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BASED ON PAPER* BY

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THE varied properties required of a brake lining material calls for careful selection and blending of its ingredients.

Lining requirements are:

1. Correct coefficient of friction, which is influenced by temperature reaction, aging qualities, water reaction, and oil and grease reaction;
2. Durability;
3. Relative freedom from any tendency to score drums;
4. Quietness in operation; and
5. Nonoffensive odor.

Lining friction coefficients generally run between 0.20 and 0.40. Manufacturers usually describe linings as having high, medium, and low friction coefficients without specifying friction value numerically. It's not hard to compound a lining with an initial specific friction coefficient; but to produce a lining with uniform braking performance under various operating conditions takes much compounding study and laboratory and road testing.

The ideal lining would have a constant friction coefficient at high and low temperatures, under wet and dry conditions, throughout the lining's life. There is no such lining. All linings disintegrate under high braking temperatures. Chemical and physical changes either increase friction coefficient (build-up) or decrease it (fade).

With fade, if friction characteristics return to their initial condition, the lining is said to have good recovery properties. Satisfactory linings fade slightly with each brake application, but recover immediately after cooling. Linings producing build-up in friction coefficient are not satisfactory.

Friction coefficient may increase or decrease with age. When it decreases, it develops a hard pedal. Some linings harden and tend to score drums and be noisy.

Other linings are sensitive to water on the friction face, with effects as pronounced as those from temperature. Moisture also causes "morning sickness." Iron oxide forms on the drum and gives high friction reaction during the first two or three stops made after the car has been parked over night. Because of contact with oil and grease in service, linings should have some resistance to these materials.

Linings also should wear slowly and uniformly. This insures more consistent braking action by continually renewing the friction surface. Negligible wear may produce a glazed friction surface.

Certain ingredients tend to score drums. Steel drums score more readily than cast-iron ones. Brake system quietness is a function of the lining as well as other factors. Ingredients must not produce offensive odors at high braking temperatures. Good compounding ingredients may be discarded because of this limitation.

Brake lining materials derive their properties from fillers, binders, and wear-enhancing ingredients, such as those in Table 1. Selection and percentages of ingredients used varies with the type of lining.

Chief lining constituent is Chrysotile asbestos, used as the primary reinforcing material. Chemically, it is an hydrous magnesium silicate ($H_4 Mg_3 Si_2 O_9$). The mineral fibers are 1/8 to 6 in. long. Under high magnification the fiber looks like many finer crystalline threads bundled together. Diam-

* Paper "Automotive Brake Lining Materials," was presented at SAE Annual Meeting, Detroit, Jan. 13, 1950. This paper is available in full in multilithographed form from SAE Special Publications Department Price: 25¢ to members, 50¢ to nonmembers.)

Table 1—Brake Lining Ingredients

Binders	Fillers		Friction Modifying and Wear Enhancing Agents	Curing Agents and Accelerators
	Reinforcing	Nonreinforcing		
Elastomers	Chrysotile Asbestos	Barium sulphate	Cashew nut liquid products (powders)	Standard rubber and resin primary and secondary curing agents and accelerators
Rubber		Calcium sulphate	Rubber and synthetic rubber	
GR-S		White lead	Ground rubber tire scrap	
Buna N		Lead carbonate	Iron oxide	
Neoprene		Clay	Metals—lead, zinc, brass	
Phenolic resins		Asbestine	Lead salts	
Oil modified phenolic resins			Talc	
Cashew nut oil resins			Graphite	
Drying oils			Bituminous materials	
Sulfurized oils			Abrasives	

BRAKE LINING MATERIAL

Ingredients Hold Key To Service Behavior

eter of the smallest fiber which can be separated is about 0.00003 in.

Asbestos makes a good friction material because of its heat resistance, chemical resistance, flexibility, low thermal conductivity, and hardness. Its reaction to heat is particularly important.

The asbestos fibers start losing their water of crystallization at about 500 F. The loss rate increases with temperature and become rapid at 1000 F. When the water is driven off, asbestos looses its crystalline properties and becomes a powder. Asbestos fiber breakdown to powder with heat makes possible rejuvenation of the lining's friction surface. Today's brake linings would be impossible if heat generated in braking a car decomposed only organic materials and changed asbestos into a hard, organic fused layer of abrasive material.

Poor heat-conducting properties of asbestos help keep heat from penetrating deeply into the lining. This would produce chemical changes in binder materials and would harm lining friction characteristics.

Asbestos fabrics have a friction coefficient of about 0.35. This is within the 0.2 to 0.4 range around which satisfactory braking systems have been designed.

Brass, lead, or lead alloy wires used in woven materials strengthen the yarn. Some claim lead surpasses other metals because it stabilizes the friction coefficient, acts as a dry lubricant to prevent drum scoring, and inhibits formation of abrasive particles on the friction surface.

Metallic powders, such as zinc and lead, improve performance at high temperatures. Limitation with fine lead is that it oxidizes easily to litharge, which promotes oxidation in unsaturated organic compounds. Some believe these powders help break the continuity of the friction surface film during braking action. Large amounts of metal (40%), such as brass chips, are added to linings for very high temperature requirements.

Brake lining compounders also add lead to compositions in the form of organic salt. High temperature liberates it as finely divided lead in a reducing or inert atmosphere. This prevents oxidation of the metal to an oxide and permits it to function as a friction stabilizer.

Graphite in lining compounds imparts a lubricating effect for smoother stopping. It can be incorporated in the hard rubber or added separately. Some compounders see two advantages for graphite encased in rubber. First, it does not interfere with flow of the resin binder during curing. Second, graphite is released for its lubricating action only after the rubber is softened by high braking temperature.

Iron oxide in small amounts sometimes is used as a friction-controlling element. It tends to have a self-polishing action which partly controls surface frictional properties.

The compound usually requires large amounts of inorganic fillers to produce frictional effects. This necessitates an improved friction stabilizer that functions over a wide temperature range. Organic modifiers—such as rubber, ground rubber scrap, pitches, and gilsonite—function best over narrow temperature ranges.

A powdered product made from cashew nut liquid is one of the better friction-stabilizing and wear-enhancing agents used today. This material works satisfactorily up to temperatures of 700 to 650 F. Tire scrap particles function up to about only 500 F. About 6 to 8% of dust is needed to improve wearing qualities.

Ground-rubber tire scrap has been, and will continue to be, widely used because it is a cheap raw material. Other friction modifiers—such as pitches, gilsonite, coal, and petroleum coke—can be used in limited quantities only because of their low temperature resistance. Braking temperatures destructively distill these materials to form tarry or pitchy residues at the friction surface. These increase the friction coefficient at low temperatures. But at high temperatures, volatile materials may be driven off too rapidly before formation of tarry products, losing their effectiveness.

Research today is aimed at getting binding materials with high heat resistance. Currently the

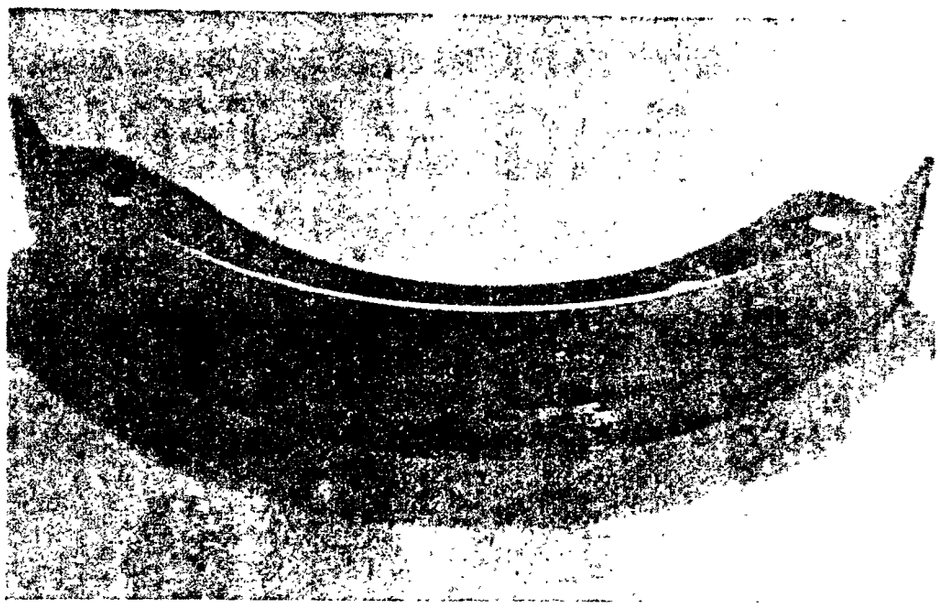

Fig. 1—As this brake shoe shows, bonded lining makes available twice the usual lining and virtually eliminates drum score

Lists New Need With Bonding Lining

Add bondability as a sixth lining requirement, advises S. G. Tilden, The Permafuse Co. The advent of bonded brake linings makes this a must.

Tilden's organization has set up an arbitrary minimum bond strength requirement of 600 psi in shear. This gives a total shear strength of 11,500 lb on a $1\frac{3}{4} \times 11$-in. segment. That is about five times the maximum shear force exerted on linings by a simulated emergency stop with a 1 g deceleration.

All lining factors producing good bondability have not been established. But tests have been made to find the effect of porosity. Strangely enough, denser and less absorbent linings bond better.

Bonding suitability also calls for availability of the entire lining thickness for use. That's why wire-back linings are not suited for bonding. They can be used only down to the wire backing; after that they score the drums. With wire backing, the promised double wear from bonded linings cannot be realized.

Typical of the extra wear available with bonded lining is the lining in Fig. 1. This brake shoe with bonded lining was used until the segment had worn completely through to the shoe at the central tangential area. Note the lack of drum score, except for the lower edge portion; this came from actual metal-to-metal contact between brake shoe and drum.

Tilden points out that bonded linings also improve the path for conducting heat into the brake shoes, backing plate, and axles. It provides a bridge without the insulating air layer usually present in riveted linings.

main binding agents are synthetic resins, drying oils, rubber, and bituminous materials. Most important group is the synthetic resins. Oil modified phenolics are mostly used. Synthetic resins hold much promise because they can be synthetized in the laboratory to meet desired binding material requirements.

Available resins vary in their properties. Some can be used alone, others must be used together with natural, synthetic, or reclaimed rubber. Oil modified types also are commonly used with these rubbers.

Used as a binder, rubber or GR-S must be vulcanized to function properly. In lining compositions they usually are cured to a hard rubber with 25 to 40% sulfur as the vulcanizing agent. Their relatively low softening and decomposition temperatures limit rubbers alone as binding agents. In the future it may be possible to synthetize rubber polymers that will make satisfactory brake lining binding materials. Some day special rubbers may be expressly made for this use.

Drying oils, used for many years in brake lining formulations, are limited because of control of polymerization (hardening). They are used in air-curing type and woven linings. Wide use also is made of them as a binding component in modifying phenolic resins.

(The paper also tells how fabric and molded linings are made.)