U. S. DEPARTMENT OF COMMERCE NATIONAL BUREAU OF STANDARDS

RESEARCH PAPER RP1427

Part of Journal of Research of the National Bureau of Standards, Volume 27, October 1941

EFFECT OF ROUGHNESS OF CAST-IRON BRAKE DRUMS IN WEAR TESTS OF BRAKE LININGS

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ABSTRACT

Five representative types of commercial brake linings were tested against centrifused cast-iron brake drums having widely different values of roughness. It was found that (1) the rate of wear of brake lining is an increasing function of the initial roughness of the drum, (2) the actual wear characteristics of a given lining are a function of the character of the surface of the drum and of the type and quality of the lining, (3) the roughness of the drums, in general, has a greater effect on the wear of woven linings than on the wear of molded linings, and (4) the rate of wear of brake linings tested against relatively smooth drums becomes practically constant after the first few hundred stops. For relative wear tests a drum of specified type and finish, having a roughness of not more than 15 microinches root mean square is recommended.

The effect of the roughness of brake drums in service is probably similar to that obtained on the testing machine but less in magnitude.

The coefficient of friction appears to be slightly lower the rougher the drum, but for all practical purposes the effect of roughness on the coefficient of friction may be neglected.

CONTENTS

I. INTRODUCTION

Experience in the testing of brake lining by means of the small inertia testing machine described elsewhere [1] [1] clearly indicates that control of the characteristics of the drum surface is necessary for reproductible determinations of wear. The rates of wear of some linings have been observed to vary by more than 300 percent when tests have been made with drums differing widely in roughness. Roughness, however, is by no means the only condition of the drum

[1] Figures in brackets indicate the literature references at the end of this paper.

surface which may affect the wear of brake linings, but it is probably the most important from the standpoint of relative wear if the drums used are all of the same type and kind.

Wear has always been one of the major problems of the brake-lining industry, and many of the factors related to it have been extensively studied. In fact, it would be presumptuous to assume that any one factor had not at least been considered by someone. Brake drums have been improved periodically, and with the development of more convenient methods for measuring surface roughness and of better grinding equipment the quality of the finish is being improved. The effect of the roughness of brake drums on the wear of the linings has been recognized for some time. It is only within the last few years, however, that convenient methods have been available for evaluating roughness of metal surfaces, and, so far as is known, no quantitative data have hitherto been published on the relation between the roughness of drums and the rate of wear of the linings. The present investigation was undertaken to study this relation.

Five representative linings were tested against a number of brake drums which covered a considerable range of roughnesses. Superfinished drums and the smoothest of the ground drums represented one extreme and turned drums the other, while drums of intermediate characteristics were prepared by grinding in different ways.

II. METHOD OF TEST

The tests were made by means of the small inertia-type machine mentioned above, which has been the subject of a previous publication. The linings were selected so as to be representative of those in commercial use. Drum surfaces were prepared so that their respective roughnesses differed over wide limits but other factors which might have affected the wear were kept as nearly constant as practicable.

1. EVALUATION OF DRUM SURFACES

The general problem of evaluating a metallic surface should take into account not only the roughness but also the microstructure of the material at the surface, the flaws which may be present—such as holes, inclusions, hard spots, peaks, and scratches—the method by which the surface was finished, and the waviness of the surface. Swigert [2], in "The Story of Superfinish", lists a number of terms used for describing the finish of surfaces and gives precise definitions of them, which have been formulated in connection with the work of the Chrysler Corporation.

Many of these characteristics were eliminated from consideration in the present investigation because the primary concern was relative wear and because centrifused cast-iron drums were used throughout. Under the circumstances the principal concern was with deviations of the surface of the drum. Shurig [3] suggests three factors—namely, roughness, waviness, and flaws—which should be considered in evaluating the deviations of a surface. For present purposes the method of finish was added to this list, since it affected the character of the roughness. Of these four factors roughness was the only one given a numerical evaluation. The method of finish was considered in the presentation of the results. Waviness and flaws, however, were not found to be significant except possibly in one or two cases.

The evaluation of the roughness of surfaces has been greatly facilitated by the recent development of the Profilometer [4], the profilograph [2], and the Surface Analyzer [5]. An American Standard for Surface Roughness [6] has been proposed and is designed to enable the roughness of a surface to be readily measured and specified within close limits.

The roughness of the brake drums which were used in the present investigation was measured by means of a Profilometer. Observations were made on each drum before and after a test. The measurements after a test were not altogether satisfactory, however, because minute score marks were sometimes produced in the drums by the linings. The slight scoring which took place apparently had no effect on the rate of wear of the linings but, it did cause the Profilometer readings made after test to be unreliable from the standpoint of relative values.

The Profilometer consists primarily of a tracer element having a diamond point 0.0005 inch in radius and a small coil which vibrates in a magnetic field as the tracer point is drawn over a surface. The voltage generated by these vibrations is proportional to the roughness and is impressed on a meter which is calibrated to read the root mean square (rms) value of roughness in microinches.

It was not to be expected that the roughness of the surface of any one drum would be uniform, but rather that it would vary from spot to spot. Actually the needle of the Profilometer meter vibrated over a range as the tracer point moved over the surface. The observer estimated the average high and average low values. The sum of the average high and average low values divided by two was taken as the roughness. The deviation of the high and low averages from the evaluated roughness ranged from approximately 2 microinches rms for the smoothest drums to approximately 15 microinches rms for the roughest drums.

The rms value of roughness [6] is defined as the square root of the average value of the squares of the perpendicular distances of points on the surface from some mean reference plane. Swigert [2] gives the ratio of rms values to the maximum values as from 1/3 to 1/5.

The Profilometer does not measure surface deviations when the frequency of the recurrent or random irregularities is less than about 100 per inch. Consequently it does not evaluate flaws or waviness. The surface deviations resulting from waviness can be measured by means of a conventional dial gage of appropriate sensitivity. Such measurements, however, were not made in the present work.

2. PREPARATION OF BRAKE DRUMS

Thirty centrifused cast-iron drums were employed in this investigation. Twelve of these drums had been in use for about 3 years and had been refinished several times. Twelve were new commercially turned drums and six were new superfinished drums. Each of the new drums was used to make one test before it was ground.

Except for these initial tests, each drum was wet-ground on a Heald grinder, No. 4927, type 7, style F, before using it for a test. The speed of the grinding wheel was 6,000 rpm, and the speed of the work was 160 rpm in the opposite direction. The rate of the feed can be set at 26 and 72 inches per minute; both feeds were used in the course of the work. The thickness of the cut was regulated by the operator of the grinder to get the desired result. In order to get the smoothest drums, it was necessary to let the machine run after the final cut had been taken until contact between the grinding wheel and the work had practically ceased. Three grades of 5-inch hard-bonded silicon-carbide grinding wheels were used at different times. They were Norton wheels Nos. 3740–J5, 3760–J6, and 3780–J6 and were of medium open structure with grit sizes 40, 60, and 80, respectively.

Considerable difficulty was experienced in preparing ground drum surfaces of the desired degrees of roughness, particularly surfaces with roughnesses below 20 microinches rms and above 50 microinches rms. The superfinished drums and the best of the ground drums had a roughness between 10 and 15 microinches rms, and the commercially turned drums had a roughness of approximately 100 microinches rms. The majority of the ground drums were given roughnesses ranging between these two values by using different combinations of wheels and speeds. It was found that the smoothest surface could be obtained by using the 3760–J6 wheel with a feed of 26 inches per minute and by letting the machine run until the last cut was completely ground out. It was found necessary to dress the wheel frequently.

The general procedure was to grind all of the available drums at one time, under given conditions, measure the surface roughness, and use them to make tests on one or all of the five linings. Each time a group of drums was reground the method of grinding was adjusted in accordance with the above variables to give the roughnesses desired for the next set of tests. The drums and linings were used in such combination that each lining was tested against a series of drums covering the desired range of roughness.

3. SELECTION OF BRAKE LININGS

The five brake linings used in these tests were selected as being representative of the higher grades of the different types of commercial linings in common usage at this time. A description of each lining is given in table 1.

TABLE 1.—*Description of brake linings*

Lining No.	Type	Color	Metal in lining	Structure	Grade[1]
48	Rigid molded	Tan	None	Granular	Good.
62	do	Black	Brass particles	Hard, dense	Excellent.
76	Flexible woven	Tan	None	Loosely woven	Good.
160	Flexible molded	Brown	do	Tough, resilient	Excellent.
161	Flexible woven	Tan	Zinc wire	Dense, closely woven	Do.

[1] This grading has no commercial significance but merely indicates the relative standing of these linings compared with a large number of linings tested by the National Bureau of Standards on a comparative basis.

4. TEST PROCEDURE

The wear of the brake linings was measured in terms of the reduction in thickness which was brought about by using specimens of the lining to stop the flywheel of the testing machine a given number of times. Test pieces of the lining having a 2- by 2-inch rubbing surface were clamped on the two shoes of each brake and were run against drums of measured roughness. Each test consisted of approximately

5,000 complete stops of the machine from 600 rpm at intervals of 1.5 minutes. The stopping of the machine under these circumstances was approximately equivalent to the stopping of an automobile, on the average, from a speed of 50 mph by means of the usual service brakes. The thickness of each piece of lining was measured at four designated points by means of a ratchet micrometer caliper. Measurements of thickness were made at the beginning of each test and at intervals of approximately 900 stops throughout the test. The lining and drum were cooled to room temperature before each set of measurements was made. Contrary to the procedure in testing under a specification [7], no wear-in period was employed before making the original thickness measurements because it was desired to obtain the initial as well as the sustained wear.

III. RESULTS AND DISCUSSION

The results of the measurements of wear are presented graphically. In figure 1 the wear is shown as a function of the number of stops and in figure 2 as a function of the roughness of the drums. Each curve in figure 1 represents the wear of a given brake lining against a given drum and the slope of the curve at any point represents the rate of wear of the lining at that point. The curves for the five linings are grouped in the five respective charts. The individual curves are designated by the initial roughness of the drums.

In figure 2 values for the wear are plotted against the initial roughness of the drums. Each solid circle in the figure represents the total wear of a given lining against a given drum at 3,000 stops and each corresponding open circle the sustained wear between the 1,000th and the 3,000th stop for the same test. The data from which figure 2 was plotted were taken for the most part from the curves of figure 1. As in figure 1, the curves of figure 2 are grouped in five charts for the five respective linings.

In plotting figure 1, curves for a few of the tests were omitted for the sake of clarity. Points from all of the tests, however, were plotted in figure 2.

1. RELATION OF WEAR TO NUMBER OF STOPS

As shown by the change of the slope of the curves in figure 1, there was a change in the rate of wear during each test. For tests made on the smoother drums the rate of wear decreased rapidly during the first few hundred stops to some value which remained practically constant for the remainder of the test. Tests on the rougher drums showed the same general characteristic, but the rate of wear continued to decrease throughout the entire test with the rate of decrease becoming less as additional stops were made. This is an indication that continued testing against any one drum would result in the rate of wear eventually reaching some value which is a constant for the lining. It should be noted, however, that in the case of rough drums several sets of lining might be worn out before this constant value is reached.

The high rate of wear at the beginning of a test was probably due in large part to the fine sharp edges of the finish marks on the newly finished drums and may be termed initial wear. These sharp edges, however, were soon worn off or dulled, and the rate of wear approached some constant value which may be termed the sustained wear.

Conner [8] notes the same phenomena in his studies of the relation of surface finish to the wear in internal combustion engines. Dayton [9] has defined the types of wear referred to in this paper as initial and sustained wear as cutting and abrasive wear, respectively.

The number of stops required for the rate of wear to become constant is dependent on the initial roughness of the drum and on the character of the lining being tested. For drums having a roughness

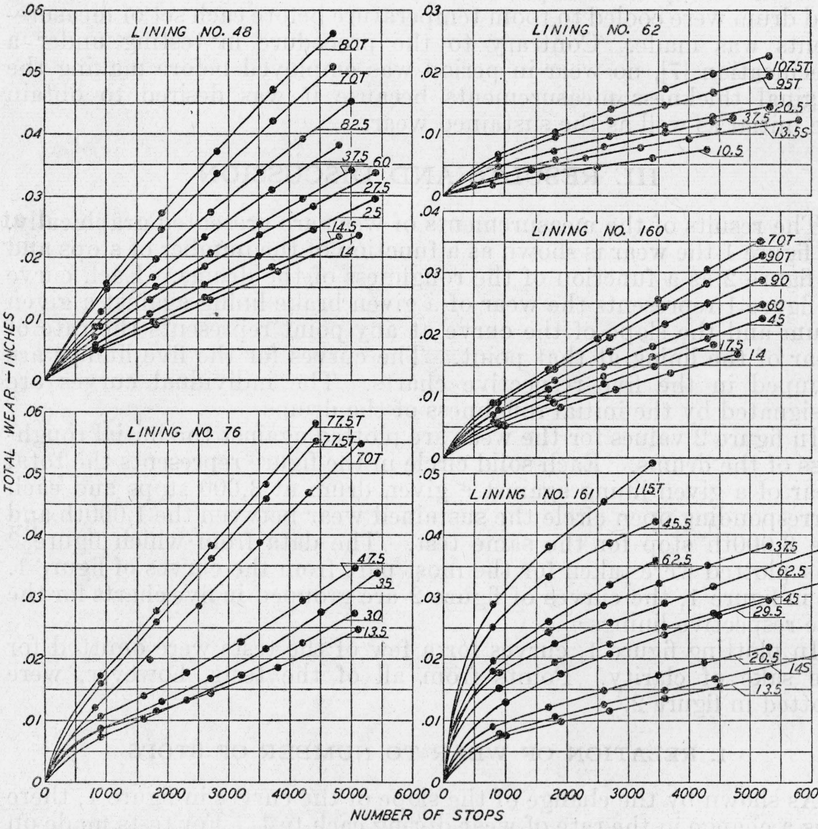

FIGURE 1.—*Relation between wear and the number of stops.*

Each individual curve is designated with a number representing the evaluated roughness of the drum on which the test was made. Curves marked *T* are for tests made on turned drums, those marked *S* are for tests made on superfinished drums, and the remainder are for tests made on ground drums.

of 60 microinches or more the rate of wear may become constant only after several thousand stops, while for relatively smooth drums having a roughness of 15 microinches or less the rate of wear may become practically constant in a few hundred stops. Hard dense linings, such as No. 62, apparently wear off and dull the rough edges of a drum much faster than softer linings, such as Nos. 48 and 76. Consequently, one may expect the rate of wear of the former to become constant much more rapidly than the latter, the initial conditions of the drums being the same.

Lining 76 differed in behavior from the other linings in that the rate of wear after the initial period (except for turned drums), showed a slight increase throughout the period of test, as indicated by a slight upward trend of the curves in figure 1. This increase in the rate of wear was probably due to a progressive change in the lining on account of heat or other factors, whereby it became progressively more susceptible to wear. The fact that the curves for the three tests made on turned drums appear to be straight lines is probably due to the drums becoming smoother at a rate sufficient to offset the tendency

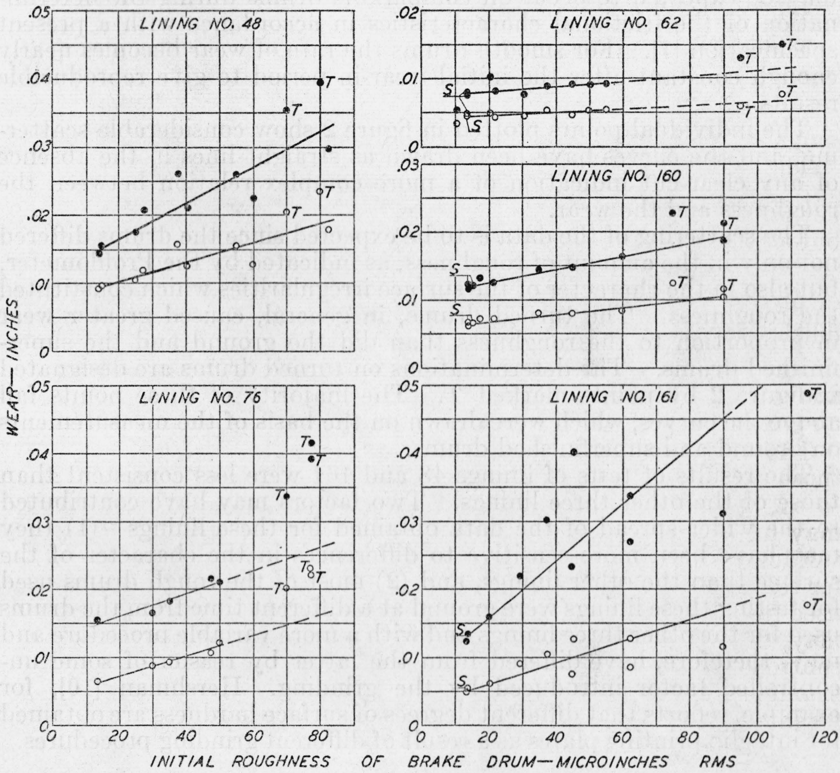

FIGURE 2.—*Relation between wear and the initial roughness of the drum.*

Solid circles represent the total wear at 3,000 stops. Open circles represent the wear between the 1,000th and 3,000th stop. Points marked *T* are from data for turned drums; those marked *S* from data for superfinished drums, and the remainder from data for ground drums.

of the wear to increase. This is borne out by the observation that the rate of wear for the tests of the other four linings, which were made on rough drums, decreased continuously throughout a test.

2. RELATION BETWEEN INITIAL ROUGHNESS OF DRUMS AND WEAR

Figure 1 gives a clear indication that the average rate of wear of linings increases with the initial roughness of the drums, since the majority of the curves fall in the order of increasing roughness. Figure 2, however, shows this relationship directly for the total wear and also for the sustained wear. As was mentioned previously, the total wear was taken as the wear which occurred during the first 3,000 stops. This number of stops was taken because it is approximately the number required in making the tests that have been established to determine the frictional characteristics of linings. A plot for 4,000 and for 5,000 stops similar to the plot for 3,000 stops in figure 2, as well as other methods of analyzing the data, apparently added nothing materially to the general picture.

The sustained wear was taken as the wear between the 1,000th and the 3,000th stop. This value is comparable with that which may be expected to occur on comparable drums during the determination of the frictional characteristics in accordance with a present specification [7]. For smooth drums the rate of wear becomes nearly enough constant after the initial wear-in period to give reproducible results.

The individual points plotted in figure 2 show considerable scattering, and the curves have been drawn as straight lines in the absence of any clear-cut indication of a more complex relation between the roughness and the wear.

The scattering of the data is to be expected since the drums differed not only in the amount of roughness, as indicated by the Profilometer, but also in the character of the surface irregularities which constituted the roughness. The turned drums, in general, caused greater wear in proportion to the roughness than did the ground and the superfinished drums. The determinations on turned drums are designated in figure 2 by points marked *T*. The majority of these points fall above the curves, which were drawn on the basis of the measurements on ground and superfinished drums.

The results of tests of linings 48 and 161 were less consistent than those of the other three linings. Two factors may have contributed to the wider spread of the data obtained for these linings—(1) they may have been more sensitive to differences in the character of the surface than the other linings, and (2) most of the rough drums used for testing these linings were ground at a different time from the drums used for the other three linings and with a more variable procedure and may, therefore, have differed from the latter by reason of some uncontrolled factor introduced by the grinding. Hershman [10], for example, reports that different degrees of surface hardness are obtained for intaglio printing plates as a result of different grinding procedures.

3. RELATION BETWEEN TYPES OF LININGS AND WEAR

A comparison of the curves in the five respective charts of figures 1 and 2 shows that the five types of brake linings tested have quite different wear characteristics. In general, lining 161 has a relatively high initial rate of wear and a relatively low sustained rate of wear while lining 48 has a relatively low initial rate of wear and a relatively high sustained rate of wear. The effect of roughness on the wear of the two woven linings, 76 and 161, is greater than it is on the three molded linings. The amount of wear for any one type of lining tested under given conditions is obviously dependent on the quality of the lining.

Considering only the tests made on smooth drums it appears that (1) the initial rate of wear is a function of the initial roughness and the type of lining, (2) for relative wear tests, the sustained rate of wear may be considered to be a function of the lining only, and (3) the total wear, which may be taken as an indication of the expected life of the lining when run against a newly finished drum, is a function of the lining and of the initial roughness of the drum. For tests made on rough drums, the sustained wear continues to be a function of the initial roughness until the rate of wear becomes constant.

4. SELECTION OF DRUMS FOR COMPARATIVE WEAR TESTS OF LININGS

The foregoing results indicate that the roughness of drums used for comparative wear tests should be carefully controlled and that the method of finishing should be specified. From the general knowledge of the properties of surfaces, it may be taken for granted that the composition of the drums, the method of manufacture, and similar factors should also be controlled as closely as possible.

The use of a relatively smooth drum is advantageous for comparative wear tests, because fewer stops are required before the straight-line portion of the wear curve is reached. Furthermore, the smoother the drums the more consistent the results. Another advantage is that when linings are tested on smooth drums, the condition of the drum is probably more nearly comparable to that of the majority of similar drums in service. Even when drums are placed on vehicles in a relatively rough condition, they are usually well smoothed-up long before the lining is worn out and if not they will in most cases be smooth for the replacement linings. A maximum value of 15 microinches rms, for the roughness of brake drums for wear tests, has been included in a recent revision of the Federal Specification for Brake Linings.

5. EFFECT OF ROUGHNESS OF DRUMS ON WEAR OF BRAKE LININGS IN SERVICE

The results presented here are in agreement with the practical observation that the smoother the drum the longer the brake linings will wear. The initial period of rapid wear would probably be less in service than in these tests, because the ratio of lining area to drum area is about five times as great on actual brakes as on the test machine and the larger area of lining would smooth the drum faster. The results indicate, however, that where very rough drums are used a set of linings may be completely worn out, even in service, before the rate of wear becomes constant.

6. RELATION OF COEFFICIENT OF FRICTION TO ROUGHNESS OF DRUMS

Measurements of the coefficient of friction of the linings on the drums were made during the wear tests by the procedure indicated in the previously mentioned description of the machine. The results indicate that the rougher the drum the lower the coefficient of friction. The magnitude of the effect, however, is small compared with that of other factors which affect the coefficient of friction.

In order to establish any quantitative relation between roughness and coefficient of friction, it appears that (1) a great many more data would be required or (2) the test conditions would have to be controlled more closely.

IV. CONCLUSIONS

1. The rate of wear of brake lining is an increasing function of the roughness of the brake drum.

2. The relation between the roughness of drums and the wear of brake linings is a function of the type and quality of the linings. In general this function may be summarized as follows: (1) The ratio of wear to roughness seems to be greatest for woven linings and least for dense, resilient molded linings; (2) the initial rate of wear is greater for woven linings than for molded linings; (3) for tests made on smooth drums the sustained rate of wear is practically constant for a given type and quality of lining.

3. A drum of specified type and finish with a roughness of 15 microinches rms or less is recommended for relative wear tests. The advantages of such a drum are that (1) results can be more easily reproduced, (2) less time is required to make a test which will be truly indicative of the life of the lining, (3) the sustained wear ceases to be a function of the initial roughness or the number of stops and may be considered to be a function of the lining only.

4. The roughness of the drum has a slight effect on the coefficient of friction which for practical purposes may be neglected.

5. The effect of the roughness of brake drums on the wear of linings is probably less in service than on the test machine.

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WASHINGTON, August 1, 1941.