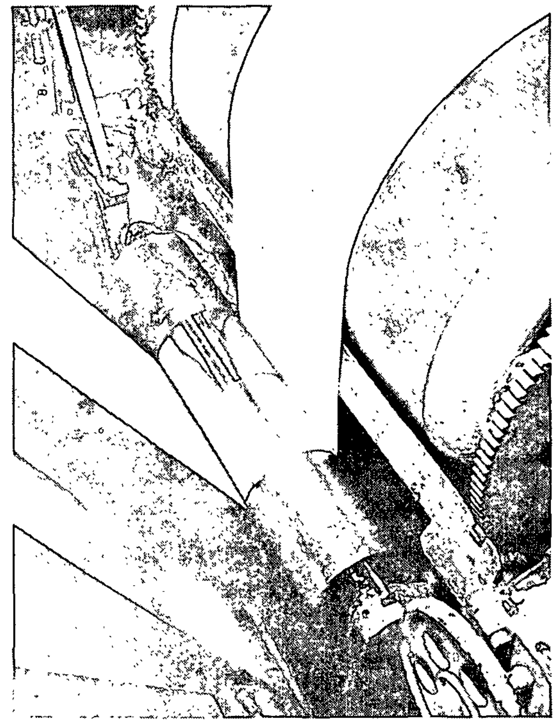
Figure 1. Web Threading Arrangement for Abrasion Test

Except for preliminary trials, the foil specimens were cut to a size of 6 x 10 inches and carefully cleaned and weighed on an automatic analytical balance to the nearest 0.0001 gram. They were then taped to the 5.5 inch diameter fixed roll, as illustrated in Fig. 2. The sheets were located on the fixed roll so that a brass foil specimen was exposed to abrasion by the front half of the 12-inch wide medium web and the steel face was abraded by the back half of the medium web. After one-half of the desired medium was passed over the foils, the position of the foils was reversed and the remaining medium footage was tested. This was done in order to even out possible differences in wear due to uneven tension across the web width. The effective abraded area on each foil specimen was 44.25 square inches. Two levels of medium web tension were employed, namely 0.5 and 2.75 lb/inch. The 0.5 lb/inch is near the minimum web tension usually employed on the Institute's corrugator.

After abrasion, the strips were carefully cleaned again. The detailed cleaning procedure is summarized in Appendix I and involved washing the specimen in alcohol-benzene, acetone and carbon tetrachloride. The abraded and washed specimens were reweighed on an automatic analytical balance and the weight loss due to abrasion was obtained. The abrasion loss in pounds per square foot of abraded area per million ($\overline{MM}$) feet of medium was then calculated from the weight loss, abraded area and linear footage of medium involved. Estimates of roll life were made based on the steel abrasion results and these are discussed in the text. For each medium, type of surface and web tension condition, duplicate tests were performed.



View Showing Foil Attachment to Fixed Roll. Tape Attachment on Left



After Rotation of Foil into Medium Nip

Figure 2. Foil Location

NEEDLE PENETRATION METHOD

As mentioned previously the second method investigated involved use of an electric sewing machine to penetrate a 5 thickness pad of medium a given number of times with a "calibrated" brass needle. The loss in weight of the needle is taken as a measure of the abrasiveness of the medium. A jeweler's lathe is used to provide the proper needle shape and surface conditions at the start of each test. For this study, each medium sample was evaluated in duplicate using 10,000 needle penetrations per test. A microbalance was used to determine the needle weight loss. The medium samples were preconditioned for 24 hours at less than 35% RH and conditioned for at least 48 hours at 50 ± 2% RH, 73°F prior to test.

DISCUSSION OF RESULTS

WEB ABRASION TEST RESULTS

As previously mentioned, this procedure involves drawing a given length of the medium web over metal foil sheets attached to a fixed steel roll and determining the weight loss of the foil sheet due to abrasion. Two initial trials were carried out to determine if measureable amounts of abrasion wear would be obtained with brass and steel foil surfaces. Three carefully cleaned sheets of 0.002 inch brass foil (shim stock) cut to about 10 x 3 inches in size were weighed on an automatic analytical balance and taped on a 5.5 inch diameter fixed roll. The sheets were located in the roll so as to be exposed to abrasion by the operator, center and drive side of the 12-inch wide medium web.

The foil sheets were then abraded by passing 2000 feet of medium at a web tension of 2.75 lb/inch and a speed of 100 fpm over the foil. The wire side of the 26 lb medium was in contact with the foil. After drawing the medium over the foil, the foil was cleaned with acetone and reweighed to determine the weight loss of the abraded area. A similar trial was carried out with steel foil except that 4000 feet of medium was employed. The results obtained are shown in Table I.

The results in Table I were encouraging inasmuch as measureable amounts of abrasion were obtained. Also, as would be expected, the brass surfaces were abraded more severely than the steel surfaces. The variations across the web were believed to be primarily due to differences in web tension across the web caused by caliper differences, draw variations within the roll, etc.

TABLE I

PRELIMINARY ABRASION RESULTS

Web Position	Abrasion Loss, lb/ft^2 Abraded Area/$\overline{\text{M}}$M ft	
	Brass	Steel
Operator side	0.19	0.019
Center	0.13	0.005
Drive side	0.14	0.017
Average	0.15	0.014

In view of the above, it was decided to evaluate eight 26-lb commercial mediums using both types of foil and two web tension levels, mainly 0.5 and 2.75 lb/inch. The 0.5 lb/inch web tension is a low level frequently employed in past Institute corrugator operation. The 2.75 lb/inch is a relatively high web tension level and was selected to insure that measureable wear would be obtained. Duplicate trials were carried out in order to obtain a measure of the variability involved. Before proceeding with the trials, a detailed procedure for cleaning the 6 x 10 inch foil specimens was developed as previously mentioned.

The abrasion loss results obtained after 2000 feet of each medium were drawn over each foil specimen are shown in Table II. (Note: the observed weight losses in milligrams are shown in Appendix II.) Based on the abrasion losses on steel, estimates of potential corrugating roll life were also made for an arbitrarily selected degree of roll wear (0.005 inch) as shown in Table III. These estimates have not been checked against actual corrugating roll wear as this was beyond the scope of the project. While the estimates may not properly account for the effect of the many corrugating conditions which may influence wear, they do provide a relative indication of potential roll wear.

TABLE II

ABRASION RESULTS FOR VARIOUS COMMERCIAL CORRUGATING MEDIUMS

Web Tension, lb/in.	Trial No.	Abrasion Loss,[a] lb/ft^2/MM ft Roll 5609	Roll 5510	Roll 5537	Roll 5559	Roll 5561	Roll 5570	Roll 5576	Roll 5579	Av.
		Brass Foil Surface								
0.5	1	0.0129	0.0032	0.0129	0.0029	0.0018	0.0022	0.0047	0.0086	--
	2	0.0144	0.0036	0.0054	0.0018	0.0014	0.0014	0.0097	0.0083	--
	Av.	0.0136	0.0034	0.0092	0.0024	0.0016	0.0018	0.0072	0.0084	0.0060
2.75	1	0.0646	0.0075	0.0334	0.0050	0.0057	0.0079	0.0205	0.0420	--
	2	0.0531	0.0039	0.0330	0.0050	0.0047	0.0079	0.0273	0.0470	--
	Av.	0.0588	0.0057	0.0332	0.0050	0.0052	0.0079	0.0239	0.0445	0.0230
Gr. Av.		0.0363	0.0046	0.0212	0.0037	0.0034	0.0048	0.0156	0.0264	0.0145
		Steel Foil Surface								
0.5	1	0.0036	0.0014	0.0065	0.0004	0.0004	0.0022	0.0018	0.0054	--
	2	0.0043	0.0014	0.0025	0.0011	0.0018	0.0029	0.0025	0.0039	--
	Av.	0.0040	0.0014	0.0045	0.0008	0.0011	0.0026	0.0022	0.0046	0.0026
2.75	1	0.0215	0.0018	0.0018	0.0032	0.0011	0.0043	0.0043	0.0176	--
	2	0.0180	0.0018	0.0133	0.0014	0.0022	0.0032	0.0061	0.0172	--
	Av.	0.0198	0.0018	0.0126	0.0023	0.0016	0.0038	0.0052	0.0174	0.0081
Gr. Av.		0.0119	0.0016	0.0085	0.0016	0.0014	0.0032	0.0037	0.0110	0.0054

[a]Weight loss per square foot of metal abrasion area per million lineal feet of medium.

Note: Standard deviations of roll averages about the average at each condition were as follows:

Brass, 0.5 lb/inch: Std. dev. = 0.0052
Brass, 2.75 lb/inch: Std. dev. = 0.0208
Steel, 0.5 lb/inch; Std. dev. = 0.0015
Steel, 2.75 lb/inch: Std. dev. = 0.0074

TABLE III

ESTIMATED CORRUGATING ROLL LIVES BASED ON WEAR OF STEEL FOIL

Web Tension, lb/in.	Corrugated Roll Life,[a] MM ft^2/0.005 in. wear								
	Roll 5609	Roll 5510	Roll 5537	Roll 5559	Roll 5561	Roll 5570	Roll 5576	Roll 5579	Av.
0.5	407	1167	365	2059	1458	625	745	357	898
2.75	83	897	130	714	1029	432	315	94	462
Diff., %[b]	-80	-23	-64	-65	-29	-31	-58	-74	-49

[a]Estimated corrugating roll life based on an arbitrarily selected amount of wear, namely 0.005 inch for a 96 inch width machine.

[b]Based on results at 0.5 lb/inch web tension.

With this in mind, the results in Table III are illustrated in Fig. 3 and show that large differences in estimated corrugating roll life were obtained for the eight mediums evaluated in the study. At the low web tension of 0.5 lb/inch, the lives ranged from 357 to 2059 million square feet for medium rolls 5579 and 5559, respectively. This corresponds to a ratio of about 5.8. As would be expected, increasing the medium web tension to 2.75 lb/inch markedly decreases the estimated corrugating roll life. The decreases in life ranged from 23 to 80% and averaged 49%. Thus, operation of the corrugator at elevated web tension levels can be expected to markedly decrease corrugating roll life although the affect depends somewhat on the abrasion characteristics of the medium as discussed in the following.

An analysis of variance was carried out on the abrasion loss data in Table II and the results are summarized in Table IV. The analysis indicated that the differences on wear between the mediums evaluated were highly significant.

The increases on abrasion wear which were obtained when the medium web tension was increased from 0.5 to 2.75 lb/inch were also highly significant. Moreover, there was a significant interaction between web tension and the medium samples. This effect is illustrated in Fig. 4 and 5 for the wear results on

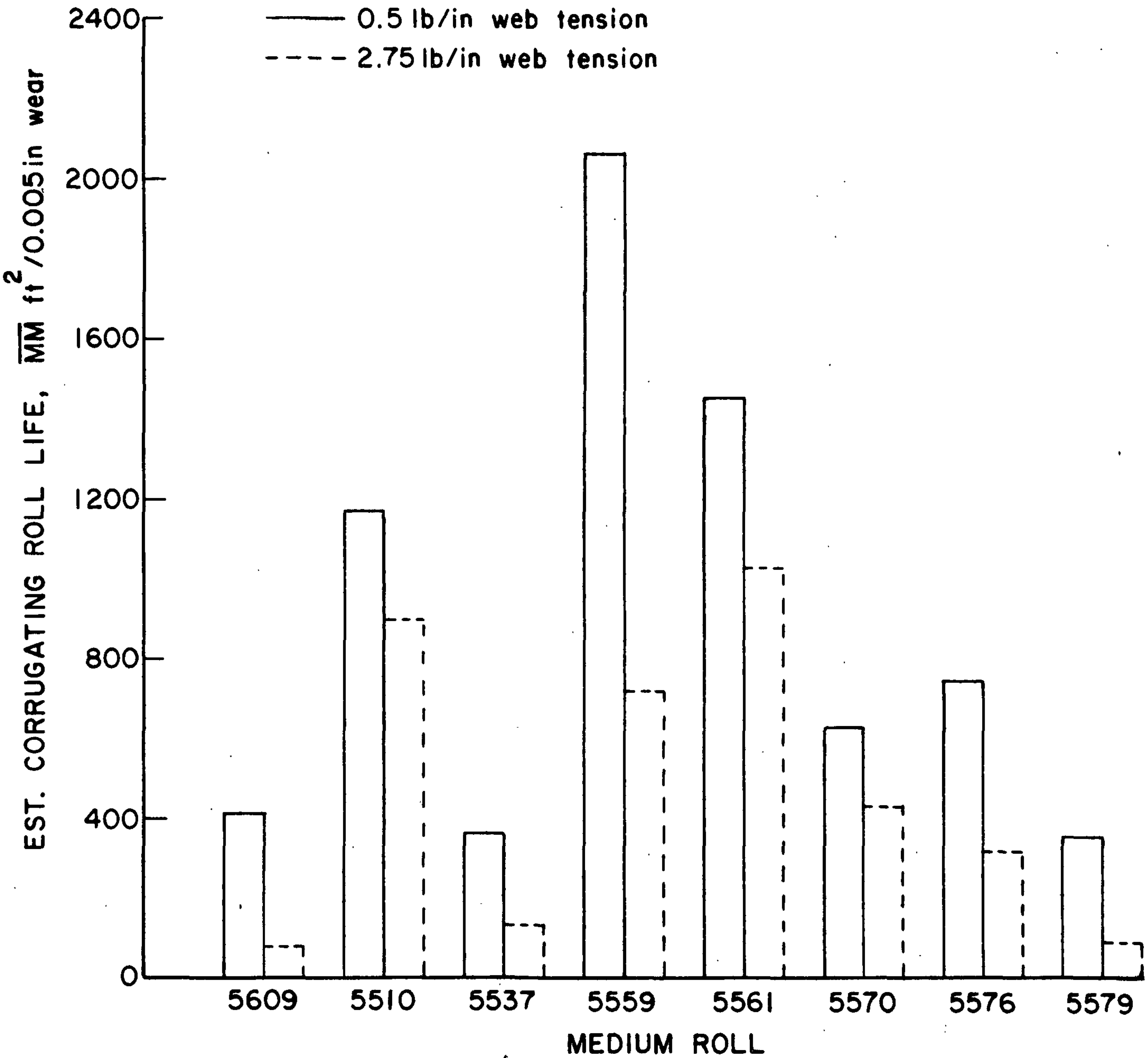


Figure 3. Estimated Corrugating Roll Life for an Arbitrary Degree of Wear for Various Medium Samples

brass and steel foil, respectively. The figures show that the effect of increasing web tension on wear varied from medium-to-medium and was usually more pronounced for the more abrasive mediums.

TABLE IV

ANALYSIS OF VARIANCE OF ABRASION LOSS

Source of Variance	Deg. of Freedom	Mean Square	F	Statistical Significance[a]
Medium samples	7	0.000565	38.44	0.01 level
Type of foil	1	0.001340	91.16	0.01 level
Web tension	1	0.002025	137.76	0.01 level
Tension x foil interaction	1	0.000544	37.01	0.01 level
Tension x sample interaction	7	0.000255	17.35	0.01 level
Foil x sample interaction	7	0.000139	9.46	0.01 level
Residual	39	0.0000147	--	

[a] F ratios for significance at the 0.01 level
7 and 39 degrees of freedom: F = 3.12
1 and 39 degrees of freedom: F = 7.31

Table V shows that the average amounts of abrasion obtained on the brass foil were about 2.3 and 2.8 times greater than on steel at 0.5 and 2.75 lb/inch web tension, respectively. The differences in wear between brass and steel were highly significant in the analysis of variance (see Table IV). The analysis of variance also indicated that the differences in wear between steel and brass depended somewhat on the medium sample and web tension level. For example, Fig. 6 shows that the abrasion differences between the two metals were generally greater for the more abrasive mediums.

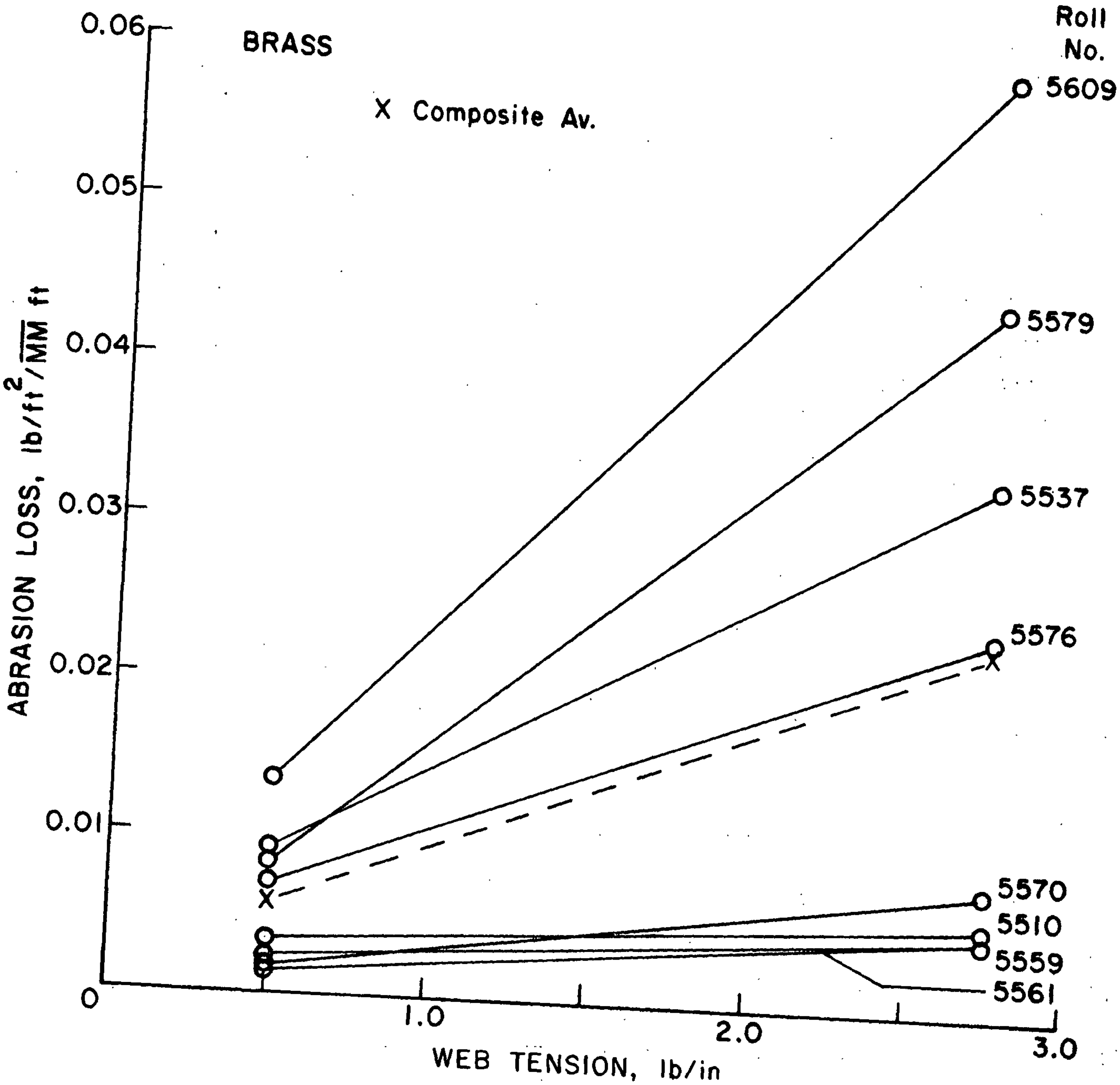


Figure 4. Effect of Medium Web Tension on Abrasion Loss on Brass Foil

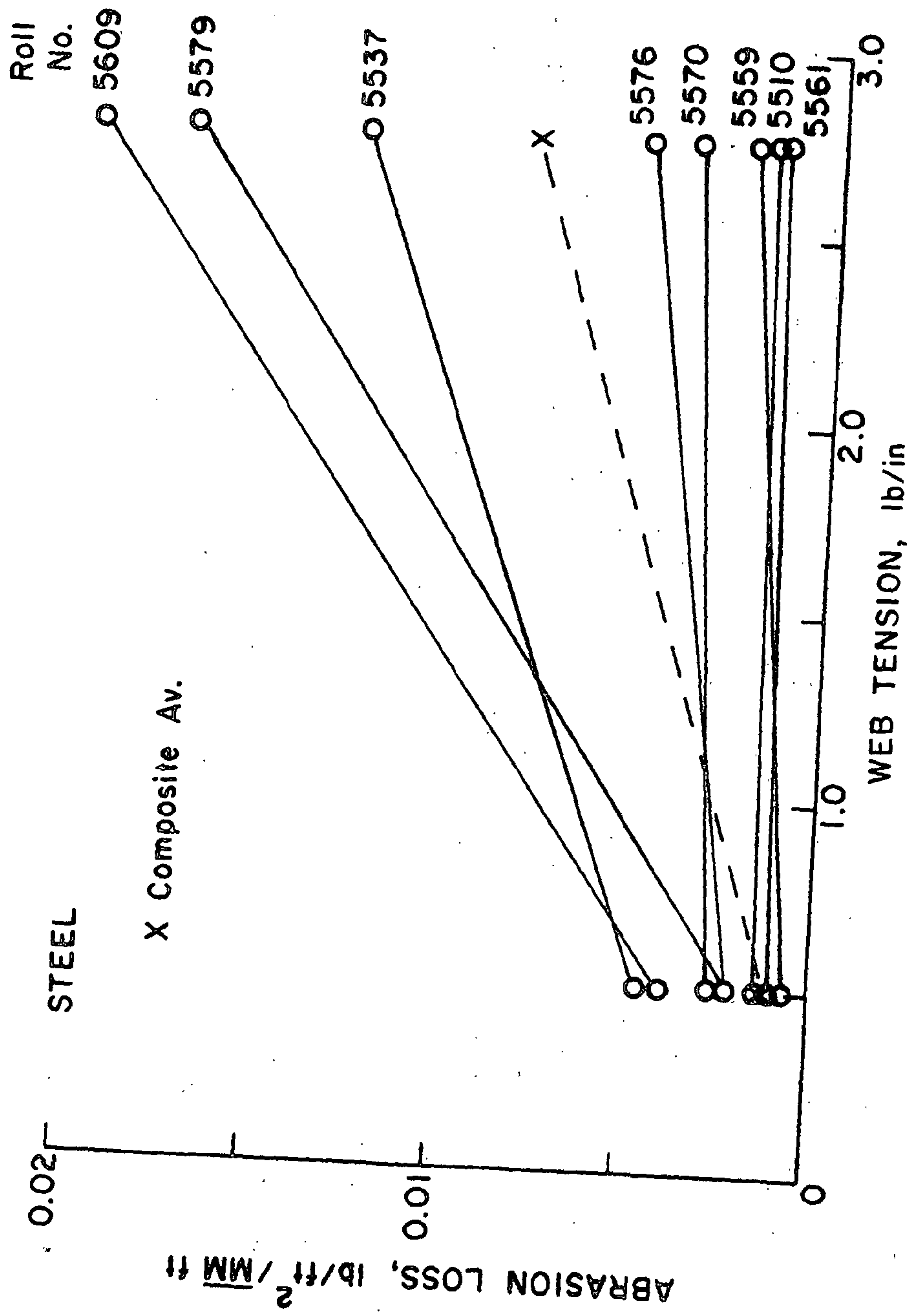


Figure 5. Effect of Medium Web Tension on Abrasion Loss on Steel Foil

TABLE V

COMPARISON OF ABRASION RESULTS FOR
BRASS AND STEEL FOIL

Type of Foil Surface	Abrasion Loss, $lb/ft^2/MM\ ft$	
	Web Tension, 0.5 lb/inch	Web Tension, 2.75 lb/inch
Steel	0.0026	0.0081
Brass	0.0060	0.0230
Ratio: brass/steel	2.31	2.83

From a measurement standpoint, it is desirable to obtain weight losses which are above the accuracy limitations of the method. This was the principal reason for evaluating the brass foil because greater wear could be obtained for a given footage of medium than in the case of the steel foil. High web tensions resulting in accelerated wear have a similar measurement advantage. Therefore, the relationships between wear on brass and steel are illustrated in Fig. 7. The results indicate that the amounts of wear on the two types of surfaces are significantly correlated at low and high web tension levels. It is believed that a higher correlation coefficient was obtained at 2.75 lb/inch tension than at 0.5 lb/inch tension because the results were less affected by measurement error due to the greater wear. When the results were composited over both tension levels, a highly significant correlation coefficient of 0.98 was obtained.

Figure 8 shows that the results at low web tension were significantly related to the results at high web tension for both brass and steel. The correlation coefficient of 0.90 obtained on the steel foil was slightly lower than the coefficient of 0.97 obtained on the brass. However, this is probably due to the low degree of wear obtained on the steel, particularly at low web tension, for the medium footage used.

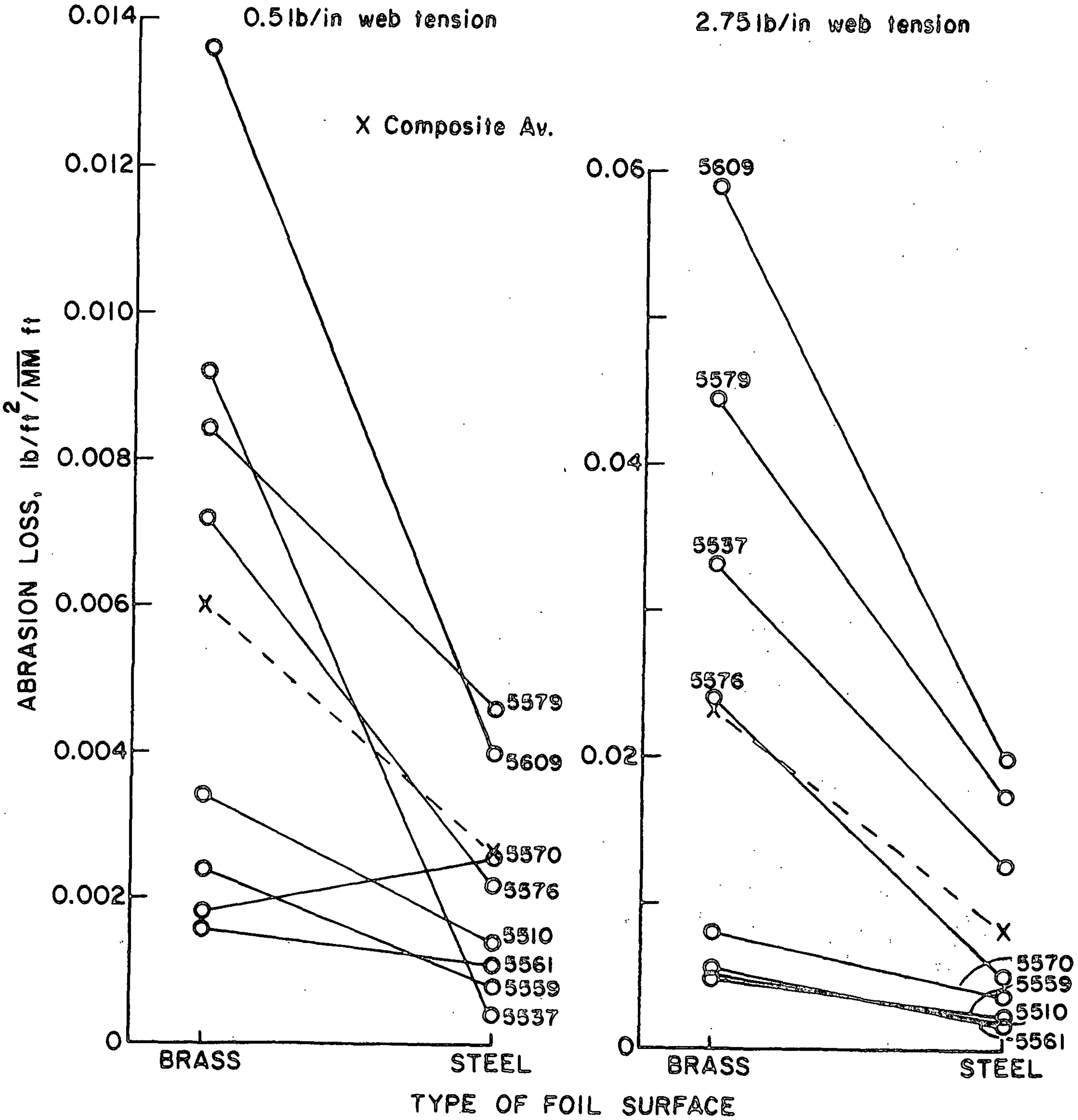


Figure 6. Effect of Type of Metal Foil Surface on Abrasion Loss

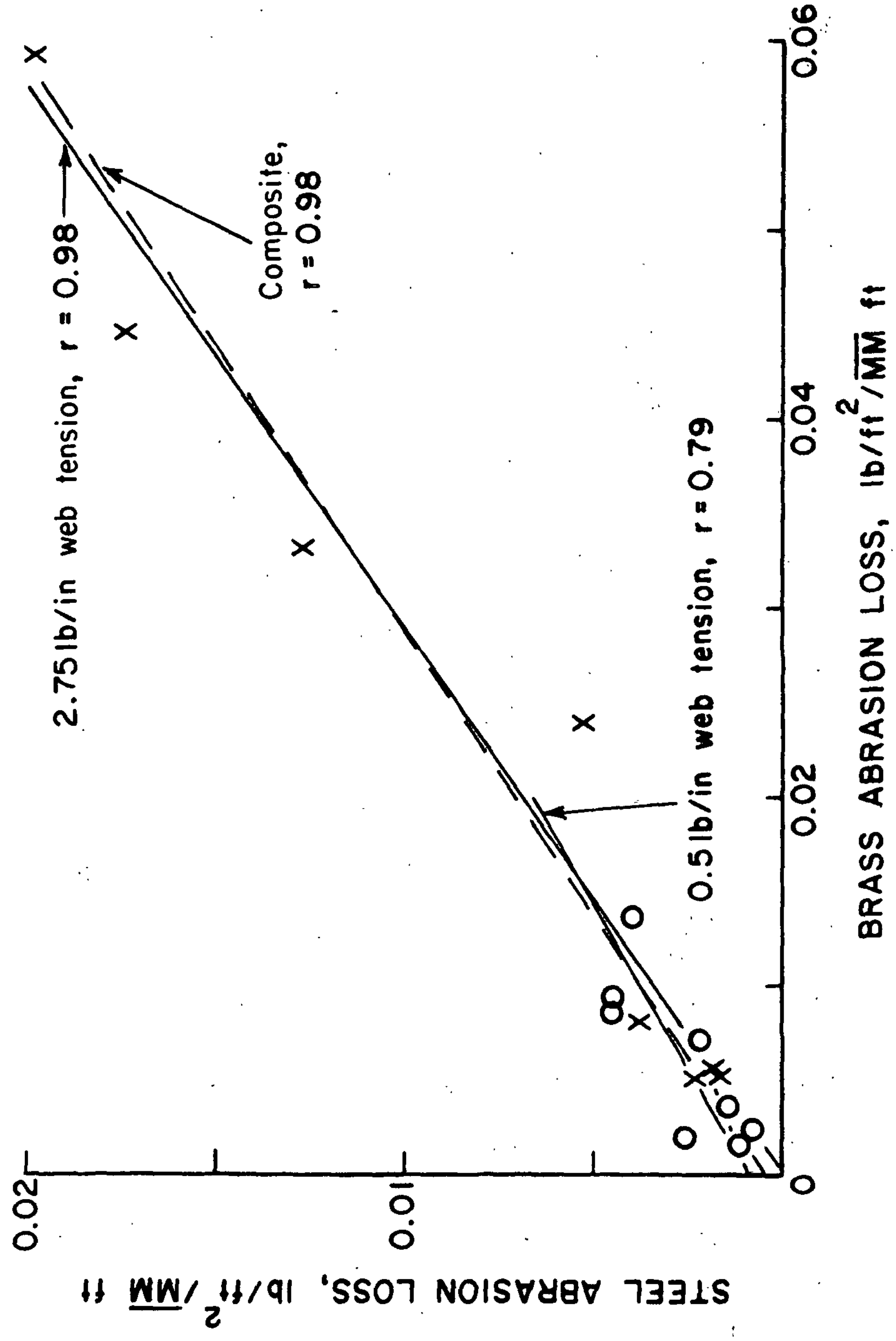


Figure 7. Relationship Between Brass and Steel Wear

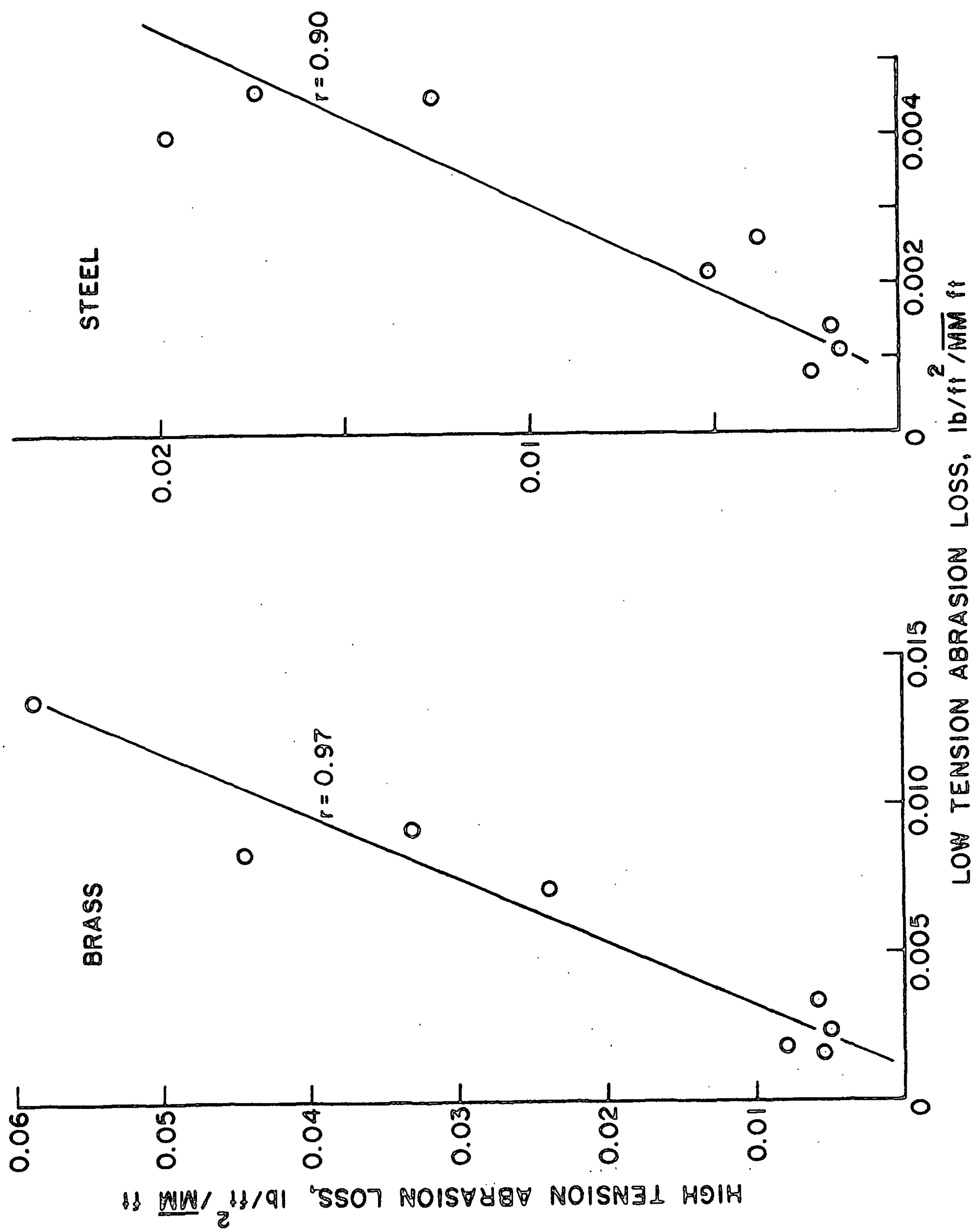


Figure 8. Relationship Between Abrasion Loss at Low and High Web Tension

Thus, it appears that the test conditions which result in higher weight losses — high web tension or brass foil — are quite well related to the abrasion characteristics of medium on steel surfaces at low web tension. The more severe conditions are advantageous from a measurement standpoint. In this connection, at 0.5 lb/inch web tension, the weight losses averaged 0.7 milligram on the steel foil which approaches the limiting accuracy of the method. This probably could be overcome by increasing the lineal footage of medium used on each test by a factor of 3 to 4, i.e., from 2000 to perhaps 8000 feet.

NEEDLE PENETRATION TEST RESULTS

As previously mentioned, limited trials were carried out using a needle penetration method devised by Wink (1) which has related to wear in other paper applications. This method involves the use of an electric sewing machine to penetrate a pad of paper a given number of times with a "calibrated" brass needle. The loss in weight of the needle is taken as a measure of the relative abrasiveness of the paper. Ten medium samples were evaluated in duplicate as shown in Table VI using 10,000 needle penetrations per test. (Note: the number of penetrations was arbitrarily selected; a greater number would improve precision at a modest increase in test time.)

Needle weight losses ranged from 90 to 315 micrograms for the various mediums. While the differences between duplicate tests were large in some cases, an analysis of variance (see Table VII) showed that the mediums exhibited statistically significant differences in abrasion. As mentioned, the reproducibility could be improved by increasing the number of penetrations and number of replicate tests.

TABLE VI

ABRASION RESULTS USING NEEDLE PENETRATION METHOD

Medium Roll No.	Needle Weight Loss, μg[a]			
	Test 1	Test 2	Av.	Range
5609	300	260	280	40
5510	110	140	125	30
5537	90	90	90	0
5559	70	130	100	60
5561	140	150	145	10
5570	190	310	250	120
5576	80	130	105	50
5579	260	370	315	110
5604[b]	210	370	290	160
5608[b]	250	210	230	40

[a]Weight loss based on 10,000 penetrations of brass needle through five thicknesses in micrograms.

[b]These samples were not included in the web abrasion evaluation due to insufficient material.

TABLE VII

ANALYSIS OF VARIANCE OF NEEDLE PENETRATION RESULTS

Source of Variance	Deg. of Freedom	Mean Square	F
Between mediums	9	15,646.67	5.01[a]
Within mediums	10	3,120.0	--
Total	19		

[a]Significant at the 0.01 level.

The needle penetration tests were correlated with the web abrasion results as shown in Table VIII for the eight mediums.

TABLE VIII

CORRELATION BETWEEN NEEDLE PENETRATION AND WEB ABRASION RESULTS

Web Abrasion Tests	Corr. Coefficient (N=8)
Brass at 0.5 lb/inch web tension	0.37
Brass at 2.75 lb/inch web tension	0.57
Steel at 0.5 lb/inch web tension	0.55
Steel at 2.75 lb/inch web tension	0.63

Table VIII shows that the web abrasion and needle penetration tests were not highly correlated. In general, it would be expected that the web abrasion test should be dependent on abrasion matter in the surface of the medium, whereas the needle penetration test results may be affected by abrasion matter through the whole thickness of the sheet. The surface matter may be expected to be more important in the case of corrugating roll wear. Therefore, in view of the relatively low correlation between the web abrasion and needle penetration methods, it was decided to terminate the work on the needle method at this stage.

LITERATURE CITED

1. Wink, W. A. A needle penetration test for evaluating the relative abrasiveness of paper. IPC Research Bulletin 40(1):46.

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APPENDIX I

DESCRIPTION OF CLEANING PROCEDURE

The following procedure was adopted for preparing the foil used in the abrasion study.

Solvents used:

Acetone — C P Grade
Benzene — Reagent Grade
Ethyl Alcohol — Absolute
Carbon Tetrachloride — Reagent Grade

1. Wash porcelain trays and glass stirring rod with hot water and detergent. Rinse with hot water and air dry. Rinse tray with the solvent which is to be in the tray.

2. Cut foil to desired size and identify.

3. Prepare a heated protective enclosure with a rod and wire hooks for suspending cleaned foil.

4. Prepare alcohol-benzene solution.

   1 part ethyl alcohol
   2 parts benzene

5. Fill trays 1/2-inch deep with solvent.

6. Attach paper clip to foil.

7. Immerse foil in acetone and wash for one minute (30 seconds on each side) using a kleenex tissue and tweezers. Hold firmly by the paper clip with glass rod. Turn with tweezers by the paper clip. Air dry before immersing in next solvent.

8. Repeat step 7 for alcohol benzene.

9. Repeat step 7 for carbon tetrachloride.

10. Hang by paper clip in the protective enclosure. Avoid contact with foreign objects.

11. Repeat steps 6-10 for each specimen.

12. Change tissues after every 4 washings and solvent after 16 washings.

13. Suspend the foil in an oven at 200°F and hold for 5 minutes.

14. Using canvas gloves, carefully remove the foil from the rod in the protective shield and roll up individual specimen. Hold together with a tared retaining ring.

15. Weight to the nearest 0.1 millogram. Deduct the tare weight of the ring. Record weight.

16. Repeat steps 4 through 15 after abrading.

17. In cases where residue from the abrading process is left on the foil, longer washing times may be necessary.

APPENDIX II

WEB ABRASION TEST WEIGHT LOSSES

TABLE IX

WEB ABRASION RESULTS ON VARIOUS CORRUGATING MEDIUMS

Web Tension, lb/in.	Trial No.	Weight Loss, mg[a] Roll 5609	Roll 5510	Roll 5537	Roll 5559	Roll 5561	Roll 5570	Roll 5576	Roll 5579	Av.
				Brass Foil Surface						
0.5	1	3.6	0.9	3.6	0.8	0.5	0.6	2.0	2.4	--
	2	4.0	1.0	1.5	0.5	0.4	0.4	2.7	2.3	--
	Av.	3.8	1.0	2.6	0.6	0.4	0.5	2.0	2.4	1.7
2.75	1	18.0	2.1	9.3	1.4	1.6	2.2	5.7	11.7	--
	2	14.8	1.1	9.2	1.4	1.3	2.2	7.6	13.1	--
	Av.	16.4	1.6	9.2	1.4	1.4	2.2	6.6	12.4	6.4
Gr. Av.		10.1	1.3	5.9	1.0	1.0	1.4	4.3	7.4	4.0
				Steel Foil Surface						
0.5	1	1.0	0.4	1.8	0.1	0.1	0.6	0.5	1.5	--
	2	1.2	0.4	0.7	0.3	0.5	0.8	0.7	1.1	--
	Av.	1.1	0.4	1.2	0.2	0.3	0.7	0.6	1.3	0.7
2.75	1	6.0	0.5	3.3	0.9	0.3	1.2	1.2	4.9	--
	2	5.0	0.5	3.7	0.4	0.6	0.9	1.7	4.8	--
	Av.	5.5	0.5	3.5	0.6	0.4	1.0	1.4	4.8	2.2
Gr. Av.		3.3	0.4	2.4	0.4	0.4	0.9	1.0	3.1	1.5

[a] Loss in weight of foil specimen after abrasion by 2,000 feet of medium (wire side) at indicated web tension. The abraded area on the foil specimen was 44.25 square inches.