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Brakes & Braking

Discussion of Sintered metallic linings

WHAT'S NEW IN BRAKE LININGS

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WHAT'S NEW IN BRAKE LININGS

INTRODUCTION

The development of brake linings capable of meeting all the requirements of the progressive American passenger cars is one of the most pressing problems of automotive engineering. Great effort is expended annually by the automobile industry to develop the most effective braking systems possible. It is in the development of improved linings that perhaps the greatest effort is being made. Millions of dollars are spent on experimental engineering, and millions of miles of brakes tests are made each year to produce efficient, dependable brake linings.

There are numerous brake designs currently being carried on in the industry, both here and abroad. These engineering designs cover disc type, band type, water-cooled and oil-immersed brake systems. However, regardless of the brake design under discussion, a review of friction materials today is essentially a study of two linings -- the organic type and the metallic type. It is the intention of this paper, therefore, to restrict its subject matter to these two basic lining materials.

To be acceptable to the automobile manufacturers, present day linings must have the following characteristics:

1. Wearing ability. Without sacrificing any other attributes, a brake lining must have a low wear rate.

2. Minimal friction variations. Brake linings must have a high coefficient of friction that is equal at all four wheels and consistent on all cars to prevent pull, "grabbiness" or other erratic braking conditions.

3. Resistance to high temperature and fading. Linings must be capable of withstanding and dissipating heat to prevent brake fade, which is a temporary reduction of brake effectiveness resulting from heat, and linings must have adequate mechanical strength through all operating temperatures.

4. Lining surface must be compatible with mating surface to prevent galling, excessive wear or heat checking of the drums.

5. Consistency of performance in all braking systems. The majority of cars are still equipped with unassisted braking systems. Therefore, brake linings must engage smoothly with low effort and operate effectively with both standard and power brakes.

6. Quietness of operation. Quietly operating brakes are an important comfort factor in passenger cars, therefore, lining and drum engagement sounds must stay below the audible level.

7. Low cost. In this era of cost-conscious engineering, it is essential that the expenditures for brake lining fabrication and warranty servicing be controlled.

The compounding of friction materials that successfully meet all these requirements is the specialty of some of the anonymous heroes of the automotive industry. The uninitiated might think that, with a stable brake design and evaluation reduced to simple terms, the friction material compounder's job would be routine. This is far from the case. The many influences on brake performance, resulting from variations in vehicle weights, climates, road conditions, vehicle equipment and driving habits, make the engineering of brake lining friction materials a most challenging assignment, and a highly secretive operation. The formula of a brake lining is the well-guarded secret of the supplier, while other brake components are used commonly throughout the industry.

BASIC DRUM AND SHOE BRAKE DESIGNS

For purposes of clarity, all data presented herein applies to a drum and shoe brake of the duo-servo type. (Fig. 1) The two other drum and shoe brake designs generally employed are the two leading shoe type and two trailing shoe type. (Fig. 1) There is also a one leading one trailing shoe type in general use which is not shown.

ORGANIC BRAKE LININGS

All American passenger cars use organic brake linings. There are two organic linings which are classified by their method of fabrication. Organic dry mix is basically a gray-white compound of asbestos, filler materials and powdered resins which is thoroughly mixed, preformed to shape, and placed under heat and pressure until it forms a hard, slate-like board. Then it is cut and bent into individual arcuate segments and attached to the shoe.

Organic wet mix is a compound of asbestos, organic fillers and liquid resins that has a gray-brown color when blended. The compound is processed by any of several different methods which include high pressure extruding, screw extruding, calendering and other processes. Figure 2 shows a step in the high pressure extruding process. The extruded lining is being removed from a die that has formed it into a long slab that will be compressed to a uniform density under heat and pressure.

Organic linings are generally composed of six basic ingredients. Asbestos, with its high heat resistance and high coefficient of friction in contact with iron and steel, is the basic material.

Friction modifiers, such as the oil of the cashew nut shell, give linings desired friction qualities.

Fillers are a wide variety of materials, such as rubber scrap, which are added to linings to control noise, wear or other brake characteristics.

Curing agents and/or accelerators are added to a lining compound to produce required chemical reactions in the ingredients.

Materials for special effects are added to compounds to improve overall braking performance. They include powdered lead, brass chips and aluminum powders.

Binders, which are predominantly phenolic resins, hold all the other ingredients together and are selected to govern the physical strength of the material at high temperatures.

Organic brake linings have several distinct and important characteristics, regardless of how they are compounded:

1. The fabricating cost is low in general.
2. A high initial friction is inherent with organic linings, along with a light pedal effort which hardens with usage.
3. They vary only slightly in effectiveness with speed.
4. They show a moderate change in effectiveness with temperature.
5. Organics do not have a build-up at end of stops.
6. They protect themselves from heat damage by fading at high temperatures.
7. Organic linings do not require extremely smooth lining facing or drum finishes (60-150 micro-inch range permissible on drums), but organic surfaces are sensitive to moisture and contaminants.

METALLIC BRAKE LININGS

The other lining compound under wide development is the sintered metallic type. Metallic linings represent the most important new development in brake lining.

Metallic linings are composed of finely powdered iron or copper, graphite and lesser amounts of inorganic fillers and friction modifiers.

The dry powders are accurately weighed, placed in a sifter in a specific order, and mixed in a tumbling cone type blender for 30 to 50 minutes. A lubricating oil is added to prevent segregation of the individual ingredients which are of different sizes and densities.

The powders are then put through a briquetting process in which the backing and friction material powders are compressed between a punch and a stripper to form the lining. In the first step, the stripper is lowered slightly and the powder that forms the backing of the lining is poured into a cavity as shown in the schematic drawing in Figure 3. The stripper is lowered again and the lining facing powder is poured into the cavity. Then the powders are compacted under high pressures. During the briquetting stroke the two layers of powder are pressed into an integral unit with green strength. The briquettes then are automatically conveyed into a furnace and sintered in temperatures well over a 1000°F. The furnace creates exothermic atmosphere generated from 1000 BTU natural gas that protects linings from oxidation. This heat treatment forms sintered bonds between particles that give linings great strength and durability. The manufacture of metallic linings is highly automatic, a fact that will lead to more competitive pricing as production increases.

Present day metallic linings have several distinct and important characteristics:

1. In comparison with organic linings, the metallics are relatively high cost. At present the cost factor is one reason the application of metallic linings is restricted to the "heat-problem" brakes.

2. Metallic linings have a low initial friction, and a resultant hard pedal that lightens with usage.

3. They have reduced effectiveness at low speeds and temperatures.

4. They are extremely heat and fade resistant.

5. Only slight roughness is detectable at high speeds with metallics.

6. Metallics are not affected by wetness.

7. They do require a smooth facing grind and drum finish. The metallic lining brake drum has a mirror-like finish with a uniformity of surface that is required to assure stability of braking.

The compounder must select the exact combination of ingredients from hundreds of possibilities to produce linings that have all the required characteristics. His success is measured by the manner in which his linings stand up under a battery of tests.

LABORATORY TESTING OF BRAKE LININGS

To complete the comparison of organic and metallic linings, it is necessary to evaluate the performance characteristics of both types as established by the wide range of laboratory and road tests being conducted by the automotive industry. Laboratory testing provides fast, low-cost evaluation of the wide range of linings developed annually. Over 1500 compounds of various metallic combinations already have been developed by one manufacturer and organic lining compounds run into the thousands.

The Chase machine shown in Fig. 4 is invaluable in quickly comparing friction materials for durability, wear, and the effects of temperature on friction and wear characteristics. The Chase machine consists of a heavy iron brake drum that is rotated by a variable speed motor and magnetic clutch assembly. A specimen of friction material is held against the drum by dead weights. Instruments record all test results.

The curves in Fig. 5 indicate the basic differences between metallic and organic linings throughout their rise in temperatures caused by their own friction plus external heat applied to the drum within the Chase machine. The friction co-ordinate is shown at left, drum temperature at the right and time at the bottom of the chart. The organic lining curve shows some increase in friction up to about 850° and then a rapid fade out. The metallic lining curve indicates a constant, lower friction that increases at high temperatures. Metallic lining drum temperature goes higher than the organic.

Dynamometers of the type in Fig. 6 provide an excellent evaluation of a brake on an accelerated laboratory schedule of tests including effectiveness, fade, recovery, durability, drum score and odor. The dynamometer duplicates the energy load of the automobile.

Only linings that prove worthy in the laboratory receive further testing.

ROAD TESTING OF BRAKE LININGS

As is true of all automotive development, the vehicle itself must produce the final verification of laboratory brake findings. Large fleets of vehicles and numerous engineering personnel are continually engaged in brake development and testing operations (Fig. 7). Tests of every type of Chevrolet brakes totaled 1,680,000 miles from October 1957 to October 1958.

The results of brake road tests described herein apply to organic lining bonded to the shoes, as contrasted to the riveted type, both of which are shown in Fig. 8.

Tests on metallic linings apply to the type shown in Fig. 9, with the lining riveted to the shoes in segments. The metallic segments on the shoe are flexible in their application in that they can be varied in number, position on shoe or material formula to produce the braking effort desired.

The ultimate structure of all linings is determined by test. A brake lining material that has progressed from laboratory to road testing first undergoes a "general feel" test. Brake development engineers try the facings for an overall impression.

If the findings are good, an effectiveness test is made. The 50 and 80 mph brake deceleration test results shown in Fig. 10 depict the effectiveness of high speed emergency stops with organic and metallic linings. This test requires the use of a load applicator, decelerometer and recording unit. Load is applied to the brake pedal automatically and the recording unit indicates pedal load, deceleration, pedal travel and time required to make test stops. The 50 and 80 mph brake deceleration curves show the brake effectiveness of the organic and metallic linings. The rate of load application on the brake pedal to obtain the curves is 30 pounds per second and each curve represents a single stop. The curves reveal that the organic material is less speed sensitive and more effective in this test. It should be pointed out that the metallic lining curves are those in which the brakes were cool at the start of the stop. For the organic lining, the pedal load required at a deceleration rate of 20 feet per second per second from 50 mph is 80 pounds, and from 80 mph is 118 pounds. Under the same conditions for metallic lining, the pedal load from 50 mph is 103 pounds, and from 80 mph is 165 pounds.

If linings perform well in the effectiveness test, they are subjected to the fade test. The chart in Fig. 11 illustrates a brake fade test comparison of organic and metallic linings. Line pressure is indicated by the co-ordinate at the left and stop numbers at the bottom of the chart. The stops were made from 60 mph at 15 feet per second per second deceleration. The interval between fade stops was 4-tenths of a mile, or about 40 seconds. Initial feel and recovery stops were made from 40 mph at 6 feet per second per second at one mile intervals. The organic curve shows a slightly decreasing initial to final line pressure during the first three stops with each successive stop becoming harder. This is indicated by the shaded distance between the broken and solid line curves. By the 4th stop the line pressure increases progressively during each stop and the pedal becomes harder. By the 7th stop, line pressure is over 800 psi and fade continues with each stop. Recovery is slow and requires 7 miles to level out to within 20 pounds per square inch of the initial. As the metallic lining curves indicate, the line pressure increases only 50 pounds per square inch during entire test. The line pressure decreases during each stop with no recovery being required. Tests such as this show the need for organic linings that have less heat build-up and, thereby, less fade. Therefore, some organic linings are being grooved down the middle to ventilate the lining and mitigate the heat problem. Grooving of the linings also reduces heat spotting of the drum. In addition lining areas are being increased, because for a given rate of vehicle braking, the pressure per square inch of lining area decreases as total area increases, and heat concentration is reduced.

Following the fade test, the brake linings are checked for general durability. This is accomplished by installing linings on vehicles scheduled for the 25,000 mile durability run. Consistency of effectiveness is observed during periodic stops which occur about every two miles throughout the 25,000 mile run.

Concurrently with the tests described, linings are subjected to a steam room humidity test, wet brake tests, grade parking checks and others.

In addition to the many standard tests for brakes, the brake development engineers conduct many special tests to collect performance data.

One of the most comprehensive and revealing special tests of organic and metallic brake linings was conducted recently on a 1000 mile police vehicle schedule. (Fig. 12) On the chart, line pressure is shown at left, and the 5th and 12th stop and slowdown of each test cycle are shown. The length of each arrow indicates the range of line pressure during a stop or slowdown. The wide range of line pressures during stops and slowdowns shows the effectiveness of organic linings to vary much more than metallic linings, especially during the first 200 miles. A much greater difference shows up on the fade stops. Note that with organic linings, the 35 mph at 8 feet per second per second stop fades from 425 psi to 1000 psi. Also during the first stop at 60 mph at 15 feet per second per second with brakes hot, line pressure reaches 1200 psi. This fade conditions gradually improves as long as the lining lasts but is always present. Note the arrows at the end of fade schedules pointing upward indicating increasing line pressure during decelerations. With the metallic, fade is absent because the arrows in metallic part of test are pointing downward. Organics developed considerable noise, odor, roughness, pulls, and near the last grabbiness. Failure occurred at 396 miles, while the metallic linings remained constant throughout the 1000 mile schedule. The police schedule is extremely rugged and shoe temperatures usually go above 600°F during the fade stops.

The letters PO at the noise test line stand for "pinch out," a short noise at extreme end of stop. WB stands for "wire brush," a scraping noise through the entire last part of a stop. The length of each noise line indicates intensity of sound. Light lines are primary shoes, dark lines are secondary shoes.

The stability line on the chart indicates vehicle pull to right, light lines, and left, dark lines, during stops. The length of lines indicates amount of pull. Notice the superior stability of vehicles with metallic lining in this test.

Wear was another measurable differential between the two linings indicated by the police schedule. Notice the extent of organic lining wear shown in Figure 13. The right front primary lining wore .112 of an inch and the right front secondary lining wore .182 of an inch and broke off at 396 miles to end the test. As the chart shows a maximum wear of only .014 of an inch occurred on the right rear secondary metallic lining at the end of a 1000 miles of high speed stops. The police durability schedule emphasizes the inadequacy of organic linings on heat-problem brakes.

What about a brake test for the average passenger car in one of America's urban areas? To establish such a test, General Motors engineers studied the necessary slowdowns and stops on several routes in cities throughout the country and finally decided on a Los Angeles route. The Los Angeles schedule is shown in Fig. 14. It calls for seven phases of stops, slowdowns and cooling periods of varying duration over a 50 mile run. The first phase is 20 stops at speeds ranging between 20 and 30 mph at 5 feet per second per second, and 28 slowdown from 30 to 20 mph at the same rate in a distance of 15 miles. The second phase is 16 stops from 35 mph to 0 at 8 feet per second per second, and 10 slowdowns from 35 to 15 mph at 8 feet per second per second in 5 miles. The third phase calls for 15 stops and 21 slowdowns at 5 feet per second per second in a distance of 10 miles. Phase 4 is a cooling period of no stops for 5 miles. Phase 5 is a repeat of phase 3. Phase 6 is a repeat of phase 2. Phase 7 is a repeat of phases 3 and 5.

As the curves illustrate in Fig. 14, the organic and metallic lining temperatures for front and rear brakes follow almost parallel plots. The significant fact depicted here is that at each given temperature reading for both organic and metallic linings, the metallic lining pressure is considerably below the organic. The metallic lining brakes are operating more efficiently with less effort required. This test does not mean that organic linings are unsafe during severe stopping conditions encountered in everyday driving. Organic linings are capable of meeting all the requirements of safe stopping. The test does establish the superiority of metallic linings in stopping a vehicle with ease under severe and prolonged braking requirements.

There are tests also that call for braking ability far beyond the requirements of everyday driving. The long winding descent of the road from the summit of Pikes Peak, Colorado is the site of a special brake test of this type. Fig. 15 indicates the result of separate runs down Pikes Peak to measure the comparative braking effectiveness of metallic and organic linings. The car with metallic linings descended Pikes Peak in drive range. Speeds were kept in a 20 to 30 mph range. Brake checks were made every 1/2 mile at 8 feet per second per second regardless of the braking that was required to maintain the speed range. In the lower portion of the chart you can see that the metallic line pressure remained practically constant for the entire descent.

A vehicle with organic brake linings making a similar descent failed at 10-1/2 miles with brakes entirely gone.

In comparing wheel cylinder temperatures, it can be noted that the cylinders with organic lining brakes increased slightly more than the cylinders on metallic lining brakes. The thermocouples were exposed in the end of the bleeder screws on the cylinders.

The secondary shoe temperatures shown were measured at the back of rim-web juncture near the horizontal center of the shoe. Notice that the temperature in metal shoes tends to flatten out when work is lighter. When the work load is severe, temperatures in the front shoes go above the rear shoes. The organic fronts cannot take the load and fade holds down the temperature increase.

Metallic fronts continue to work and temperature rises steadily. Note that the highest temperatures on the metallic are still below the organic lining readings. It must also be kept in mind that when considering comparative temperatures the thermocouples in metallic lining shoes respond faster due to conductivity.

Both the police durability and the Pikes Peak brake tests are extremely severe and prove the value of metallic linings for vehicles that must withstand abnormal braking requirements.

Field testing* of brake linings on police and taxi fleet vehicles is also a most important method of gathering important test data. Chevrolet has installed metallic linings on police vehicles in three different areas of the country. The police departments participating reported actual operational observations, including facts on wear, feel, fade noise and additional data, to Chevrolet field service engineers that confirmed company test results. As a result of their superior performance in heavy-duty operations, Chevrolet has released metallic linings as optional equipment.

CONCLUSION

The post-war trend in automobile developments has been a veritable nightmare for the brake engineer. As cars have become heavier and far more powerful, his working area has been reduced with the size of wheels. Yet his brakes, and particularly his linings, have proved equal to the test.

In comparing the overall capabilities and weaknesses of today's organic and metallic linings, it has been shown that both have their good and bad characteristics. Today's organics are more than equal to the demands of average daily driving. The metallics are equal to the demands of the "heat-problem" braking of police cars, sports cars, and other vehicles subjected to high speed, prolonged decelerations.

However, in striving for the perfect brake friction material, engineers are not completely satisfied with either the organic or metallic linings. In defense of the metallics it should be kept in mind that they have undergone intensive development work only in the last 3-1/2 years, and great progress has been made in that short period in improving their objectionable characteristics. On the other hand, organics have been under intensive development for over 30 years and, although further deficiency improvement may be obtained, they have possibly reached their peak of perfection with the ingredients to which they are now restricted. The competition between the organic and metallic friction materials is a healthy condition that points to rapid progress in the attainment of the versatile, highly effective brake lining of the future.

*- SAE paper Dragnet For Defects - Field Testing, 1958, by Edward Gray described Chevrolet's field testing activities.