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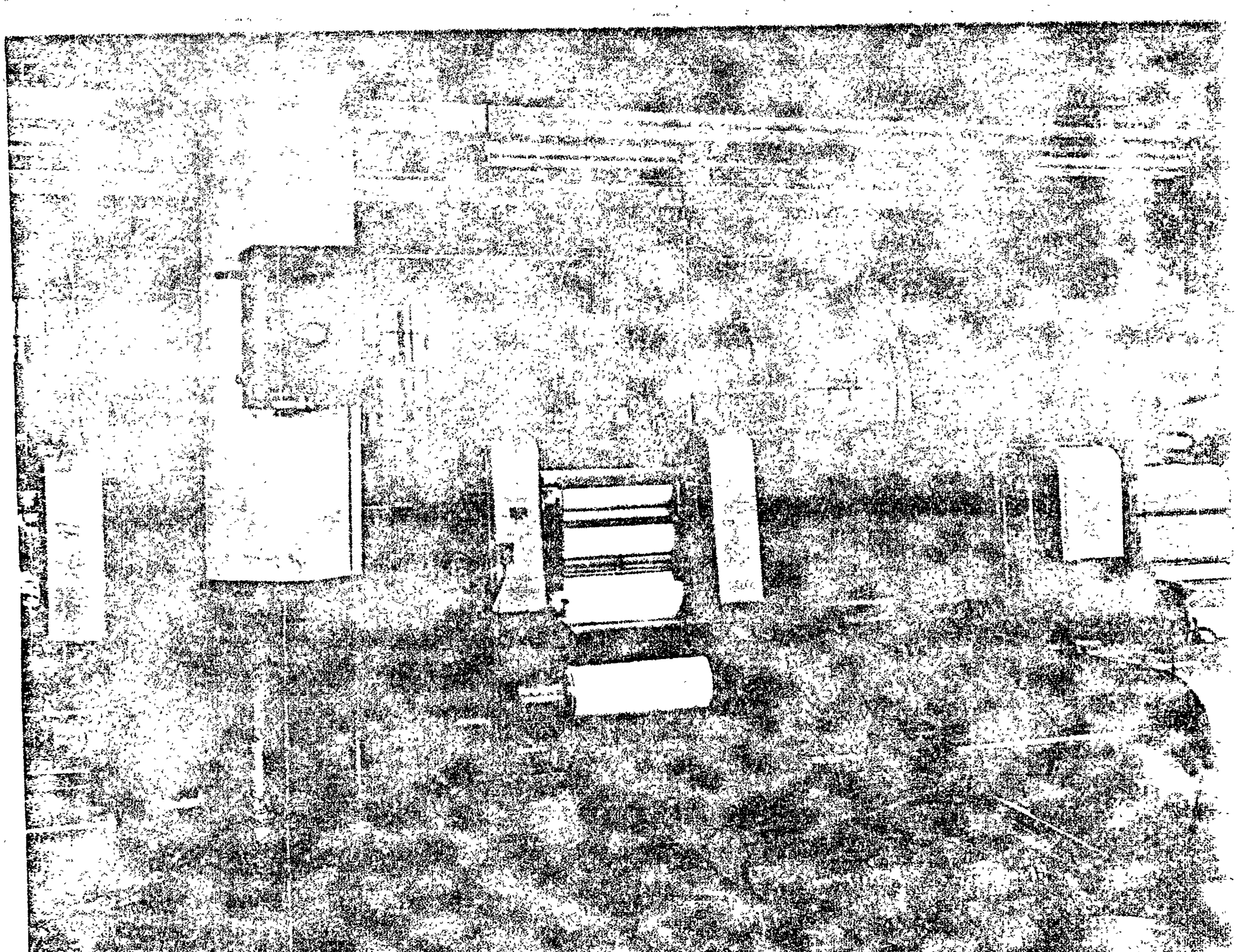

In this issue: **PLASTIC RESINS AS PROTECTIVE COATINGS**

Friction Brake Linings
Types, Uses and Design Data

Six general types of brake linings are described briefly; some applications of the types are mentioned and illustrated; and the use of coefficients of friction, brake band or drum temperatures and wear data in selecting a lining during the design of brakes is discussed. The performance basis of selecting a lining in automobile service is explained.

BRAKE LININGS can be classified as (1) woven, (2) fabric, (3) dry mixed, (4) wire back, (5) extruded and (6) sheeter type. None of the types meets all the requirements for linings in today's brakes. Each type, though adaptable to a wide variety of operating conditions, has to be designed to function with the other members of the brake, particularly the shoe and the drum, if good performance would be assured.

Woven Linings are one of the oldest types. In construction, this type is a solid tape, woven from asbestos and cotton yarn having a wire core. A soft brass wire is generally used in the core but alloy wires of lead and zinc are also common. The tape is impregnated with oils and heat-resisting compounds, cured by baking, and formed to size between rolls. Linseed oil, thermal setting resins, gilsonite, artificial asphalts, rubber cement, mineral oils, pitches and coal tars are some of the other constituents of brake linings.

Fabric Linings, also one of the oldest types, have a cloth base. The cloth is woven from asbestos and cotton covered wire. Pieces of the cloth 40 to 60 in. wide and a 100 yd. or more in length are common. After dipping in a light impregnating fluid, the cloth is passed between heated rolls where rubber or Buna S friction compounds are pressed into the spaces of the fabric. Brake linings of the fabric type are made of layers of the cloth, which can be built up by successive layers of equal width, by folding pieces of the cloth one or more times and by rolls that can be cut in segments. The lining is compressed during curing at pressures around 2,000 lb. per sq. in., which causes the built-up thickness to diminish by 25 percent. A curing temperature of 300 deg. F. or slightly higher is customary.

Dry Mixed Linings are so named because the materials composing them are mixed in the dry state. The rubber and cotton ingredients are finely pulverized. Short asbestos fiber, almost a powder, is used. Sulphur, thermal setting resins and drying compounds are added in the powdered state. The thoroughly mixed materials are placed in a press under pressure of the magnitude of 2,000 lb. per sq. in. and heated. The heat softens the binder compounds. Continued heat and pressure harden the material, which upon cooling can be removed from the press in finished form. Generally the material is cooled and removed from the press in an uncured state, cut to size and cured in heated molds.

Wire Back Linings contain a wire screen as reinforcement. The wire screen can be readily built into dry mixed, wet mixed and dough mixed linings. One method of applying the friction materials to the screen uses a pair of heated rolls of unequal diameters. The wire screen passes over the larger roll. The friction materials flow from a hopper to keep filled the space between the rolls as they revolve together. The lining in the pliable state is cut to size and cured in molds.

Extruded Linings get the name from the process of molding them. Wet mixed materials can be fed into the hopper of a standard extruding machine where they are forced by the revolving spiral blade through an orifice, which forms them to the desired width and thickness. A hydraulic ram is an

Fig. 1—An inertia brake dynamometer is often used in testing airplane wheel brakes under simulated landing conditions.
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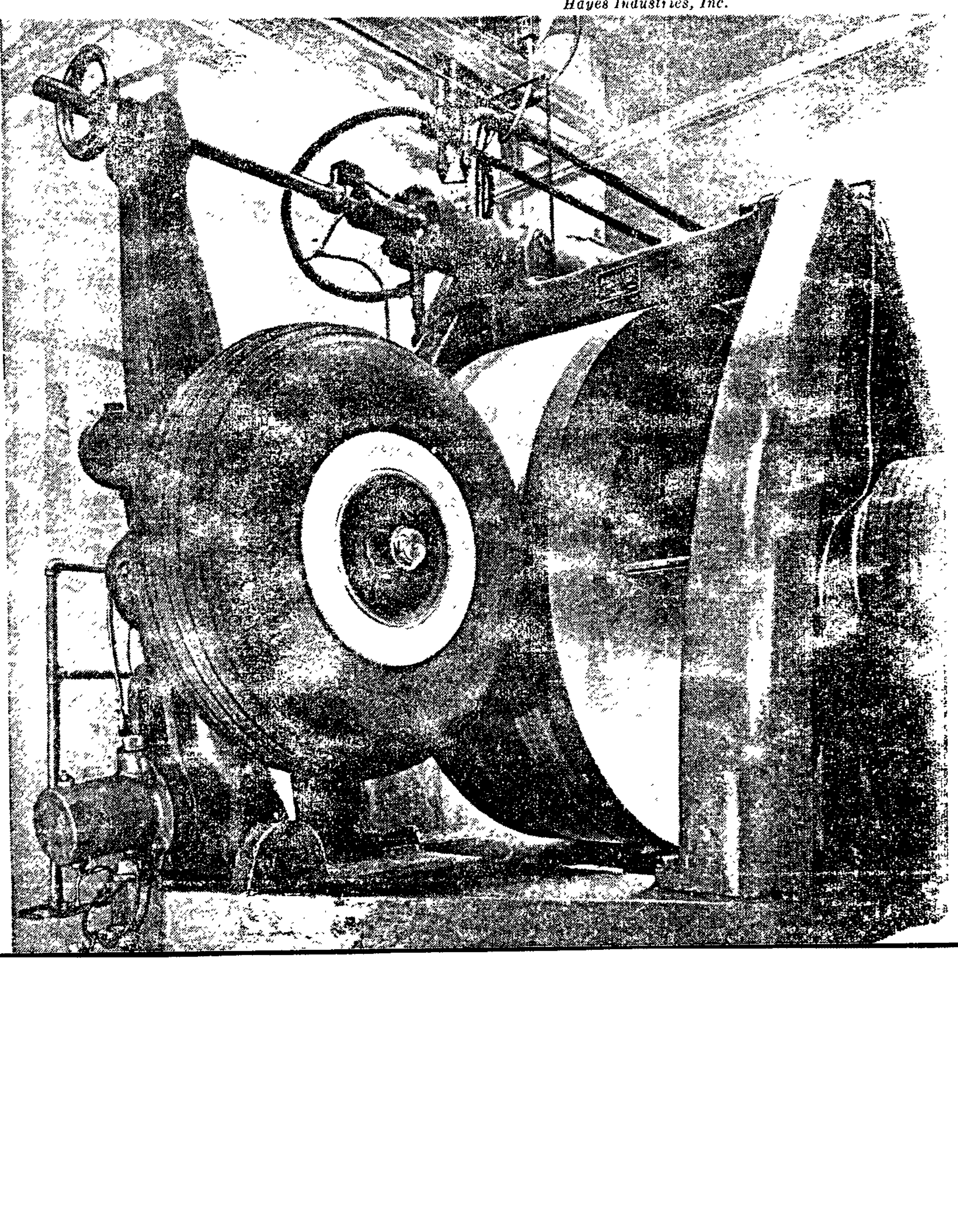

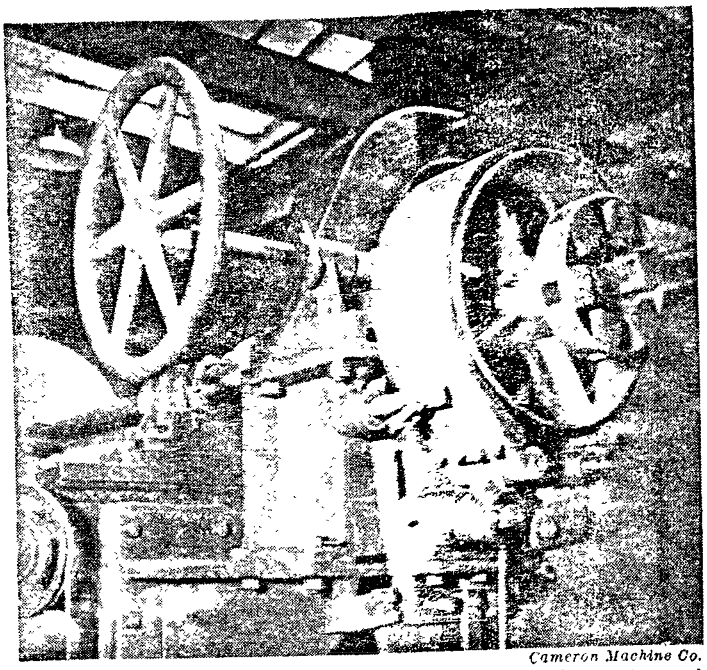

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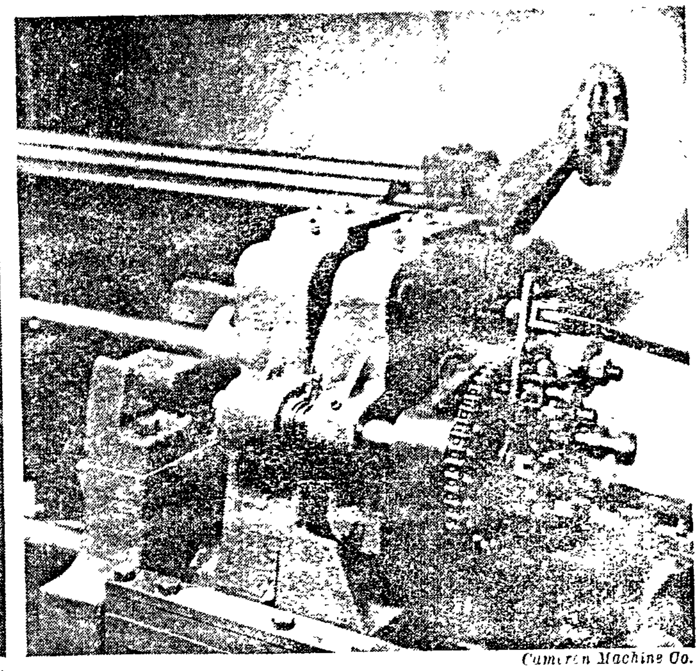

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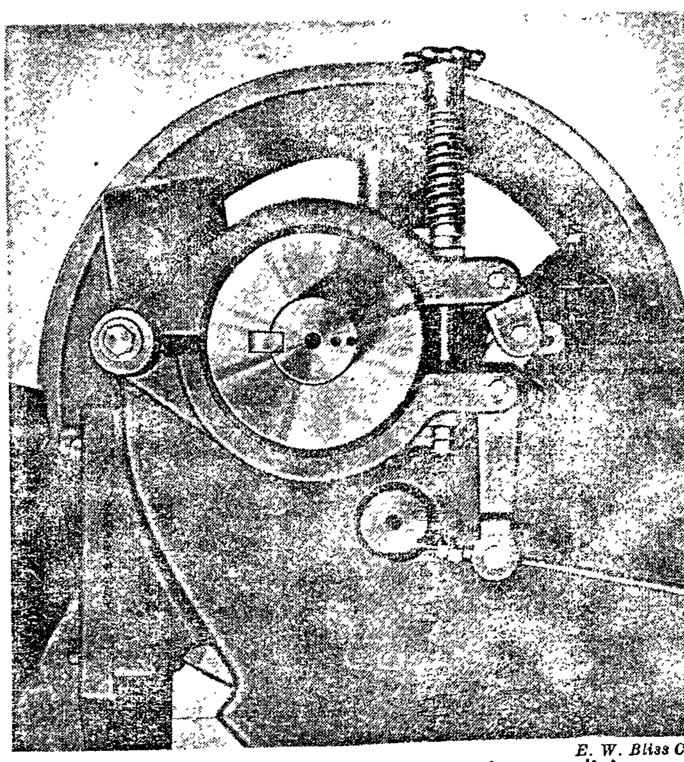
Fig. 2—A heavy duty woven lining is used on band brakes of paper winding machines.
Fig. 3—Woven linings are also used on the disk brakes of paper machinery.



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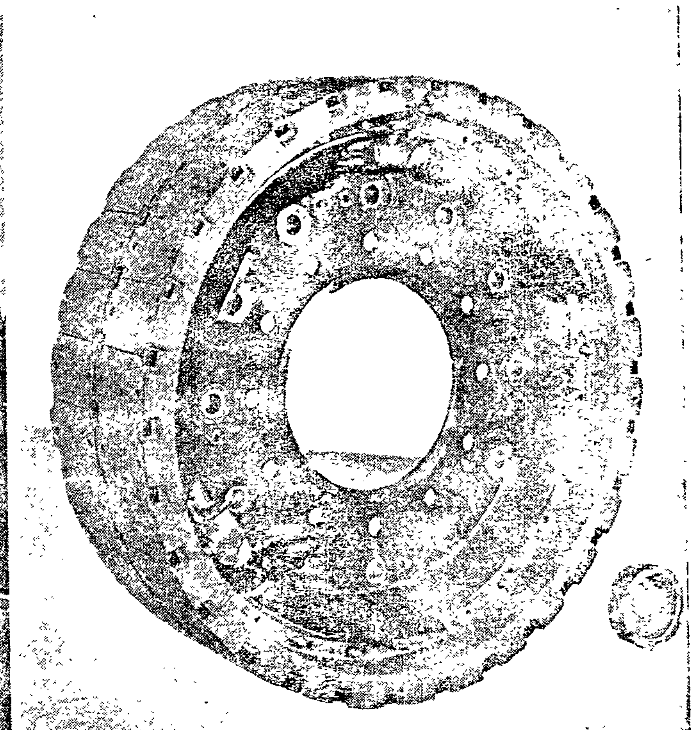

Hayes Industries, Inc.

Fig. 4—Fabric and woven linings are used on the band brakes of presses.
Fig. 5—Blocks of molded lining are used on expander-tube brakes of aircraft wheels.

alternate method of forcing the wet materials through the orifice. The extruded material is deposited on a slowly moving belt. Wire can be pressed into the partially dried lining at this stage if desired. The lining is then cut to size and cured.

SHEETER LINING is made on a "sheeter" machine, which is a modified rubber mill. The larger roll, which is 3 to 5 ft. in diameter and 10 to 15 ft. long, is heated. Mixed material is fed into the opening between them. The material clings to the heated roll. The thickness between the rolls is increased as material accumulates on the heated roll until the desired lining thickness is attained. Then the sheet is slit, removed from the roll, cut to size and cured.

The different types of linings are available in a great variety of styles, sizes, thicknesses, shapes and coefficients of friction. These data are available in lining manufacturers' catalogs, to which the designer is referred because they are too voluminous for coverage here. Friction blocks differ mainly from the other molded linings in that they are thicker, wider, and shorter.

General Application

Woven linings are widely used on the contracting members of external band brakes. The brakes of hoists, cranes, presses, winches, tractors and oil-drilling machinery are familiar examples. One reason for the choice of woven linings on band breaks is the flexibility of the woven type of construction. The lining bends with the band without cracking. The flexibility allows the lining to adjust itself to irregularities in both the drum and the band, thereby attaining gradual engagement of the rubbing surfaces over large areas.

Another reason is the high coefficient of friction. Asbestos fiber, which constitutes from 50 to 80 percent of the volume, is a high friction material. It is a hard material too, being harder than the drum in some instances. The harder compounds, such as iron oxide, emery, cement and others, which are sometimes found in linings, can also be incorporated into woven linings.

A heavy duty woven lining is used on the band brake of the paper winder, Fig. 2. Fig. 3 shows a water-cooled disk brake having a woven lining. The lining is secured to both sides of the rotating steel disk, which is compressed between the water-cooled jackets during braking action.

Woven linings have been relegated to a secondary place in the automobile industry. They are used still on propeller shaft brakes and on some light types of war vehicles that are designed for operation in mud, sand and dirt.

The fabric linings are used on many industrial applications in types of service similar to those for woven linings. Fig. 4 shows an external band brake on a press. The purpose of the brake is twofold: It arrests the upward movement of the ram at the top of the stroke; it keeps the ram from descending except when tripped for a working stroke.

Fabric linings are used also on the expanding shoes of internal brakes. They are used to some extent on trucks and on war vehicles where operation in mud and grit are encountered. Fabric linings can be designed to have a wide range of friction coefficients and as either semi-flexible or rigid linings. They contain lower asbestos content than woven linings and consequently are easier on brake drums.

The dry mixed, wire back and extruded types, often designated collectively as molded linings, find wide application in automobile passenger cars. The wire back type is used on many trucks; the block type is common on the heavier trucks and on buses of medium and large sizes.

Molded linings can be designed with friction coefficients in the high, medium or low ranges, but linings in the medium friction range are the most frequent. Molded linings are dense, hard and rigid. The dough-mixed wireback type are slightly the more porous and have a little flexibility. All molded types should be ground to fit both the drums and the shoes.

Airplane wheel brakes of the expander-tube type carry thin blocks of molded lining; the disk type of wheel uses segments. Fig. 5 shows the friction blocks assembled on a large expander-tube type of wheel. The torque lugs in the frame not only position the brake blocks but also prevent them from rotating.

The disk-type railroad-car brake uses a molded block. Fig. 6 is a recent development in a small motor brake. The drum is a molded friction material. The brake band, when the motor switch is shut off, grips the drum from either direction of rotation, the motor being reversible.

Coefficients of Friction

Manufacturers and suppliers of brake linings describe linings as having high, medium and low coefficients of friction, frequently without designating a numerical range of the three classifications. Linings having friction values of 0.40, 0.30 and 0.20 are generally recognized as belonging respectively to the three ranges. Although opinions differ over boundaries of the three ranges, the values 0.35 and 0.25 represent convenient limits between them. Thus 0.30 plus or minus 0.05 would establish a range within which a medium friction material could reasonably be expected to fall.

Although manufacturers of brake linings are reluctant to limit themselves to a range of this magnitude, they have developed friction materials to the point where a designer can specify such a range of friction coefficients, supplemented by the conditions of the brake tests and service, and reasonably expect the manufacturers to furnish a product to meet the requirements. The importance of designing the band or the drum, whichever is the other member of the rubbing pair, to suit the brake lining should not be overlooked.

Temperature of Operation

Changes in temperature affect the behavior of a brake lining perhaps more than any other single condition, despite the fact that measurements of temperature are seldom made. Friction brakes convert energy of motion, usually rotation, into heat energy. The band or drum absorbs and dissipates the heat. The friction material absorbs practically none of the heat, but its surface temperature approximates that of the contacting band. Incandescence can be observed along the contacting edges under severe braking action.

Any lining subjected to braking action beyond its capacity will either disintegrate and fade or build-up and wear rapidly. Linings can disintegrate through softening and pulverizing of the bonding constituents. Vulcanized rubber softens at 300 deg. F. and thermal setting resins begins to carbonize at 600 deg. F. Asbestos fiber begins to lose water of crystallization at 700 deg. F. At 1,200 deg. F. all the water of crystallization is driven off, the fibers are close to glowing, and when cooled,

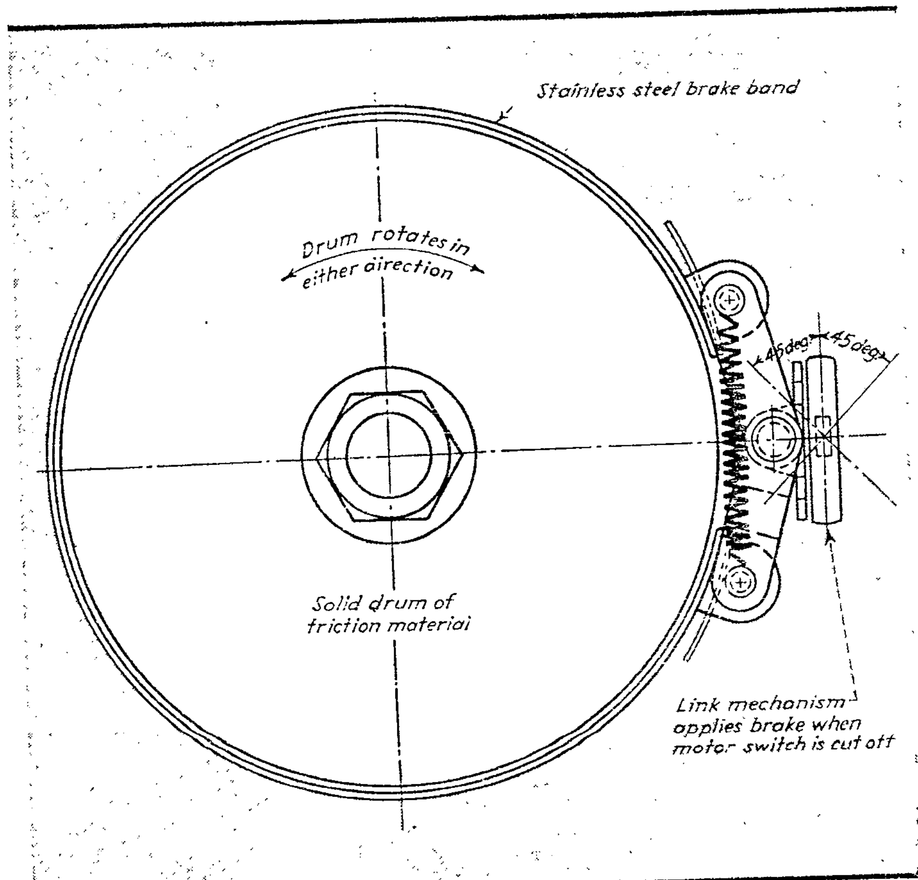

Fig. 6—A recent design of a small motor brake in which the drum is a wheel of molded friction material and the rubbing surface is a flexible band of steel.

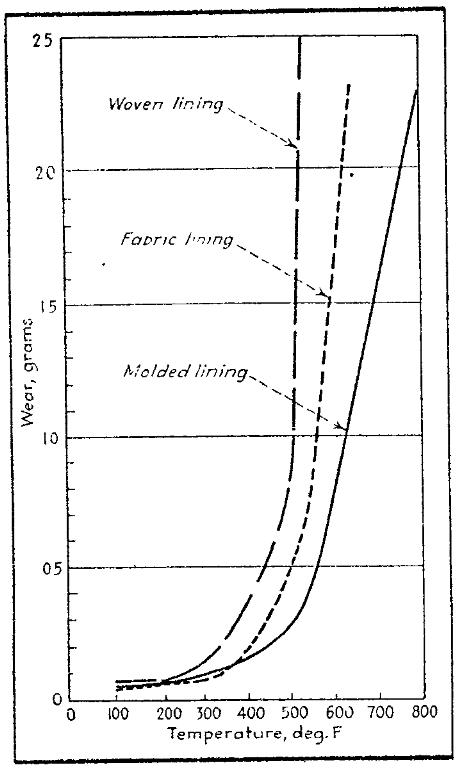

Fig. 7 — Curves showing the relative wear of lining materials at different temperatures.

the asbestos has been reduced to a fine white powder.

A lining is said to fade when its coefficient of friction diminishes under braking action. Sometimes the fade during a single application of the brake is meant; at other times the word denotes the falling off of brake effectiveness upon successive applications of the brake.

If the coefficient of friction increases when the brake is applied, the lining is said to build-up. Some linings soften and become sticky at moderate temperatures to exhibit an increase in friction coefficient. Abrasive action of either rubbing surface on the other hand also can cause build-up. Generally abrasive action is undesirable because the rapid wear associated with it shortens the life of the lining.

The curves of Fig. 7 indicate the relative wear of linings at different temperatures. They were drawn from data obtained from laboratory tests in which the wear was measured at constant temperature. Since brakes seldom operate at constant temperatures, the curves have little design significance; nevertheless they serve as a warning concerning what happens to brake linings if brakes are operated at high temperatures for prolonged periods.

Selecting a Brake Lining

The specification or selection of a lining in the design of a brake is not a simple matter. Long life and constant friction are incompatible with elevated temperatures of operation; hence brake designs represent compromises. As a consequence the selection of the lining is based on that condition of greatest moment in the predicted or known service of the lining. For example, some brakes must function in grease or oil. It would be folly not to place this condition foremost in designing the brake.

The coefficient of friction, the maximum temperature attained during braking service and empirical data often guide the designer through the drawing board stages of the design. Important brakes are proved under actual service conditions before the design is considered closed.

Whenever the coefficient of friction is used in computations, the values at the limits of the range are preferred to the mean value. The coefficient of friction is bound to fluctuate under service conditions and the effect of fluctuations should be studied and allowed for in the brake design. Brakes to absorb moderate or large amounts of energy seldom are designed on a basis of the coefficient of friction alone. Small brakes and brakes that prevent movement, but do not arrest motion, can be. Such brakes may be larger than necessary.

In calculations to determine temperature rises, all the energy of the arrested motion is treated as being converted into heat. Heat is dissipated while stoppage of the motion is in progress. Ten percent represents an average estimate of the amount of heat dissipated during generation so that 90 percent of the energy accumulates momentarily in the drum or band. The corresponding rise in drum temperature can be computed.

As an example suppose 6,000 ft.-lb. of energy is absorbed per sq. in. of swept area in an airplane wheel brake. This is the equivalent of 6,000/778 or 7.7 B.t.u. per sq. in. The disk is 5/16 in. thick and both sides are rubbing surfaces. Assuming ten per cent of the heat is dissipated immediately, 13.8 B.t.u would be stored in a 5/16 cu. in of the metal at the end of braking action. A temperature rise of about 1,300 deg. F. would be attained in a steel disk.

The amount of heat generated in stopping a 3,000 lb. automobile from 60 m.p.h. at a deceleration of 20 ft. per sec. per sec. is about 475 B.t.u. This is enough heat to raise the temperature of an ordinary 5/32 in. drum about 300 deg. F. A 3/16 in. drum would undergo a rise in temperature of 240 deg. F. upon absorbing an equal quantity of heat.

The two examples illustrate in a quantitative way the manner of using drum temperatures in computations. A comparison of some of the conditions of operation in the two kinds of service shows why the higher temperatures are tolerated in the brakes of airplane wheels. The brakes in automobiles are used oftener than those on aircraft; automobile brakes would be unsatisfactory to the customer if the linings wore as fast. Automobile brakes need greater reserve capacity because the forecasts of maximum brake loads are less reliable and also because they are more likely to be used while already hot from previous braking action.

Some linings will stand higher temperatures than others. Table I contains drum temperatures that apply to average specimens of the various types of linings. The data are suitable for design calculations. They should be confirmed by data from lining manufacturers in the final selection of the lining.

Many brake designs are based on empirical data. In the automobile industry for example, rules like 20 lb. of car weigh per sq. in. of lining are criticized because too few of the factors, such as speed, weight, deceleration, operating temperatures and others, are reflected in them. The rule of ½ hp. per sq. in. of brake lining contains more of the factors, but operating temperature is not among them. Some simple method of determining and evaluating the rates of heat generation and dissipation would be a great help in brake design.

Deceleration-Pedal-Pressure Tests

Automobile manufacturers buy brake linings on a performance basis. Fig. 8 is a typical performance specification. The

Table I—Drum Temperatures Suitable for Different Types of Linings

Type of lining	Drum temperature after normal brake service, deg. F.	Maximum drum temperature, deg. F.
Woven	300	500
Woven, heavy duty	450	750
Fabric	350	600
Dry mixed	450	750
Dry mixed blocks, heavy duty	700	1,100
Wire back, dough mixed	300	500
Extruded	400	700
Sheeter	400	700

Table II — Time in Seconds to Stop Inertia Dynamometer Wheel During Fade and Recovery Test

Stop No.	Fade, sec.	Recovery, sec.
1	8.2	13 6
2	9 4	12 6
3	11.0	14.0
4	13.0	16 0
5	14 0	19 0
6	13 2	21.2
7	14 0	19 0
8	14 0	18 0
9	14 0	20 0
10	14 6	20.2

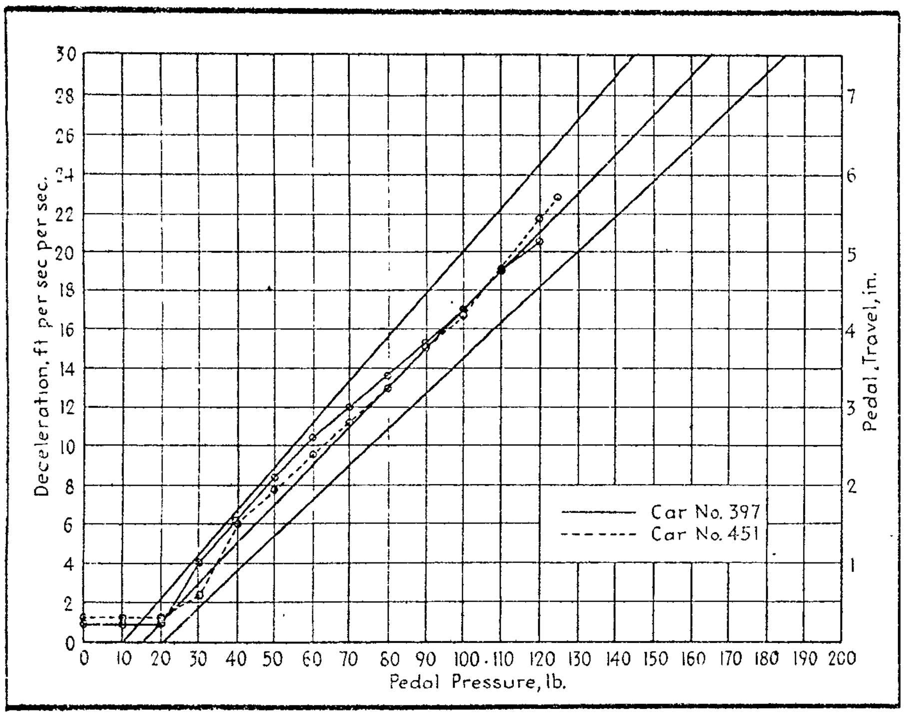

Fig. 8—Typical deceleration-pedal pressure performance of automobile brakes.

lines establish limits on the effectiveness of the entire braking system. The mean slope of the lines is determined by the coefficient of friction of the lining, and fluctuations in the coefficient of friction are a major cause for departures of test results from the mean slope. The two curves within the limit lines, Fig. 8, represent tests of specimens of the same lining in two passenger vehicles. The tests were made from an initial speed of 50 m p.h. It is customary to make such tests from two and sometimes from three speeds.

The pedal pressure required to overcome the retracting springs in both cars was 20 lb. as indicated by the horizontal portions of the test curves, Fig. 8. The resultant deceleration from bearing friction, wind resistance and other items was slightly less than one ft. per sec. per sec. for the test in car No. 397 and a little more than one ft. per sec. per sec. for the other car.

Frequent attempts have been made to devise laboratory tests that would prove a brake lining for automobile service. Dynamometer tests provide a good index on lining performance; nevertheless the industry generally admits that road testing in test cars is still necessary.

Lining fade, its property to recover after fade, deceleration curves, lining build-up and wear tests are among the qualities that can be determined by inertia dynamometer tests. Table II contains data from a fade and recovery test. The fade test was conducted in the following manner. The inertia wheel, weighted proportionally to a fully loaded automobile, was brought up to a speed equivalent to 50 m.p.h. and then stopped by the brake. The time in sec. to stop the loaded rotating wheel was 8.2 sec. Twenty-five sec. later the wheel was stopped again from the same speed in 9.4 sec. and so on for ten stops. The lining was cold at the beginning of the test. The pressure on the brake was kept constant through out all stops so that the increase in the time of stopping the rotating wheel is indicative of lining fade.

The recovery test started 72 sec. after the tenth stop and from the same speed, i.e. the equivalent of 50 m.p h. The time required to stop the wheel was 13.6 sec., which is less than 14.6 of the tenth stop and indicates a recovery of nearly 16 per cent of the frictional loss. Further recovery takes place during the second 72-sec. interval. As noted from the times in sec., Table II, the lining exhibits a wavering fade and recovery during the other eight stops.

Some investigators measure wear as diminished thickness of the lining before and after a specified number of stops; others by the loss of weight. Still others prefer to measure wear in units that are indicative of the amount of energy absorbed, such as oz. per million ft.-lb. or cu. in. per hp.-hr. Ease of measurement is one reason why the different methods are in use. The change in weight of a lining mounted in some brakes is readily obtained whereas dismounting of the lining might be required to measure the change in thickness. On the contrary the change in thickness is sometimes easier to get than the change in weight. Changes in weight can easily be converted into average changes in thickness if the density of the lining is known.

The effect of temperature on lining wear has already been mentioned. The metal against which the lining rubs is another factor that influences wear. Steel and cast iron normally cause about the same amount of wear of the friction element, although steel is more likely to score under severe service and as a consequence cause the lining to wear faster. On the other hand a comparison between the rates of lining wear against steel and aluminum show a marked difference. Bronze and other alloys also exhibit differences in rates of wear of the friction material.

Normally a friction material that wears little is desired. Yet, brake effectiveness may be impaired through a glazing of the friction surface if the lining does not wear at all. Fig. 9 is a wear curve obtained from dynamometer tests. The wear is nearly constant. The more rapid wear at the beginning of the test is characteristic of some linings.

Editor's Note: The assistance and the contributions of matter for this article from more than thirty lining manufacturers, machine builders and makers of automobile and aircraft-wheel brakes are gratefully acknowledged.

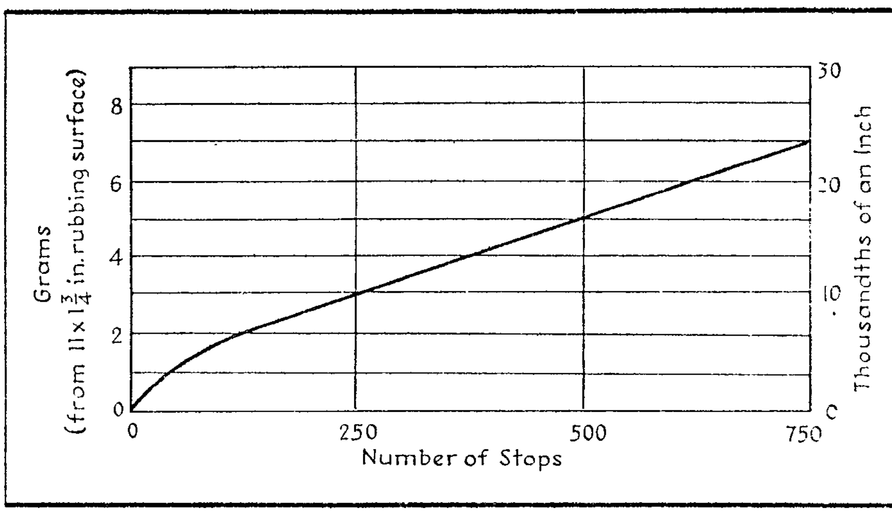

Fig. 9—Typical wear curve, data for which were taken from dynamometer tests of a wire-back medium-friction lining for automobile passenger cars.