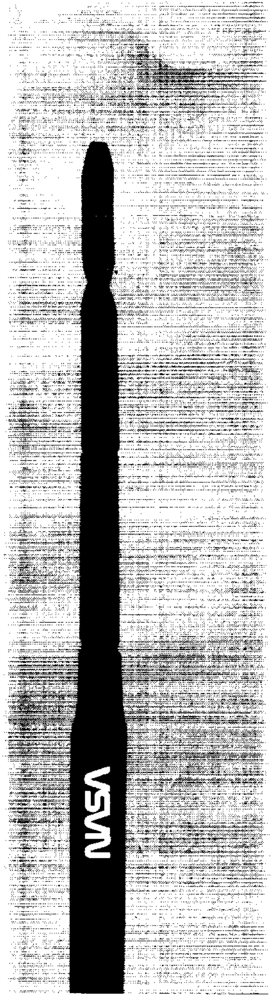

BRAKE FRICTION MATERIALS:
A MARKET SURVEY

By: James P. Wilhelm
Andrew V. Loomis

Conducted for the

TECHNOLOGY UTILIZATION ~~OFFICE~~
NATIONAL AERONAUTICS AND
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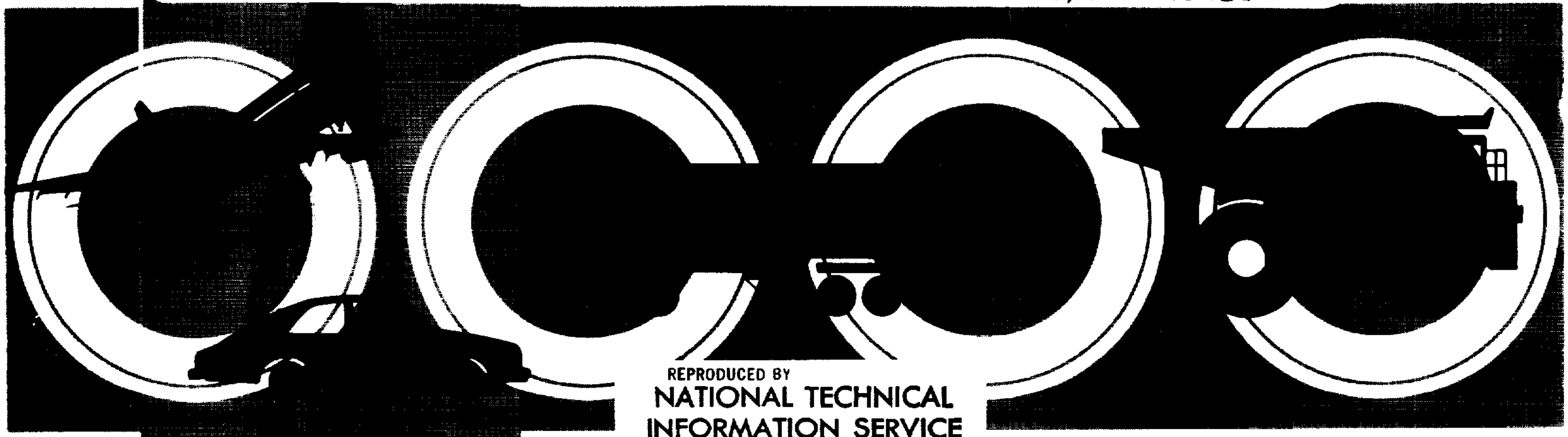

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BRAKE FRICTION MATERIALS: A MARKET SURVEY

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WASHINGTON, D.C.

EXECUTIVE SUMMARY

A composition material developed by National Aeronautics and Space Administration (NASA) may be useful as an improved vehicle brake friction material. To assist NASA in identifying a potential market for this material, the SRI Technology Applications Team has conducted a survey of the market for vehicle brake friction materials in the United States.

The purpose of this market survey is to outline the technical and economic requirements that a candidate composition friction material must meet before it can be considered a viable product. In addition, we have reviewed the properties of composition brake friction materials currently on the market to identify those properties that, if improved, would be a useful advance to the product. Consequently, any new material that possesses any of these improvements may have a competitive advantage over currently available materials.

The brake friction material developed by scientists at NASA's Ames Research Center exhibits an essentially constant coefficient of friction with temperatures ranging as high as $650^\circ F$ and an average coefficient of friction of approximately 0.34. A comparison of the change in coefficient of friction versus temperature for the NASA material and conventional brake lining materials demonstrates the superiority of the NASA material at temperatures greater than $400^\circ F$. At these higher operating temperatures the NASA material's coefficient of friction actually increases while that of conventional brake linings decreases markedly. Wear improvement at elevated temperatures has also been noted.

Considering the market, based on the data gathered during the course of this survey, the bus-brake market appears to have the highest potential for the successful entry of a new brake friction material. Such a material would need to exhibit the following improvements over conventional linings:

- Reduced noise during braking
- Reduced fade, more stable coefficient of friction at elevated temperatures.
- Reduced lining wear
- Reduced drum wear
- Either comparable in price to conventional linings or exhibiting no more than a 40% increase.

Market size is estimated at 750,000 to 800,000 pieces per year (original equipment) and as high as 8.0-8.2 million pieces per year (after-market). This represents a yearly market of $22-27 million.

The market chosen as the second most favorable for the penetration of a new friction material is the heavy truck brake lining market. Rising labor costs and increased federal legislation have increased the industry's awareness of its need for such new materials.

The original equipment market for truck linings in 1975 is estimated to be approximately 8.0-8.5 million brake blocks at a market value of $20-21.3 million. An additional 1.46 to 1.49 million pieces at a value of $3.65 million to $3.75 million will be sold for use on new trailers manufacturers in 1975.

The after-market for trucks and trailers is estimated at 9.50 to 10.25 million brake blocks at a value of $23.8 to $25.6 million.

Although a considerably more detailed study than was possible in this survey is necessary to accurately determine the size of the market, it appears that improved brake friction materials are also needed in the industrial equipment sector. This category includes equipment such as overhead cranes, hoists and the like and represents an overall brake-lining market value estimated at $80-100 million annually.

Other areas studied include passenger cars, light trucks, heavy trucks and truck/trailers, rail cars and light aircraft. Estimates of the current brake lining market for these sectors are given below:

Vehicle Type	Market	Volume Pieces/ Year (000)
Passenger Cars	Original Equipment	72,000-73,000
Passenger Cars	After-Market	210,000-220,000
Light Trucks	Original Equipment	16,000-18,000
Light Trucks	After-Market	22,000-24,000
Trucks	Original Equipment	8,000-8,500
Trucks	After-Market	4,000-4,250
Trailers	Original Equipment	1,460-1,490
Trailers	After-Market	5,500-6,000
Buses	Original Equipment	750-800
Buses	After-Market	8,000-8,200
Rail Cars	-	3,290
Light Aircraft	-	600

Market entry into these sectors is strongly limited by lining cost (i.e., a very strong technical advance over current materials would be required to justify any additional lining cost). For this reason, and our belief that the NASA material does not exhibit these advances, we do not anticipate market penetration in these areas.

In summary, it appears that the NASA Ames brake friction material will gain its easiest market entry in the bus, truck and industrial equipment brake sectors. To insure this penetration the NASA material, once released, must exhibit a more stable coefficient of friction at elevated stable temperatures than conventional materials, must show some wear improvement over conventional materials and will have to be at best cost competitive or at least, cost effective.

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I. INTRODUCTION

A composition material developed by National Aeronautics and Space Administration (NASA) may be useful as an improved vehicle brake friction material. To assist NASA in identifying a potential market for this material, SRI has conducted a survey of the market for vehicle brake friction materials in the United States.

The technological advances achieved by NASA as it fulfills its mission of exploring space, have proved highly useful when applied to earthbound problems. The transfer of the advanced, particularly product-oriented technology however, usually does not occur spontaneously. A technology must be proven technically and economically feasible for its intended earthbound application before it can be transferred.

The purpose of this market survey is to outline the technical and economic requirements that a candidate composition friction material must meet before it can be considered a viable product. In addition, we have reviewed the properties of composition brake friction materials currently on the market to identify those properties that, if improved, would be a useful advance to the product. Consequently, any new material that possesses any of these improvements may have a competitive advantage on the market. This information can then be used to match the known properties of the NASA material with the product market area or areas for which it is best suited.

II. THE NASA FRICTION MATERIAL

During its activities, the SRI Technology Applications Team, under contract to the NASA Technology Utilization Office, identified a need in the public sector for longer wearing, more effective, and quieter brakes. Aware of ongoing research efforts at NASA-Ames Research Center, Moffett Field, California, directed toward the development of improved brake materials for SST use, the SRI team brought this problem to the attention of the scientists involved. The Chemical Research Projects Office of NASA-Ames Research Center initiated an experimental program using aerospace expertise and techniques to develop friction materials for application in lightweight trucks and automobiles.

The program included the assessment of new, experimental materials substituted in each of the functional categories of fiber, binder, and modifier. Almost immediately pronounced effects of one-to-one substitutions of experimental materials for conventional brake materials in the fiber and binder categories were noted. For this reason, fiber and binder modification and/or substitution were chosen for program emphasis. Program testing leading to material formulation optimization included the use of sample dynamometers and full-scale inertial dynamometers under conditions simulating both drum lining and disc pad configurations. At this writing, vehicle testing had not yet been accomplished.

As a result of this program, a brake friction material composition was developed which exhibits an essentially constant coefficient of friction with temperatures ranging as high as 650°F and an average coefficient of friction of approximately 0.34. A comparison of the change in coefficient of friction versus temperature for the NASA material and conventional brake lining materials is given in Figure 1. A trend in decreasing wear rate with temperature compared to conventional materials has also been noted (Figure 2). As the temperature increases, the wear is equal to conventional wear at low temperatures and increases to an average 30% wear improvement over the temperature range 400-650°F.

These improved properties were achieved solely by replacing asbestos with a particular potassium titanate fiber and by formulation adjustments from the optimum conventional formulation available. Further formulation modifications yielding improved brake performance characteristics are the subject of patent applications currently being filed.

Precise costs of the NASA-developed brake lining composite are difficult to reliably predict at this time; however, current estimates submitted by Ames indicate that cost-effective formulations have been developed, especially when extended life operations on a fleet basis, where vehicle repair time is a significant factor, is considered.

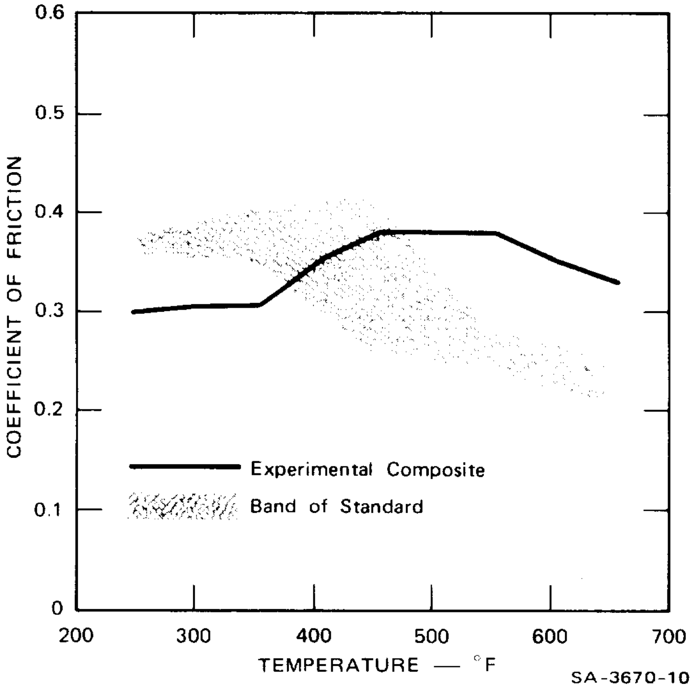

FIGURE 1 COMPARISON OF NASA DEVELOPED BRAKE LINING COMPOSITE WITH CONVENTIONAL (STANDARD) MATERIALS

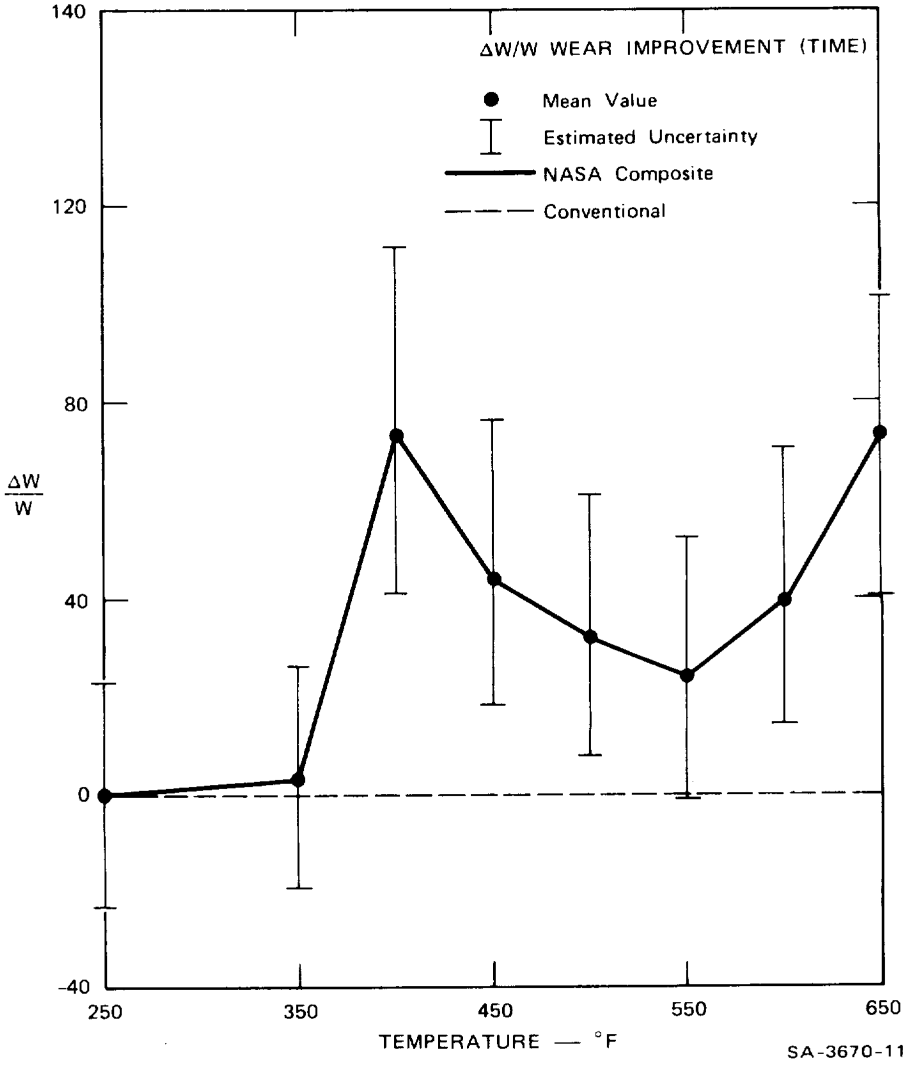

FIGURE 2 COMPARISON OF WEAR OF NASA DEVELOPED BRAKE LINING COMPOSITE WITH CONVENTIONAL BRAKE LINING

III. PASSENGER CARS AND LIGHT TRUCKS

A. Background

The category of passenger cars and light trucks includes all passenger cars regardless of vehicle weight, trucks of gross vehicle weight (GVW) of 6000 pounds and less, and vehicles of the pickup type in the 6001-10,000 lb GVW range. These vehicles will be classified together because all the vehicles use essentially the same braking system and all have basically the same brake lining requirements.

These vehicles use hydraulic braking systems ,which are either manual hydraulic systems that use unassisted driver effort, or power-assisted systems that reduce manual pedal effort.

Brake lining materials used in passenger cars and light trucks fall into two categories: drum brake segments, which are less than 3/4" thick, and disc brake pads. Brake lining and disc pad sizes vary in width, thickness, and length according to vehicle requirements. This information has been standardized and catalogued for use in the industry and is available from the Friction Materials Standard (FMS) Institute, Inc. Each size lining is given a FMS number, and the replacement lining for each vehicle model is given. The catalog gives all brake lining data required by the after-market manufacturer and brake lining installers.

Passenger cars and light trucks are used as a means of transportation to work, in family business, or recreational travel. Surveys indicate that 70% of all travel by these vehicles is for trips of less than ten miles with a considerable amount of stop-and-go driving at low speeds requiring considerable use of the braking system. The remaining 30% of travel consists of longer trips at speeds of 50-55 mph, involving much less use of the vehicle's braking system, but requiring linings capable of stopping a vehicle traveling at high speeds.

The amount of heat produced in the braking system is dependent on the vehicle weight, speed, and stopping distance. The deceleration rates and amount of energy absorbed by the braking system is dependent on vehicle weight and braking habits of the user. Brake lining operating temperatures during fade tests for compliance with Federal Motor Vehicle Safety Standard (FMVSS) 105-75 regulation vary considerably from one type of vehicle to another. Brake linings tested on 60 sample vehicles ranged from 350°F to 1100°F during the second fade test with an average temperature of 635°F, with 70% of the vehicles falling into the 500-800°F range.* Regulations and vehicle tests have been set up for brake linings used on passenger cars and light trucks and will be discussed in the section on testing (Section X).

B. Product Requirements and Performance

In addition to the requirements for brake lining materials used on passenger cars and light trucks covered by FMVSS 105-75, the following quality standards for brake lining materials should be considered:

Brake Lining Wear--A number of articles have been written on wear characteristics of conventional brake linings for passenger cars and light trucks. It is generally accepted knowledge that the conventional asbestos-binder-based linings have an average life of 30,000-35,000

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* NHTSA Technical Report DoT HS-801 133

miles when used on passenger cars and light trucks. Such an estimate for original equipment and after-market linings is questionable because in reality their life expectancies vary considerably with driving habits, terrain over which a vehicle is operated, vehicle type, and use. A great number of vehicles require replacement of linings at 17,000-20,000 miles and others obtain as high as 60,000-70,000 miles on a set of linings.

Vehicle manufacturers and users do desire longer brake lining wear, but at no additional cost. However, studies of the brake lining market and interviews with the brake lining manufacturers, vehicle manufacturers, and after-market distributors, reveal that conventional brake lining wear expectancy is quite acceptable, because (a) the average life of these vehicles is estimated to be 7-8 years, and (b) average vehicle use is 11,000-12,000 miles per year. Based on this information and the life expectancy of a conventional brake lining, we can estimate that the average vehicle will use only three sets of linings, one set of original equipment linings and at most, two sets of after-market linings. Also, several longer wearing brake lining formulations that are available, at somewhat higher cost, have not had any impact on the market. In addition, U.S. car manufacturers are actively seeking means to reduce costs, and would not wish to incur any additional lining costs for the purpose of better wear. It appears that longer wearing linings in the passenger car and light truck after-market would not have large impact, especially if prices were appreciably higher. The first set of after-market linings would be the only market area for longer wearing linings. This market would be quite small because the average vehicle has traveled approximately 35,000 miles when it receives the first after-market set,and conventional linings will last an additional 35,000 miles for a total of 70,000 miles.

Friction Requirement--All pieces of the friction material in the vehicle braking system must be of uniform friction. If friction is not uniform, braking will be unbalanced, exhibiting variable side-to-side pulls.

Noise--For passenger cars and light trucks, no actual regulations on brake noise currently exist, but the original equipment manufacturers have their own rating system for noise and attempt to have noiseless braking systems.

Water Recovery Properties--All conventional brake linings are temporarily inoperative after water immersion, but a good brake lining will shed water readily and recover fully. Federal regulations have water recovery tests and specifications which all brake linings must meet. However, a new brake lining having better water recovery properties would definitely be desirable to the vehicle operator and the vehicle manufacturer. Acceptable increased costs to obtain better water recovery properties cannot be estimated with any accuracy.

Moisture Sensitivity--A new brake lining material must be entirely free of moisture sensitivity (as opposed to submersion). Many linings have a moisture sensitivity which causes a violent stop after the lining has been subjected to a high humidity environment. This is believed to be caused by dust-caking. A number of linings currently on the market are entirely free of this moisture sensitivity.

Abnormal Wear--A brake lining should not cause any abnormal wear of the brake drums or rotors. Many linings that have been formulated for longer or improved wear properties have been found to cause abnormal wear of brake drums or rotors. Any brake lining material must be compatible with the other members of the brake assembly, such as the brake drums and rotor components.

Improved Coefficient of Friction--An improvement in the coefficient of friction over conventional linings would be desirable in a new lining material. This property, if present in a brake lining, might make additional cost acceptable. Brake lining manufacturers are continually trying to develop materials with a more stable coefficient of friction at elevated temperatures, and original equipment manufacturers also appear to be interested in lining improvement in this area.

Structural Integrity--The brake lining must have good structural integrity; that is, the lining must remain firmly attached to the brake shoe even during panic stops, throughout the life of the lining. This requirement is especially important in riveted linings, where the material must have sufficient tensile strength to remain safely attached to the brake shoe during heat build-up created during stops.

C. Market

The brake lining market for passenger cars and light trucks is separated into two areas, (1) the original equipment market and (2) the after-market. Passenger car and light truck original equipment and after-market linings, are currently being supplied by at least six major manufacturers. In addition, two major car manufacturers operate their own brake lining manufacturing facilities which supply most of their original equipment needs and a portion of the after-market. Approximately 120 million passenger cars are in operation in the United States today; these vehicles account for 986.4 billion miles of travel a year. The life expectancy of a passenger car is 7-9 years, traveling an average distance of 11,000-12,000 miles per year.

1. The Original Equipment Market

The distribution system for brake lining materials to the original equipment manufacturer in many cases involves a direct purchase of lining materials from the manufacturer by the original equipment manufacturer. In this case, the OEM would contract the work of attaching the linings to the brake shoe. Lining distribution may also be through a distributor who would purchase the linings from the manufacturer, attach the lining to the brake shoe or backing plate, and sell the complete brake assembly to a user. Distribution of after-market brake linings involves the purchase of linings from the manufacturer by an after-market fleet specialist or distributor, who then attaches the linings to a shoe or disc pad assembly, and in turn, sells the finished part to a fleet owner or installation facility.

The original equipment market volume of brake linings for the passenger car and light truck industry for 1975 is estimated to be approximately 72-73 million pieces for passenger cars plus an additional 16-18 million pieces for light trucks. These figures are based on projected car and light truck (6000 lbs or less) sales for 1975, calculated from figures supplied by the Motor Vehicles Manufacturers Association. Approximately 40% of these linings are discs and the remaining 60% of the pieces are lining segments, used in drum brake assemblies.

The figures for the 1975 original equipment brake lining market are considerably lower than the market volume for previous years. For instance, in 1973 the number of brake lining pieces for the original equipment market was approximately 91.2 million pieces, 77.6 million of which were for cars, and 13.6 million, for light trucks.

2. The Brake Lining After-Market

The brake lining after-market volume is considerably larger and more competitive than the original equipment market. Sales volume for 1974 was 197-210 million brake lining segments for passenger car and light truck installation, plus an additional 24-25 million disc brake pads. The practice of installing disc front brakes as original equipment on U.S. cars has only been adopted in the past few years, which accounts for the small percentage (≃ 17%) of disc pads in the total lining after-market.

During the next five years, the manufacture of new cars and light trucks is expected to increase gradually, possibly reaching the 1973 production figures of 11,350,995 cars and 2 million trucks. The growing tendency among vehicle owners to keep cars for a longer time than in the past will cause a gradual increase in the after-market for brake linings.

Some information has been obtained on conventional brake lining cost, as sold by the lining manufacturer. Drum lining segments sell for an estimated $0.30-0.40 per segment. Disc pads sell for $0.40-0.45 per piece. These prices are for the friction material as supplied by the manufacturer and may be considered the manufacturers wholesale price to a jobber or to a distributor.

3. Major Manufacturers

Some major manufacturers of original equipment brake linings and after-market linings are: Abex Corporation, Bendix Corporation, Chrysler Corporation, General Motors Corporation, H. K. Porter Corporation, Raybestos-Manhattan, Inc., and Thiokol Chemical Corporation. Some fifteen other companies also manufacture after-market linings. See Table 1 for the complete list of brake lining manufacturers.

IV. TRUCKS AND TRAILERS

A. Background

The category of trucks includes all vehicles used for the transportation of articles and having a gross vehicle weight (GVW) of 10,000 pounds or more. The category includes a great variety of units employed for a number of different uses, and brake lining needs for all these vehicles therefore are difficult to specify accurately. The GVW for trucks traveling on the nation's highways in many cases exceeds 33,000 pounds. The weight of the vehicle itself plus its cargo weight, places stringent requirements on the brake lining materials.

Braking systems used by trucks, truck tractors, and trailer combinations are air-assisted hydraulic (air brake) systems. Truck and trailer braking systems are regulated by Federal Motor Vehicle Safety Standard (FMVSS) 121.

Trucks with GVW of 10,000 pounds or more use friction materials referred to as brake blocks. The main distinction between brake segments and brake blocks is their thickness; a brake segment that is 3/4-in.-thick or more is classified as a brake block. Blocks are used on heavier vehicles where wear rates are considerably higher and the energy which must be absorbed by the braking system is greater. Truck linings may reach temperatures in excess of 1360°F at the braking interface. The normal operating temperatures are considerably lower, usually in the 600-800°F range.

B. Product Requirements and Performance

Brake Lining Wear-- Brake lining wear in trucks and trailers is rather difficult to estimate because of the variety of uses and broad weight range of the vehicles. A reasonably correct estimate for conventional brake lining life for the lighter vehicles using brake segment is 35,000-45,000 miles of vehicle use, depending on use and the terrain over which the vehicle is operated. A fairly accurate estimate for brake lining life on tractor and trailer combinations, which is generally accepted throughout the trucking industry, is 75,000-100,000 miles per set for tractor trucks, and 150,000 miles per set for trailers. These vehicles are mostly used for long haul moving of goods and are not subjected to the stop-and-go traffic of city driving. Tractor wear rates of 200,000 miles per lining set, as quoted by some trucking firms, do not seem to be the norm for the industry.

Labor costs for replacement of linings have risen sharply over the past years. Approximately two hours are required to replace a truck brake lining set (one axle) at a labor cost of $22.00-$24.00. In addition to high maintenance costs, truck retail prices have increased approximately 26% in the past two years. This increase in costs may cause many trucking firms to keep their trucks for longer time periods than before. Current use life for trucks is 44 months, or approximately 480,000 miles. Average trailer life is seven years, at an average of 500,000 miles. Rising vehicle unit costs and increased labor costs over the past few years may provide an impetus for obtaining improved lining wear properties. Until now, brake lining wear has been considered adequate.

Brake Lining Materials--The brake lining materials in trucks and tractor-trailer combinations must have uniform coefficient of friction values to reduce the hazards of unbalanced braking exhibiting side-to-side pulls. A friction material must exhibit a uniform coefficient of friction which (a) must not increase with time to the point of becoming grabby or uncontrollable, (b) must not increase with temperature during braking application, and (c) should have some degree of fade. If this fade, which occurs in conventional linings, was not present to some degree, heat would build up far too rapidly and produce a sudden failure in the braking system or wheel assembly. However, a definite need exists for a brake lining with a more stable coefficient of friction. Such an improved brake lining providing safer braking performance would be readily accepted by the OEM and users. It has also been stated that truck braking systems, using conventional linings were not capable of meeting original FMVSS 121 stopping distances of 245 feet at 60 mph. This regulation was revised to 277 feet at 60 mph stopping distance but is expected to revert to the original 245 feet in 1977 or 1978. A more stable coefficient of friction at elevated temperatures would certainly aid in meeting this regulation.

Brake Drum Wear--A new brake lining material that would contribute to less drum wear in tractors and trailers would reduce drum maintenance and replacement costs. The large trucking lines would be especially interested in using linings with improved wear and drum wear properties. A material with these properties could contribute to considerable labor and material savings for large trucking firms.

C. Market

The brake lining market for trucks and trailers consists of the original equipment market and the after-market. Vehicles in this classification are those with a GVW of more than 6000 pounds excluding pickup trucks in the 6001-10,000 GVW range.

1. Original Equipment Market

Distribution of brake linings for use on trucks and trailers is somewhat the same as lining distribution for passenger cars and light trucks. In many cases, the lining manufacturer will sell directly to the OEM who has the blocks attached to the shoes in-house, or by a jobber. In some instances, the linings are sold to a jobber or distributor who attaches the blocks to shoes and sells to the OEM. In the after-market, the lining manufacturer will sell linings to a jobber or fleet specialist who does lining attachment work and sells the finished component to the user. In many cases, the large trucking firms will buy linings directly from the manufacturer and do their own attachment work.

The OEM for truck linings in 1975 is estimated to be approximately 8.0-8.5 million brake blocks. An additional 1.46-1.49 million pieces will be sold for use on new trailers to be manufactured in 1975.

2. After-Market

After-market sale of brake blocks for both trucks, trailers, and buses for 1974 was approximately 18.2 million pieces. This figure includes buses, because of the inability to distinguish between the types of vehicles on which the brake blocks were being used. By taking total vehicle registrations and lining life expectancies for each vehicle class, we can estimate that approximately 9.50-10.25 million brake blocks were used by the trucking industry.

This estimated 20 million brake lining pieces used by the trucking industry yearly accounts for an annual production of approximately 140 million lb of friction material produced for this industry alone.

Brake block cost is approximately \$2.50/piece as purchased in large quantity from the brake lining manufacturers, but this figure may vary considerably depending on the manufacturer or in many cases, the purchaser. A total sales volume of 20 million brake lining pieces per year, with an average cost of \$2.50 - 3.00 per piece provides for an estimated \$50 - 60 million annual sale of brake lining material to the trucking industry.

3. Major Manufacturers

Some of the major manufacturers of brake blocks are: Abex Corporation, Auto Friction Corporation, Bendix Corporation, Carlisle Corporation, H. K. Porter Company, P. T. Brake Lining Company, Inc., Wheeling Brake Block Manufacturing Company, and a number of others. See Table 1 for the complete list of brake lining manufacturers.

V. BUSES

A. Background

The number and variety of buses in use today seems to be increasing steadily with the increased demand for public transportation.

The braking systems used by buses are similar to the conventional air brake system used by large trucks. The bus braking system must be capable of stopping the bus in distances specified by the FMVSS 121 regulation. This regulation, which covers both trucks and buses with air brake systems, went into effect March 1, 1975. Approximately 85-90% of the buses in use are in the 19,500-26,000 lb GVW class. Operating temperature of bus braking systems are in the same range as that of heavy trucks (600 - 800°F).

Brake linings on buses are almost entirely brake blocks used by the drum brake system. However, at least one large bus line* with a fleet size of more than 5000 units is testing disc brakes on the front axles of some of its buses. The use of front disc brakes is expected to produce better stopping ability and give longer wear than the drum brake system.

B. Product Requirements and Performance

Brake Noise--Brake noise is one the major concerns of the busing industry today. Many conventional linings are not acceptable in this respect. For all the busing companies studied, noise was the number one problem with currently used brake linings. One user with a fleet size of 800 units has changed brake lining suppliers several times, in

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* Greyhound Bus Lines

an attempt to eliminate the noise problem. This company is mainly involved in intracity transit where squealing brakes become a definite noise pollution problem.

Brake Lining Life--The life of bus brake linings is very dependent on the type of use of the vehicle. Intracity buses require brake lining change after approximately 25,000-35,000 miles of use. Express buses traveling between cities or from outlying suburbs average 60,000-80,000 miles on a set of linings. Buses in interstate travel have a lining life of approximately 75,000 miles on the rear axles and 100,000 miles on the front axles. Several bus industry representatives have expressed concern over the reduced brake lining life apparent on vehicles meeting the new FMVSS 121 regulation. Conventional brake lining materials capable of meeting this regulation must have higher coefficient of friction values and appear to have decreased wear properties and shorter life.

Labor costs for replacement of brake linings on a bus average \$16.00-35.00 per axle set, based on a \$8.00-9.00 hourly wage and 2-4 hours of time required to replace the lining set and turn each brake drum. When linings are replaced normally, drums are cut at least to a depth which removes surface blemishes and irregularities. Linings having two to three times the life of conventional linings at 30-40% increased cost, would definitely be cost-effective based on the high lining replacement rates and labor costs for this industry.

Drum Wear--Conventional linings create excessive drum wear, and improvements to reduce drum wear are definitely needed in the bus industry. Drum maintenance and drum replacement are costly items to large bus lines, and new friction materials with improved drum wear characteristics would contribute to maintenance savings for the bus lines.

Improved Coefficient of Friction--Conventional linings do not have a sufficiently stable coefficient of friction at elevated temperatures. Although some brake lining fade may be necessary with braking systems currently in use, considerable improvement over conventional linings is needed. Additional costs to obtain safer braking performance would be accepted by the bus industry.

C. Market

The market for bus brake linings is quite similar to that of trucks. Buses and trucks use basically the same types of linings, or brake blocks. Total U.S. motor bus registrations currently exceed 400,000 and are continually increasing as demand for more efficient public transportation increases. Most of these buses are in the 19,500-33,000 lb GVW class and many have rather high lining wear rates.

The distribution system for bus brake linings is nearly identical to that of truck brake linings. However, bus lines appear considerably more concerned with longer wearing and quieter brake linings and are not hesitant to change suppliers to obtain these properties. A number of bus lines keep accurate records of brake lining performance and wearability, to determine which brands are more cost-effective.

The original equipment market for bus brake linings for 1975 is estimated to be approximately 750,000-800,000 brake blocks. The after-market linings sold to the busing industry in 1974 were approximately 8.0 - 8.2 million pieces. This large after-market figure compared to number of vehicles in operation arises from the more rapid lining wear rate of buses, such as those of intracity buses.

This total of approximately 9 million pieces of brake friction material used by the busing industry each year accounts for an estimated annual production of 63-65 million pounds of friction material for use by the bus industry.

As for trucks, brake linings prices for buses are in the $2.50-3.00/piece-range, but may vary considerably with formulation and dimension variations. This cost is indicative of what the distributor or jobber would pay when purchasing linings from the manufacturer. At an average cost of $2.50-3.00/piece and an annual sales volume of 9 million pieces, it can be estimated that yearly sales of brake lining materials to the busing industry are $22-27 million.

Major manufacturers of bus brake blocks are: Abex Corporation, Carlisle Corporation, and P. T. Brake Lining Company. Other large manufacturers are: Auto Friction Corporation, Bendix Corporation, H. K. Porter Company, and Wheeling Brake Block Manufacturing Company. See Table 1 for the complete list of brake lining manufacturers.

VI. AGRICULTURAL, CONSTRUCTION AND INDUSTRIAL EQUIPMENT

A. Background

Agricultural equipment is all equipment used in farming and forestry, such as tractors, harvesters, log skidders, and the like. Construction equipment is used for the construction of roads, homes and buildings and includes wheeled tractors, rollers, scrapers, dozers, power truck cranes, hoists, shovel loaders, and the like. Industrial equipment includes all equipment used in a fixed facility or building such as overhead cranes and hoists.

Hydraulic brake systems used in agricultural and construction equipment are of either the dry or the wet brake type. Dry brakes are the conventional types of drum or disc system. Wet brakes use drum and disc brake assemblies, but in the wet brake system, the friction material is in a fluid environment. This type of brake exhibits decreased heat buildup and subsequently less fade, reduced lining and drum or rotor wear and improved braking control and reliability. Dry brake systems use the conventional organic binder/asbestos linings. A wet brake normally uses metallic brake linings.

Industrial equipment normally uses the conventional drum brake systems with organic binder/asbestos linings. Linings in industrial equipment are often made to specific dimension, wear, and tolerance requirements. In industrial equipment with smaller motors and light braking requirements, various types of disc brake systems with disc pads are used.

Brake system operating temperatures for industrial equipment reach a maximum of 550-650°F. The average operating temperatures are in the 350-450°F range. Coefficient of friction for these materials are 0.3-0.5 in the normal operating temperature ranges.

B. Product Requirements and Performance

In the agricultural, construction, and industrial equipment classification, the great variety and number of equipment uses make it difficult to state any specific brake lining requirements. In agricultural and construction equipment, a general trend is toward the use of wet brake systems (except in hoists and cranes), and satisfactory performance is being obtained with these systems. However, in equipment not using wet brakes, such as tractors, bull dozers, and the like, friction material stability and wear in many cases is not acceptable, and improved materials would be useful.

In industrial equipment, such as cranes and hoists, wet brake systems are not used, and an improved friction material with longer wear is needed. One of the major costs for overhead cranes in industrial use is lining maintenance. Frequent adjustments of the equipment brakes are required, during heavy use as often as every five to six days, and lining replacement is required every three to four weeks, leading to interrupted machine operation and considerable labor costs. Self-adjusting brakes would somewhat reduce this expense, but longer wearing linings are needed.

All brake linings used in industrial equipment contain asbestos fibers. The high wear rates and the fact that this equipment operates in enclosed factories and shops, indicates that a health hazard may exist with the use of these linings. The National Institute for Occupational Safety and Health (NIOSH) has set up recommended standards for worker exposure to asbestos dust. This standard states that no worker shall be exposed to more than 2.0 asbestos fibers per cubic centimeter (cc) of air based on a count of fibers greater than 5 μm in length.

Brake systems and brake lining materials used in agricultural, construction, and industrial equipment appear not to be covered by any government regulation. Equipment specifications devised by the manufacturers and Society of Automotive Engineers tests are the only means available for examining and categorizing new brake lining materials. However, the various equipment manufacturers thoroughly test new improved materials, sometimes over a period of one to two years, before the materials are accepted for use by the industry.

C. Market

1. Agricultural Equipment

Because of the tendency toward use of wet brake systems in agricultural equipment and the opinion that a suitable original equipment market for dry, molded organic brake linings does not exist in this category, no estimate of the lining market was made.

The brake lining after-market for agricultural equipment also proved to be difficult to estimate, because a considerable amount of these linings are sold to the original equipment manufacturer for distribution to dealerships who service this equipment.

2. Construction Equipment

For the same reasons, no original equipment market estimates were made for construction equipment. The majority of the new construction equipment uses wet brake systems, and a dry, molded organic lining may not be applicable.

The brake lining after-market for conventional organic/asbestos lining is quite large, but a lengthy study would be necessary, and considerably more time and funds than were available for this survey would be required to determine actual size and needs of this market.

3. Industrial Equipment

The industrial equipment industry is probably the one most likely to accept a new organic brake lining material possessing improved wear and friction properties. A lining having these qualities and containing no asbestos is needed by this industry.

Original equipment and after-market sales for brake linings used on industrial equipment are estimated to be in excess of $80-100 million annually. The inability to separate these two markets and the varying number of friction material pieces used in each equipment unit, makes it impossible to accurately estimate total brake friction pieces sold for each market. Indications are, however, that an improved dry composition brake lining could find market acceptance in this area. A much more detailed study would be needed to determine specific market opportunities.

Major suppliers of brake linings to the agricultural, construction, and industrial equipment industries are: Abex Corporation, Bendix Corporation, Royal Industries, Brassbestos Corporation, Carlisle Corporation, Raybestos-Manhattan Incorporated. Nearly all the suppliers listed in Table 1 supply one or all of these industries to some extent.

TABLE 1

BRAKE LINING MANUFACTURERS

Abex Corporation Friction Products Group	Winchester, Virginia
Auto Friction Corporation	Lawrence, Massachusetts
Bendix Corporation Friction Materials Division	Cleveland, Tennessee
Brassbestos Manufacturing Corporation	Paterson, New Jersey
Carlisle Corporation Molded Materials Division	Ridgway, Pennsylvania
Chrysler Corporation Chemical Division	Trenton, Michigan
Forcee Manufacturing Corporation	Tappanhannock, Virginia
Gatke Corporation	Chicago, Illinois
General Motors Corporation Delco-Moraine Division	Dayton, Ohio
Lasco Brake Products Corporation, Ltd.	Oakland, California
Maremont Corporation Grizzly Friction Products	Paulding, Ohio
Molded Industrial Friction Corp.	Prattville, Alabama
H. K. Porter Company, Inc. Thermoid Division	Pittsburgh, Pennsylvania
Raybestos-Manhattan, Inc. Grey-Rock Division Raybestos Division	 Manheim, Pennsylvania Bridgeport, Connecticut
Reddaway Manufacturing Company, Inc.	Newark, New Jersey

Royal Industries Brake Products	Danville, Kentucky
Thiokol Chemical Corporation	Trenton, New Jersey
S. K. Wellman Corp.	Bedford, Ohio
Wheeling Brake Block Manufacturing Co.	Bridgeport, Ohio
World Bestos Company, Division of The Firestone Tire & Rubber Company	New Castle, Ohio

VII. RAIL CARS

A. Background

Most railroad trains rely on two braking systems - a dynamic brake and a friction brake. Most selfpropelled rail cars, such as locomotives, rapid transit cars, and some passenger cars, have a dynamic brake, which is used either independently or together with the train's friction braking system down to about 5-10 mph, using complete friction braking for the last distance to a complete stop. Heavier trains, quicker stops, and downhill braking can require a greater use of friction braking. The friction braking system of all trains must be capable of performing the complete braking operation.

The two kinds of friction brakes in common use are the tread brake and the disc brake. The tread brake operates by the application of the brake shoe (friction material) against the rail car's steel wheel on the tread. Most brake shoes sold in the United States today are for freight cars. On passenger rail cars, disc brakes are now becoming increasingly popular.

Although the friction material used in brake shoes for tread brakes and that used in disc pads for disc brakes are similar in the railroad industry, the two brake systems are different.

In tread braking systems, two materials comprise the friction elements--the brake shoe friction material and the wheel. The majority of rail car wheels are untreated or heat-treated wrought carbon steel and cast carbon steel wheels. Wheel diameters vary from 28 to 40 inches. The material traditionally used by railroads for brake shoes has been cast iron. The first composition brake shoe made with a blend of organic and inorganic materials was accepted for rail car interchange use by the Association of American Railroads (AAR) in the mid-1960s. In the early 1970s, the first high-phosphorus (3% phosphorus) iron-alloy shoe was introduced. Today, approximately one-third of the two million freight cars in the United States are using cast-iron shoes, one-third are using the high-phosphorus iron alloy shoes, and one-third are using the composition shoes. Most new freight cars and locomotives are equipped with composition shoes. All of Amtrak's tread braked cars are now or will be converted to composition shoe brakes. Most other tread braked passenger service equipment uses mostly composition shoes. The trend in the railroad industry appears to be away from metal shoes toward the composition shoe.

Disc brake systems are used primarily in passenger service, such as on intercity passenger cars and rapid transit cars. There are usually one, or more commonly two, brake discs per axle. Although more expensive, the disc brakes have several advantages over an equivalent tread brake system by allowing higher braking forces, increased wheel life, increased braking control, and reduced braking fade.

Brake discs are commonly made of a cast iron or a steel with high-temperature stability such as meehanite. Disc sizes are generally about 23-28 inches in diameter.

In Table 2, the approximate weights, speeds, deceleration rates, and kinetic energies of the various types of railroad vehicles are shown to aid in the understanding of the operating conditions to which the brakes and friction material must respond. Although not illustrated in the table, it is important to mention a trend toward heavier freight cars in use. New freight cars installed in 1974 had an average capacity of 85 tons, compared with a 62-ton average for cars retired.

TABLE 2

RAIL VEHICLE DATA

Type of Vehicle	Weight When Loaded (lbs)		Speed (mph)		Maximum Kinetic Energy per Wheel (lbs)	Deceleration Rate (mphps)	
	Total	Per Wheel	Usual	Maximum		Service	Emergency
Freight Car	170,000-320,000	20,000-40,000	55	80	0.9 - 1.8 million	1-2	3-4
Locomotive	250,000-550,000	30,000-40,000	55	80	0.9 - 1.8 million	1-2	3-4
Intercity Passenger Car	200,000	25,000	110	160	2.2 - 4.6 million	3	4-6
Commuter Coach	160,000	20,000	80	100	0.9 - 1.4 million	3	4-6
Heavy Rapid Transit (Subway) Car	80,000-120,000	10,000-15,000	50	80	0.3 - 0.7 million	3	4-6
Light Rail Vehicle (Streetcar)	100,000	8,500	35	60	0.1 - 0.2 million	3	4-6

B. Product Requirements and Performance

When considering the purchase of a brake friction material, railroads are generally concerned with how the material's performance relates to safety, economics and train control. Specifically, braking performance, brake shoe life, wheel mileage, sparking, noise, odor and the associated price are of concern.

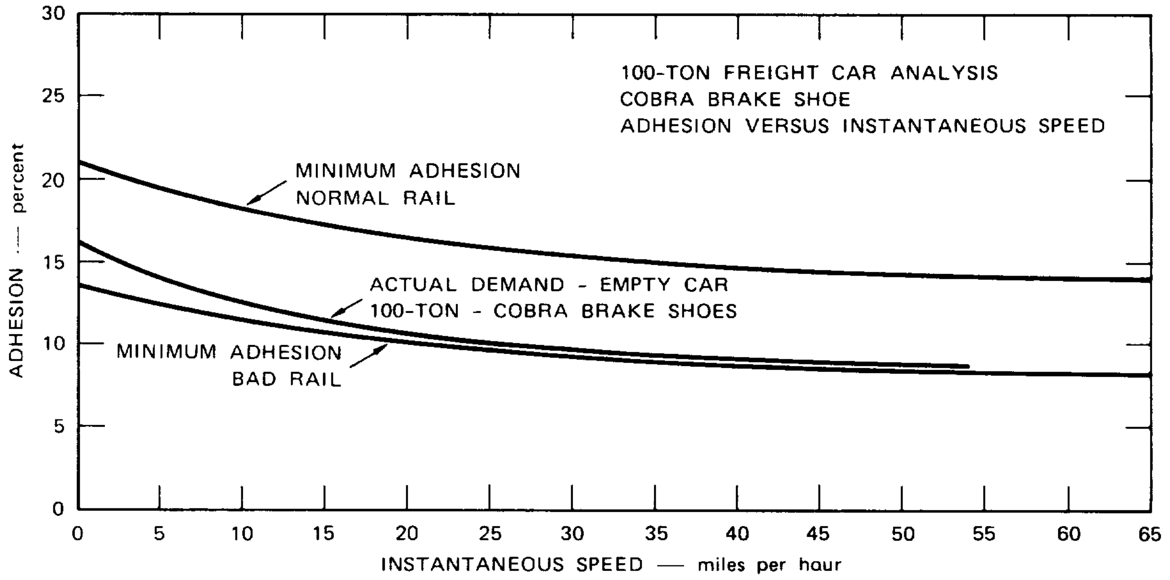
1. Braking Performance

Braking performance refers to the effect of the friction material on stopping distance, train braking control, and retardation smoothness.

Reduced stopping distance would have closely associated safety and economic advantages for railroads. At current operating speeds, a reduced stopping distance, particularly in emergency braking, can increase safety. From an operator's viewpoint, a reduction in stopping distance can allow greater operating speeds with equivalent safety, thereby allowing an increase in flow of passengers and goods per unit time.

An increase in train braking control and smooth retardation makes train brake handling easier for the train engineer and reduces car lurching, thus protecting lading and increasing passenger comfort.

Braking performance is primarily a function of the friction material's coefficient of friction and its conformability (effective shoe surface contact) with the wheel. For most effective train braking performance, a friction material with a relatively high coefficient of friction that varies with speed parallel to the variation of wheel-to-rail adhesion with speed is needed. The coefficient of friction decreases as the relative velocity between two mating surfaces increases. This is probably due to the heat effect, or fade. Thus, as train speed goes up, the friction value goes down. Similarly, wheel-to-rail adhesion decreases with increasing speed as illustrated in Figure 3.



SOURCE: Railroad Friction Products Corporation.

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FIGURE 3 COMPOSITION BRAKE SHOE ADHESION (AT CONSTANT PRESSURE) COMPARED TO WHEEL TO RAIL ADHESION

For effective stopping and ease of train handling, the coefficient of friction should vary with speed such that the actual demand on adhesion parallels the wheel-to-rail adhesion curve without exceeding it. The variation of the coefficient of friction with speed for conventional composition shoes is shown in Figure 4. When this is transferred to the adhesion demand of an empty 100-ton freight car in the line of Figure 3, the curve is nearly parallel to the wheel-to-rail adhesion curves.

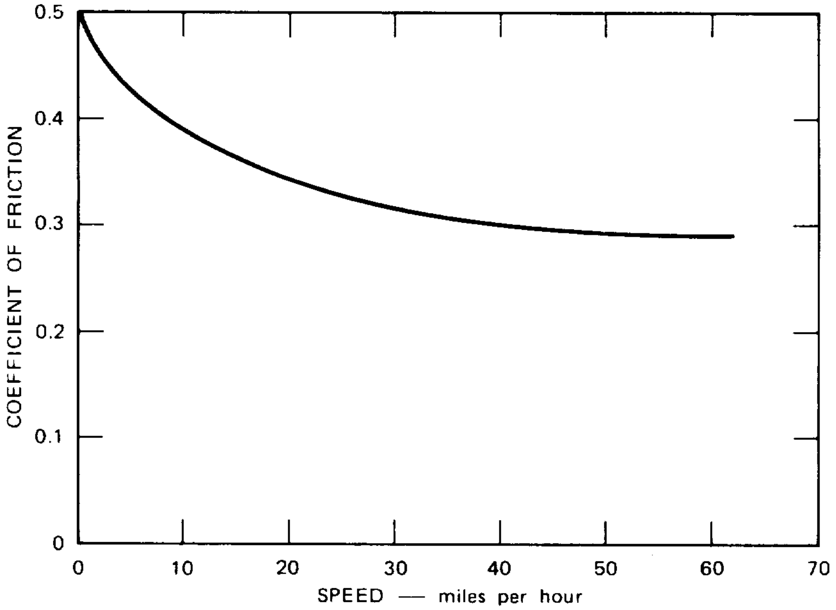
The static coefficient of friction of conventional composition shoes is approximately 0.5. The dynamic coefficient of friction of composition shoes is generally 0.27 to 0.32 depending on speed and temperature. The friction value of composition shoes remains stable until heated to about 200°F when an approximate 10-15% fade occurs. The coefficient of friction then stays fairly constant until about 900°F when fade is again likely.

The braking performance of currently used composition disc pads appears to be satisfactory. The disc pad material is probably similar to the composition material used in rail car brake shoes. The dynamic coefficient of friction is about 0.35 and, as with brake shoes, some fading is experienced at higher temperatures.

The composition materials used today appear to be very satisfactory regarding braking performance. Only a material that experiences little or no fade, such that its actual demand curve would be even closer to paralleling the wheel-to-rail adhesion curve, could be expected to be an improvement. If such a material had a greater coefficient of friction, its value to braking performance might be even greater, particularly with the railroads' trend toward the use of heavier freight cars.

2. Brake Shoe Life

Brake shoe life is determined by the wear rate of the friction



SOURCE: Railroad Friction Products Corporation.

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FIGURE 4 VARIATION OF COEFFICIENT OF FRICTION WITH INSTANTANEOUS SPEED material and its structural integrity. An increase in brake shoe life has a direct economic advantage in terms of expenditures on brake shoes and brake shoe maintenance savings. An indirect advantage, particularly regarding shoe structural integrity, is decreased rail car down-time.

The following estimates made with a 100-ton freight car equipped with 1½ inch thick conventional composition shoes, illustrate the relationship between direct shoe cost and replacement labor cost, and shoe life measured by mileage.

Composition Brake Shoe Mileage:	80,000 miles average shoe life
Average 100-Ton Car Mileage:	60,000 miles per car year
Cost of 1½ inch Thick Composition Shoe	\$5.40
Labor Charge to Change 1 Shoe:	3.15
	\$8.55
Cost per Car Set Applied (\$8.55 X 8):	\$68.40
Annual Composition Shoe Cost per Car:	$\$68.40 \times \frac{60,000}{80,000} = \$51.30$

This calculation format could be used to approximate the direct economic benefit of a longer wearing shoe material if price and mileage for the same type car and service conditions are known.

The structural integrity of the friction material significantly affects annual shoe costs. The strength of the friction material should be such that the high shoe loads, severe vibrations, and the high braking temperatures (commonly from 500°F to 1100°F) do not result in any shoe material fracturing or separating from the backing plate.

An average brake shoe life is difficult to determine. Estimates vary anywhere from 40,000 miles to 150,000 miles for freight cars, between 10,000 miles to 30,000 miles for intercity passenger cars, and between 100,000 miles and 200,000 miles for rapid transit cars. Regarding disc pad wear, intercity passenger cars travel about 10,000 to 60,000 miles per set of disc pads. Rapid transit cars travel about 20,000 to 80,000 miles per set of pads.

Improved braking performance can be acquired by an increase in brake shoe force (i.e., braking ratio)[*], however, the shoe wear rate increases with increasing force or braking ratio. Tests on composition shoes indicate that the relative wear goes up as the square of the increase in braking ratio (see Figure 5). It would appear then that friction material with comparable wear characteristics to conventional composition shoes, but with a larger coefficient of friction would require less brake force for equivalent stopping and, therefore, would have a reduced wear rate.

Associated with the increased wear rate of friction materials with shoe force, is the effect of shoe temperature on wear rate. The rate of wear of composition shoes tends to increase above 600°F. As temperatures can rise to 500-700°F in normal service braking and to 700-900°F in emergency braking, a friction material that resisted this property of increased wear with temperature would be advantageous.

3. Wheel Mileage

Improved wheel mileage can be of benefit to a railroad from both safety and economic viewpoints. Thermal damage to a wheel can initiate cracks in the wheel which, if grown with further thermal or mechanical stress, can cause wheel failure which could result in a derailment. Nonuniform wheel tread wear can require machining of the wheel, adding expense and reducing life. Similarly, wheel locking and sliding, as a result of a variance in the shoes' coefficient of friction and wheel-to-rail adhesion, can wear flat spots on the wheel, causing stress buildup

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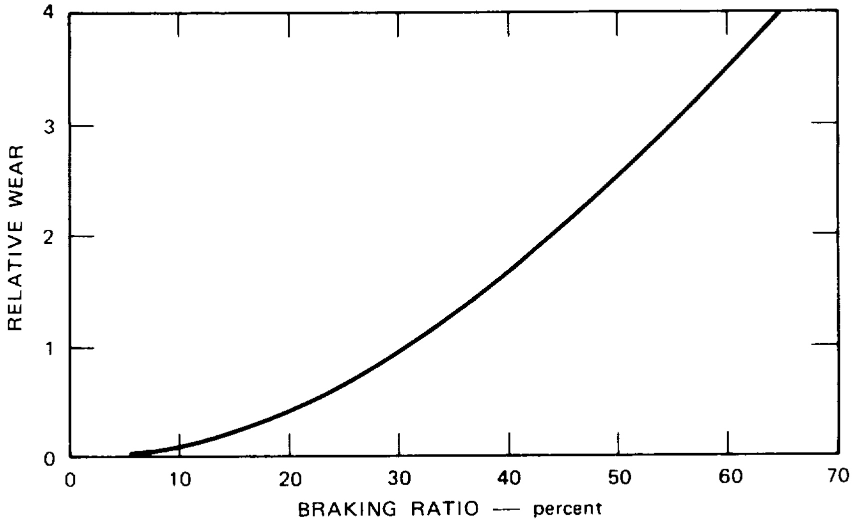
[*] Braking ratio is a ratio of net brake shoe load divided by loaded car weight, expressed as a percentage.



SOURCE: Railroad Friction Products Corporation.

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FIGURE 5 EFFECT OF BRAKING RATIO ON SHOE WEAR OF A COBRA SHOE in the wheel if not corrected, and adding maintenance expense.

An estimate of the direct costs associated with overall wheel mileage can be made with composition shoes on a 100-ton freight car. Replacement cost and installation labor for a car set of 8 wheels mounted on 4 roller bearing axles is $2000. Wheel costs per car year (based on 60,000 miles per year average car mileage and 230,000 mile wheel life with composition shoes) is $520.

The heat created at the friction surface during braking can cause the formation of hot spots on the wheels, resulting in thermal cracks (small shallow cracks in the wheel tread) and spalling of small portions of the tread between the cracks. Local hot spots on the tread which exceed 1300°F while the average temperature of the wheel tread in contact with the brake shoe is much lower, can result from nonuniform heating of the wheel tread. The nonuniform heating is probably the result of uneven shoe-to-wheel surface contact and pressure. The rate of heating and cooling contribute more to the thermal cracking of the wheel than does the total amount of heat introduced (i.e., maximum temperature reached).

A maximum of 25 braking horsepower per wheel is set by current recommended practice to lessen the chance of wheel thermal damage. This can, however, have the effect of limiting car tonnage if current speeds and deceleration rates are maintained. A friction material that allowed an increase in braking load without an increase in wheel thermal damage would therefore be advantageous to the railroads. Also, it may be possible to reduce the occurrence of hot spots by increasing the conformability of the brake shoe to the wheel.

The tread profile of the brake shoe wear pattern on the wheel, if not coinciding with the original wheel taper or if in the form of grooves, can require machining of the wheel to correct the situation. Composition shoes appear to perform satisfactorily with regard to wheel wear.

Finally, a variation of the friction material's coefficient of friction with speed as compared to wheel-to-rail adhesion at the same speed, can contribute to wheel locking and sliding, resulting in flat spots in the wheel tread. Flat spots generally require machining to correct, which adds to maintenance cost and reduces wheel life.

Brake shoe chatter and squeal noise affects the public's appeal toward the railroad as well as causing a possible occupational health and safety hazard. The brake shoe should not emit any objectionable or unhealthy odor which may be caused by high temperature braking. Currently used composition shoes appear to perform quite well with respect to odor and satisfactorily with regard to noise. Brake noise is of most concern on passenger cars. Currently used disc brakes measure less than 85 dBA at 15 feet, which is an acceptable level.

A comparison of the technical performance of a brake shoe to shoe price gives an indication of the value associated with brake shoe performance. A comparison of performance characteristics and prices of cast iron, 3 percent phosphorous iron alloy, and composition shoes may be useful as an indication. A 1½ inch thick cast iron shoe has a price of about $3.20 and a coefficient of friction value of approximately 0.15 to 0.20. A similar 3 percent phosphorous iron alloy shoe has a price of $4.00 and the following improvements over the cast iron shoe:

- Approximately twice the shoe life
- Significant reduction in sparking from shoe/wheel interface
- Higher coefficient of friction
- Coefficient of friction versus speed curve closer to wheel-to-rail adhesion versus speed curve.

A 1½ inch composition shoe is priced at $5.40 and has the following improvements over a cast iron shoe:

- Approximately four times the shoe life

- Near elimination of sparking from shoe/wheel interface.
- Much higher coefficient of friction (0.27 to 0.33).
- Coefficient of friction versus speed curve very close to wheel-to-rail adhesion versus speed curve.
- Less thermal damage to wheel

These figures indicate that no direct price association with brake shoe performance exists. This is most obvious when comparing shoe price and shoe life. Even a significantly improved new product could probably only be given a comparatively modest increase in price over currently sold composition shoes.

C. Market

Ninety-nine percent of all freight and intercity passenger railroad traffic in the United States is carried by seventy-three Class I (i.e., annual operating revenues above $5 million) line-haul railroads. Included in this category is the National Railway Passenger Corporation (Amtrak), which is the primary intercity passenger carrier. In addition, there are thirty commuter railroad operations, eight heavy rail rapid transit systems, and eight light rail rapid transit or streetcar systems operating in the United States.

In the brake shoe industry, original equipment shoes are specified by the railroad to the carbuilder, and replacement (after market) shoes are purchased by the railroad directly from the brake shoe manufacturer. In the disc pad industry, however, the carbuilder or brake builder usually specifies the brake pads for the original equipment and the railroad buys replacement pads from the carbuilder or brake builder, rather than from the brake pad manufacturer. Due to much longer car life, as compared to brake shoe or pad life, the replacement market is by far the greater in the rail car brake shoe and pad industry.

A breakdown of the number and types of cars in service at the end of 1974 and projected figures for the next five years are given in Table 3. The usage of brake shoes and disc pads varies according to the requirements for each railroad vehicle, and an overview of the current market for brake linings in the railroad industry is therefore presented for each of the vehicle categories listed in the table.

1. Freight Cars

There were 1,720,573 freight cars and about 15,000 cabooses in railroad service at the close of 1974. This number varies relatively little from year to year. There were 66,754 new freight cars placed in service in 1974 and the average number of new freight cars placed in service per year over the past 5 years is about 59,000 cars. An approximate equal number of freight cars are retired each year as new cars are added.

Not all freight cars can use composition brake shoes because of the much higher coefficient of friction of these shoes. The brake system of most older freight cars is designed for metal shoes which require a larger brake shoe force than is required with composition shoes for equivalent braking effort. Similarly, metal shoes are not effective if placed on cars with brake systems designed for composition shoes. Approximately one-third of all U. S. freight cars or 600,000 cars are equipped with composition shoes. In addition, nearly all of the approximately 60,000 new cars installed each year are equipped with composition shoes.

It is estimated that the average 1½ inch thick composition freight car shoe lasts approximately 80,000 miles on a freight car and that the average car equipped with composition shoes travels about 50,000 miles per year. As there are normally 8 brake shoes per car, an estimated 3 million composition brake shoes were installed on freight cars in 1974.

TABLE 3

ESTIMATED RAIL CAR COMPOSITION BRAKE FRICTION MATERIAL MARKET

Brake and Car Type	Total Number of Cars in 1974	Number of Cars With Composition Shoes or Pads	Average Car Mileage/Year	Average Shoe or Pad Mileage	Number of Pieces Used in 1974	New Car Purchases Over Next 5 Years
Tread Brake Shoes						
Freight Car	1,730,000	600,000	50,000†	80,000	3,000,000	300,000
Locomotive	28,400	8,000	120,000	80,000	140,000	5,000
Intercity Passenger Car	1,600	1,500*	130,000	30,000	50,000	-
Commuter Coach	5,000	5,000	50,000	50,000	40,000	600
Heavy Rapid Transit Car	8,700	2,200	46,000	150,000	5,000	800
Streetcar (LRV)	1,100	-	27,000	-	-	-
TOTAL	1,770,000	620,000	-	-	3,200,000	300,000
Disc Brake Pads						
Intercity Passenger Car	600	600	130,000	30,000	80,000	700
Commuter Coach	200	200	50,000	50,000	3,000	200
Heavy Rapid Transit	700	700	46,000	50,000	4,000	1,200
Light Rail Vehicle	-	-	30,000	25,000	-	750
TOTAL	1,500	1,500	-	-	90,000	3,000

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† In 1974 the average yearly mileage of a freight car was 21,000 miles, however, the newer, larger capacity freight cars travel considerably more than average.

* Includes cars being converted from iron to composition brake shoes.

This number will probably be relatively stable in future years as the increase of the proportion of freight cars using composition shoes and needing replacements will be partially balanced by the reduction in the average yearly car mileage for composition shoe equipped cars as these cars become more common.

2. Locomotives

There were 28,355 locomotive units in service on Class I railroads at the close of 1974. This number varies relatively little from year to year, although there has been an average of about a one percent increase in the locomotive unit fleet size each year for the past five years, with the majority of the increase coming in the last two years. The average number of locomotive units in service at any one time over the last five years has been about 27,600 units. There were 1212 new locomotive units placed in service in 1974 and average number of units placed in service each year for the past five years is about 1200 units.

About one-fifth of all locomotives are switchers which use cast iron shoes almost exclusively. Most of the new line-haul locomotives installed in the last ten years use composition shoes; most of the older locomotives still use cast iron shoes. Therefore, approximately 8000 line-haul locomotive units, most of which have one brake shoe for each of its 12 wheels currently use composition shoes. An estimated 1000 new units per year in the near future will also use composition shoes. It is estimated that the usual 2 inch thick shoe lasts approximately 80,000 miles on a locomotive. A line-haul locomotive travels about 120,000 miles per year. Consequently, it is estimated that 140,000 shoes were installed on locomotives in 1974.

3. Intercity Passenger Cars

There were about 2200 intercity passenger cars in service in 1974. About 2000 of these are operated by Amtrak. Approximately one-third of this fleet is equipped with disc brakes and the remaining two-thirds is equipped with composition and metal brake shoes. The metal shoe equipped cars, however, are currently being converted to composition shoes. Amtrak has about 700 new disc braked cars on order, which with the retirement of some older cars may increase the intercity passenger car fleet to over 2500 cars. The intercity passenger car trend is toward disc brakes.

The average intercity passenger car travels about 130,000 miles a year and both 2 inch thick composition brake shoes and ½ to 1 inch thick disc pads last about 30,000 miles in this service. There is one brake shoe for each of the 8 wheels on a passenger car so it is estimated that 50,000 composition brake shoes were installed on intercity passenger cars in 1974. Disc braked passenger cars normally have two discs for each of the four axles, and four pads are used with each disc. Consequently, it is estimated that 80,000 disc pads were used in 1974.

4. Commuter Coaches

There were about 5200 commuter coaches in service in the United States in 1974. About 5000 use tread brakes with composition shoes and the remaining 200 use disc brakes. It is expected that about 600 new cars with composition brake shoes and 200 new cars with composition disc pads will be purchased in the next few years.

The average commuter coach travels about 50,000 miles a year and 2½ inch thick composition shoes and ½ to 1 inch thick disc pads last an estimated 50,000 miles in this service. With 8 brake shoes per car for tread braked cars and an estimated 16 disc pads per car for disc braked cars, it is estimated that 40,000 composition brake shoes and 3000 disc pads were installed on commuter coaches in 1974.

5. Heavy Rail Rapid Transit Cars

There were about 9400 heavy rail rapid transit (subway or elevated) cars in operation in the U.S. in 1974. This number has remained very stable with less an a 1 percent change from the average of 9360 cars for the previous five years. About 6500 of these cars use metallic tread brake shoes, 1450 use composition tread brake shoes, 750 use composition drum brake linings, and 700 use composition disc brake pads. In Table 3 , the drum brake lining figures are included in the brake shoe figures.

The anticipated demand for new heavy rail vehicles, including those of five transit systems not currently operating heavy rail vehicles, is an average of about 400 cars per year for the next five years. Of these, it is estimated that about 160 will be composition shoe tread brake equipped and the remainder disc brake equipped. An average of 300 new heavy rail rapid transit cars were delivered per year over the past 10 years. Therefore, an increase in the total number of these vehicles operated in the U.S. by over 100 cars per year is anticipated. Most of these cars will be disc brake equipped.

With one shoe for each of the 8 wheels of a heavy rail rapid transit car, it is estimated that about 5000 2- to 2½-inch thick composition shoes were used on these cars in 1974. Simularly, with an average 8 disc pads per car, it is estimated that 4000 ½-inch thick composition disc pads were used in 1974.

6. Light Rail Vehicles

There were about 1070 light rail rapid transit cars (streetcars) in operation in the U.S. in 1974. This number has been declining by a steady average of about 50 cars per year for the past 5 years. All of these cars are equipped with metallic shoes or linings on tread or drum brakes.

Although the past trend indicates a declining market for streetcars (1952 was the last year that a new streetcar was delivered in the U.S.) streetcars or light rail vehicles (LRVs) are being considered as options for new mass transit systems by more and more U.S. cities. With U.S. Department of Transportation assistance, a standard LRV design was established in recent years. San Francisco and Boston are purchasing 100 and 175 of those new LRVs respectively. These are disc brake equipped. It is estimated that an average of about 150 LRVs will be purchased per year for the next 5 years. Generally, these 6-axled LRVs will have one disc brake per axle and the disc pads are specified to last 25,000 to 50,000 miles. These LRVs will travel an average of 30,000 miles a year.

7. Current Manufacturers and Prices

The three primary U.S. manufacturers of composition brake shoes and disc pads for rail cars are the Abex Corporation, the Griffin Wheel Company (friction material made by Raybestos Manhatten, Inc.), and the Railroad Friction Products Corporation. Due to the expanding U.S. market for rail car disc pads, other U.S. and foreign friction material manufacturers are entering this market.

Table 4 outlines the common sizes and prices of currently used composition brake shoes and disc pads by rail car type. Commonly, a manufacturer will use nearly the same formulation for all his brake shoes, although disc pad formulations frequently differ from the brake shoe formulations.

TABLE 4

COMMON SIZES AND PRICES OF RAIL CAR BRAKE SHOES AND PADS

Type Car and Brake	Approximate Size of Brake Shoe* (Length x Width x Thickness) or Disc Pad (Surface Area x Thickness)	Current Price in Pallet Quantity†
Freight car - tread	13 in x 3½ in x 1½ in	$ 5.40
Freight car - tread	13 in x 3½ in x 2 in	6.24
Locomotive - tread	16 in x 3½ in x 2 in	7.90
Intercity Passenger - tread	14 in x 3½ in x 2 in	7.20
Commuter Coach - tread	16 in x 3½ in x 2½ in	7.90
Heavy Rapid Transit - tread	12 in x 6 in x 2 in	13.30
Intercity Passenger - disc	62 sq in x 1 in	10-15
Heavy Rapid Transit - disc	55 sq in x ½ in	3-7

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* Most composition tread brake shoes have one or more slots across the shoes length totaling about 1-2 inches.

† Price includes backing plate for brake shoes.

VIII. AIRCRAFT

A. Background

The use of organic friction materials in aircraft brakes is currently limited primarily to small general aviation aircraft. The trend in larger aircraft brake materials has been toward higher energy absorption per unit mass of brake materials. Aircraft size and brake temperatures have risen through the years, and on larger aircraft, organic friction materials have been replaced by more expensive copper- and iron-based metallics. Composition friction materials are used on almost all single-engine and a few twin-engine piston general aviation aircraft of a maximum gross weight of about 8000 pounds.

The brakes of these small aircraft are used dynamically during landing and taxiing and statically during pretakeoff engine runup. During landing, the speed of an airplane is usually below 60 mph before the brakes are applied. If the runway is large enough, coasting is often used to slow the plane before the brakes are applied for taxiing and turning. During a normal landing, brake temperatures are commonly between 500-800°F.

Before about 1960, most general aviation airplanes were equipped with drum brakes. Since then, disc brakes, with one brake for each of the two main landing gears, have been common. Each brake uses a single steel disc about 8 inches in diameter. The discs are frequently made from a nonheat-treated steel, such as SAE 1018 steel. Brakes in common use have two, four, or six brake segments per brake. The number of segments used affects the brake assembly size. For example, a two-segment brake requires a single piston caliper brake assembly with about a 2000-lb brake segment force in normal braking, whereas a four-segment brake requires a double piston caliper brake assembly with a normal brake segment force of about 3300 pounds. Over half of the small airplanes use two-segment brakes and most of the remainder are four-segment brakes. The segments are made of an organic asbestos and brass chip composition material and are commonly riveted to the metal backing plate.

B. Product Requirements and Performance

The properties of importance in small airplane friction materials are the coefficient of friction, wear, disc wear, and price.

The level of coefficient of friction is most important in regard to a desired improvement over the conventional organic composition friction materials. The dynamic coefficient of friction has a large effect on the size and weight of the brake assembly. A friction material with a significantly higher coefficient of friction could allow a reduction in the size and weight of the brake assembly. A reduction in equipment weight and size would be of great economic benefit to the airplane manufacturer and user. In addition, a reduction in the brake assembly size and complexity, such as from a double to a single piston caliper brake allowed by a friction material with a higher coefficient of friction, would allow a significant reduction in the brake assembly cost. Finally, an organic composition friction material with a significantly higher coefficient of friction could possibly be used on more of the twin-engine general aviation airplanes. A reduction in segment and brake assembly cost would thus be possible for these airplanes, since currently used metallic segments cost two to four times more than equivalent organic composition segments. The conventional organic composition friction materials used have a dynamic coefficient of friction between about 0.36 when cold to about 0.25 when hot (about 800°F). Conventional metallic (iron and copper) materials have a coefficient of friction between about 0.45 when cold to about 0.33 when hot.

Conventional organic friction materials perform quite satisfactorily with respect to the other properties of importance in the airplane brake segment. The conventional materials can fade somewhat with increased brake heating, but improvement in this property is not needed for the airplanes currently using organic composition brake segments. The lack of fade in combination with a higher coefficient of friction might increase the possibility of an organic composition segment being used on airplanes where metallic segments are now used however. Smooth retardation is of importance since the landing gear is sensitive to low frequency vibrations. Segment life commonly varies between one-half year to two years, depending on the frequency and type of airplane use. It takes one hour to reline a single engine plane and about 2-2½ hours to reline a twin-engine plane. With labor rates of about $15.00 per hour, this can be significant expense. The cost of the friction material itself is also of economic importance with regard to wear.

As with most organic composition friction materials, the wear rate tends to increase at higher temperatures. Dimensional stability and structural integrity are of importance with respect to the rate at which high altitude-cooled brake segments can heat to 1000°F and above during braking in landing.

In summary, conventional organic composition friction materials used primarily on single-engine airplanes perform quite satisfactorily, although a significant increase in the dynamic coefficient of friction would be of value to the airplane manufacturers and users.

C. Market

General aviation aircraft have four basic areas of use: business, commercial, instructional, and personal. The bulk of the business general aviation aircraft are the larger multiengine aircraft that use metallic brake segments. Most commercial, instructional, and personal general aviation aircraft are equipped with brakes that use organic composition brake segments.

In the general aviation aircraft industry, the brake segments are commonly manufactured by a friction material manufacturer and sold to the brake manufacturer who installs them in the original equipment. In the aftermarket, the segments go through the chain of friction material manufacturer, airplane brake manufacturer, airplane manufacturer, and airplane dealer or distributor before they are sold to the airplane owner.

In 1972, 109,256 single-engine and 17,855 multiengine fixed-wing aircraft were registered in the United States. Of the multiengine aircraft, approximately 5 percent use organic composition brake segments. Almost all single-engine airplanes use organic composition disc brake segments. Therefore, approximately 100,000 airplanes currently use organic composition segments in their brakes.

Three companies manufacture most of the airplanes that use organic composition brake segments. These companies delievered a total of 6433 airplanes in 1971, 8227 airplanes in 1972, and 11,605 airplanes in 1973. The 1973 number is more representative of the sales of 1965-69, before the 1970 economic downturn. The 1973 figure is probably representative of the average expected shipments per year. Most of these deliveries use organic composition brake segments, consequently, an estimated 10,000 new airplanes are delivered per year with organic composition brake segments.

The average general aviation aircraft flies about 200 hours, or about 24,000 miles per year. Brake segments last an average of about one year on these small airplanes. Commonly, the brake segment is a 45 degree segment of a $7\frac{1}{2}$-in. OD, $5\frac{1}{2}$-in. ID ring that is $\frac{1}{4}$-in. thick. About 60 percent of the airplanes use two segments per brake and most of the remainder use four segments per brake. Consequently, an estimated 600,000 organic composition brake segments for aircraft are used per year.

The two primary manufacturers of organic composition brake segments for general aviation airplanes in the United States are Abex Corporation and Raybestos-Manhatten, Inc. The same size brake segment is made by both manufacturers. These manufacturers sell the segments for about $0.50 each in large quantities to the airplane brake manufacturers.

IX. BRAKE LINING MANUFACTURING PROCESSES

There are at least six basic methods of making brake linings[*], which are described briefly below:

A. Dry Process

All dry-process brake linings have as the major binder a dry "B" stage resin. In effect, a "B" stage resin is a thermosetting resin mixed with an intermediate and set in a partially cured condition. When the partially cured resin is reheated, it softens and becomes plastic. In the dry-processing of brake linings, this phenomenon is useful in the following way. All the weighed ingredients are first mixed in a tumbling barrel or similar mixer. A weighed portion of the mixed material is then spread uniformly in a shallow mold, which is placed in a hot press and heated under low pressure for a sufficient time and to a temperature that will cause the resin to flow and set, but not be fully cured. The resulting flat sheet is removed from the mold and cut into the developed section of the desired arcuate brake segment. This flat rectangular segment is then reheated to soften the resin and quickly formed to brake-lining shape on a cold mold which resets the resin. A final baking of the segment in restraining molds to retain shape converts the resin to a thermoset, or permanent, condition. The final cure, or bake, is dependent on the type of resin and the end usage.

B. Extruded Processes

Extruded brake linings are manufactured by three different processes.

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[*] Kirk-Othmer, Encyclopedia of Chemical Technology, (1966)

Two of these processes are similar in that both extrude a plastic, flat tape of lining through a shaped nozzle. The processes differ mainly in the means of application of the pressure on the plastic mass. One process applies direct hydraulic or air pressure on a ram forcing the material out, whereas the other process uses a screw-feed to extrude the stock into a continuous tape.

In the extruded process, all the ingredients are mixed together with a wet binder which may be resin, oil, rubber, or various combinations. The binder contains sufficient solvent to yield a putty-like mass whose consistency must be closely controlled to produce dense tape with good wet-strength.

After extrusion, in both processes the tape is dried in rolls and then finish-cured to shape in confining molds.

The third type of extrusion is known as roll forming. In this process, as in the first two, the lining is mixed, but it is less plastic, and after mixing consists of free-flowing, very slightly tacky granules. These granules are fed into the nip of two form rollers which compress the mixture into a continuous tape. The lining is then processed similar to the other types of extruded material. A variant of this process is the introduction of a 1/8-in.-mesh wire on the bottom roll to form a wireback lining. Roll forming produces a good quality of lining at low cost.

C. Wet Board Process

The wet board process of making a brake lining consists of adding all the ingredients except the binder to a beater or hydrapulper with a quantity of water. The mixed wet pulp is then further diluted and fed to a paper-making machine and formed into a thin sheet on a blanket, from which it is transferred to a revolving cylinder where it builds up to brake-lining thickness. The cylindrical deposit is cut from the roll to form a rectangular sheet which is dried and cut into the developed shape of an arcuate segment. The flat strip is then saturated in a liquid binder and either air- or oven-dried to remove solvents. At this stage, the binder is sufficiently flexible to allow forming into a curved mold for final cure.

D. Sheeter Process

A sheeter is a variant of a rubber mill which consists of one large, heated roll and one smaller, cold roll. These rolls revolve in opposite directions, creating a nip. The feed consists of a solvated rubber (natural or synthetic) that is mixed with asbestos and other ingredients in a heavy-duty mixer. The plastic mixture is fed into the nip of the rolls and a sheet builds up slowly on the hot roll. The gap between the rolls is automatically made to open further as the material thickens on the hot roll. The sheet is built up to thickness and is then slit from the roll in brake lining widths. Forming and final cure are similar to other processes.

E. Sintered Metal Process

Being distinctly different from the previously described methods, this process uses a metallic matrix in which the lubricants, fillers, and friction augmenting agents are held mechanically. The metal matrix is comprised of a powdered metal or metals of 100 mesh or finer. The commonest matrix is a copper-tin alloy, usually consisting of about 90% copper and 10% tin. Another popular matrix is an iron-carbon base. As an example, powdered metal normally comprising about 65% by weight of the batch is mixed with silica flour, graphite, and usually, lead. A weighed amount is placed in a mold and pressure of about 15,000 psi is applied by means of a hydraulic press. The result is a thin fragile wafer of material known as a cookie. Because sintered metal is structurally weak, it is commonly brazed to a metal member by placing the pressed wafer on a copperplated steel plate and applying pressure during heating in a furnace with a controlled atmosphere. At a temperature of about 1400°F, the time required for the copper-tin matrix is three hours. During this heat cycle, the copper-tin matrix fuses or sinters to the steel plate and the powdered metal particles sinter or bond together at their contact points, trapping the nometallic ingredients. Flat discs can be made directly with suitable molds, and curved segments can be made by processing to shape through a three-roll bender. Thick curved segments can be formed but with difficulty.

F. Woven Process

Linings made by this method are more expensive than linings made by the processes described above, because this process requires the spinning of Grade 3 Asbestos fibers. The fiber is "opened" in a hammer mill and is processed into asbestos yarn, usually with cotton comprising some 30% of the mixed fiber. The yarn is woven into tape and saturated or calendered with various binders and fillers. Final processing may produce a flexible roll lining, or rigid segments.

X. BRAKE LINING TESTING

In addition to actual vehicle testing of a brake lining material, the industry uses several laboratory test machines to characterize friction materials. These laboratory friction machines can be used to examine both wear rate and friction properties of the test materials. Although vehicle testing appears to be the only completely reliable method of testing brake lining material, laboratory tests are very useful and exhibit a number of advantages, such as:

(1) Test environment is controlled and the highly variable environment experienced during full-scale vehicle testing is avoided.

(2) Test hours can be accumulated at a continuous rate, unhampered by weather conditions, hours of daylight, and legal restrictions placed on highway operation of vehicles.

(3) Testing in the laboratory is much safer than highway vehicle testing because high-speed driving and brake application with untested materials are avoided.

(4) Laboratory tests cost less than vehicle testing because after initial equipment costs, even though these are very high, dynamometer test equipment has long life and low maintenance costs.

A. Dynamometer Testing

Dynamometer testing can be separated into two categories: bench-scale dynamometer test equipment and full-scale brake dynamometer testing.

In bench dynamometer tests, a small piece of the friction material is operated against a moving mating surface, and the forces produced by the friction couple are measured. Tests are conducted on a small scale, and results obtained more rapidly than with full-scale dynamometer tests. Results obtained on bench dynamometers are only an indication of results which will be experienced in a vehicle brake system. Testing done with a full-scale brake dynamometer, on the other hand, uses a full-scale brake and the brake lining as it is actually manufactured. This type of dynamometer testing gives a nearly complete description of the friction and durability characteristics of the lining. The dynamometer test machines used in the testing of brake linings are described below.

1. Friction Material Test Machine (FMTM)

This bench dynamometer, developed by the General Motors Corporation, attempts to record the brake lining performance by subjecting it to controlled conditions of pressure and temperature at the friction interface, and speed. A small 1-sq. in. sample is pressed against the interior of a rotating drum. The temperature of the rotating drum is controlled and, due to the large surface area in relation to the test sample, the sample temperature reaches that of the bulk drum temperature. The friction force exerted by the rotating drum against the lining sample is measured, and the coefficient of friction may be calculated. The lining and drum may be operated through a broad range of temperatures, pressures and speeds to simulate test procedures conducted on a full-scale brake assembly.

The FMTM is capable of subjecting the friction material to a broad range of interface conditions and eliminates the influence of external factors that are present in vehicle testing. However, it has not been found possible to correlate results obtained on the FMTM directly to actual brake operation. The machine has been found to be valuable as a quality control test and is quite acceptable in comparing materials from various batches.

The test procedure used for testing friction materials on the FMTM is SAE J661a. This test procedure is referred to as a brake lining quality control test, and its purpose is to establish a standard test for obtaining and reporting the friction and wear characteristics of brake lining materials.

2. Friction Assessment Screening Test (FAST) Machine

This bench dynamometer was developed by the Ford Motor Company and is operated according to a standardized test procedure developed by Ford. The FAST machine operates by pressing a 0.5 -sq. in. test sample against the flat face of a 7 in. diameter cast iron disc, rotating at a constant speed of 870 rpm. The applied force on the test specimem pad may be either constant or furnished by a piston, controlled by a servo valve. The servo valve is in turn controlled by the friction force produced by the test specimen. When the pressure is controlled by a servo valve to produce a constant friction force, the rate of energy dissipation remains constant. The disc temperature will gradually increase with time at a standard rate and a plot of the applied force versus time is, in actuality, one of force versus time, temperature increase. The coefficient of friction may be calculated, and test results from this machine will give friction versus temperature and friction versus time and temperature data. The friction versus time, temperature values are similar to the fade mechanism in conventional braking systems and, therefore, this test gives some correlation with lining fade characteristics. The FAST machine subjects a test specimen to a single heating run without recovery .

The FAST test is relatively simple and quick. Some degree of correlation has been observed between FAST test results and actual brake lining performance. Basic design of this machine resembles that of a disc brake, and a greater degree of correlation of test results with actual brake operation can be observed with disc brakes than with shoe brakes with servo action.

Results obtained with the FAST machine have proved to be quite reproducible, and no specialized operator skill is required. These characteristics make the FAST a useful standard quality control test.

Although both the FMTM and the FAST machines are useful testing equipment, neither appears to give adequate correlation to vehicle operation. A. R. Spence et al. have offered a theory on why friction material test machines, using test specimens that are small compared to the rotating disc or drum, do not give data representative of vehicle performance ("Four Tests for Consistency of Automotive Brake Linings", Paper No. 660412 presented at SAE meeting, June 1966).

3. Single End Inertia Dynamometer

This inertial dynamometer gives complete friction and durability characteristics of a friction material, and allows direct comparison to actual vehicle performance of the material. In this type of dynamometer, an actual brake mechanism is incorporated or, in some cases, the machine uses a scaled version of the brake assembly.

The machine consists of the rotating part of the brake, which is a rotor in the case of a disc brake, or a drum in a conventional shoe brake. The stationary part of the brake is the caliper head for a disc, or the backing plate holding the brake shoe, for a drum brake. Brake pressure is regulated by a hydraulic brake assembly system.

Instrumentation of this dynamometer is as follows:

(a) A tachometer to record rotating speed.

(b) A pressure gauge to record brake actuation pressure.

(c) Thermocouples and recorder to obtain brake linings temperatures.

(d) Recorder to obtain instantaneous brake torque data.

(e) Optional recorder to record all pertinent outputs and inputs including speed, brake torque, temperatures and pressures.

The dynamometer must also be equipped with an air supply capable of simulating the air cooling of a vehicle brake assembly, due to its forward motion.

4. Dual End Inertia Dynamometer

Throughout the brake lining industry, the dual end inertia dynamometer is considered the most precise method for simulating actual vehicle performance. The reason why this machine is not used to a greater extent is its initial high cost.

Basically, the dual end inertia dynamometer incorporates the same instrumentation as the single end dynamometer. The difference is that the dual end dynamometer is operated with one front and one rear brake assembly, simulating the torque transfer from front to rear in vehicle brake performance. A considerable amount of testing has been performed on this type of dynamometer and a high degree of correlation with vehicle brake performance has been found. However, vehicle brake temperatures during fade tests are difficult to reproduce with the dual end dynamometer.

An important consideration with testing on the dual end dynamometer is that if a brake standard were devised for use with this dynamometer, current merchandising practice of supplying linings in axle sets would have to be changed. This would be necessary because performance observed on this dynamometer during the dual-brake tests is the combined performance of front and rear brakes and would require linings to be sold in vehicle sets.

Both the single end and dual end inertia dynamometers are capable of simulating vehicle tests in accordance with the FMVSS 105 regulation for passenger cars and the FMVSS 121 regulation for trucks and buses.

B. Standard Dynamometer Test Procedures

Any test procedure which is within the capability of the dynamometer can be devised; however, certain specific procedures are in existence and are considered standard. Since performance of a friction material will vary depending on the brake and the vehicle on which it is used, testing must often be done under conditions simulating several different vehicles and braking system. The standard test procedures of dynamometer operation may be used with any of the brakes and vehicle conditions. In practical testing, certain specific brakes and the vehicle most likely to use these brakes must be selected, to ensure that testing remains economically feasibly. Alternatively, when comprehensive testing is required, such as in the case of a new model of passenger car, an extensive test program will be conducted on the specific brake and vehicle combination.

For the following types of tests are conducted on a full-scale brake dynamometer:

(a) Break-in or burnish results

A series of stops are made at specific intervals from a constant speed and the hydraulic pressure to the brake is controlled to maintain a constant deceleration rate from stop to stop. The pressure required to maintain constant deceleration is recorded to indicate the stability of the friction level of the lining.

(b) Effectiveness of performance curves

The curves consist of a series of stops from a specific speed with each stop made at a higher application pressure than the previous one. The deceleration rate is measured and in this way, the change of coefficient of friction of the lining with increasing pressure is determined. Effectiveness curves are usually run at several different speeds, and also serve to determine any change in friction with speed and the consequent increase in energy and heat produced.

(c) Fade

A fade run consists of a series of stops made at constant and close intervals, usually from a fairly high speed. Line pressure to the brake is regulated so as to maintain constant deceleration time, hence constant output. The fade run shows the tendency of the lining to lose friction as it rapidly overheats from abusive use. Obviously, a lining material which loses friction very rapidly is highly undesirable, but one which shows no reduction of friction can also be dangerous, such as if the lining or other brake components reach a temperature which results in catastrophic failure without the driver of the vehicle receiving any warning of the impending danger. Basically, a lining should be resistant to fade, but fade should occur and its onset should be reasonably gradual.

(d) Recovery

A recovery run is made following a fade run, with longer intervals between stops than used in the fade run, and at considerably lower speeds. The purpose of the recovery run is to determine the trend of the coefficient of friction of the lining material as it returns to normal temperature, following the excessive heating experience during the fade. An initial drop in friction is not unusual during the early stages of recovery known as a "hole in the recovery," but obviously, this characteristic must be limited to a tolerable value.

(e) Stability

Erratic changes in measured test results during a dynamometer run indicate an unstable lining material which will result in erratic performance such as uncontrollable pulling of the vehicle to one side or the other in actual road operation.

(f) Noise

Noise is an important aspect of brake lining operation and one of the most difficult to measure on a dynamometer. A fairly successful method is to operate a brake under conditions that are prone to cause noise in actual vehicle operation and observe the generation of the conditions in the brake that have previously been found to correlate with vehicle noise. Noise is most often found at low speeds and under lightly loaded conditions and often takes a considerable length of time to develop. Therefore, noise test procedures have consisted of many low-energy stops simulating typical moderate operation of vehicle brakes. A lining which ultimately produces a noisy brake has been found to have a tendency to polish the brake drum or rotor which it contacts. This observation agrees with theoretical conditions and has allowed some measurement of noise-producing tendencies of brake linings by measuring the degree to which the drum, or rotor surface, is made smoother during a long series of low-energy stops. In this type of testing, abusive stops must be avoided, because they produce a high wear rate of both the lining and the drum, which tends to recondition both surfaces and hide the polishing effect of the lining.

C. Motor Vehicle Tests

Vehicle testing is the most realistic and reliable means of testing a brake lining material. Vehicle testing ranges from normal driving making infrequent stops to high-speed driving and many sudden "panic stops".

Fleet test cars are equipped with decelerometers, line pressure gages reading brake pedal load, electric counters recording stops, and lining and drum temperature recording devices. Complete tests may be 3000 miles, subjecting the brake lining to the equivalent of 20,000 miles or more of normal driving. Wear may be determined by measuring lining thickness before and after testing; brake lining wear is normally recorded in inches per thousand stops.

Braking systems on all U.S. motor vehicles are required to conform to certain performance and equipment standards. The regulations are written by the National Highway Traffic Safety Administration for the purpose of ensuring safe vehicle braking performance. The regulation covering trucks and buses equipped with air brake systems is FMVSS 121. Cars and light trucks must meet standards set forth in FMVSS 105.

A number of product quality tests are also performed by brake lining manufacturers. Physical properties such as tensile and flexural strength, density, impact, odor, coefficient of linear expansion, coefficient of heat transfer, and permanent expansion or contraction after one hour at 450°F are determined. Many of these properties are determined for quality control purposes, and the data often indicate how a brake lining will perform in actual operation.

D. Rail Car Brake Lining Tests

Product development and testing of new brake shoes or disc pads for rail car application follow the general outline given for automotive testing. For composition brake shoes, however, the Association of American Railroad's (AAR) specification M-926-72 must be passed before the shoe can be accepted in interchange freight and passenger service. The specification outlines a series of dynamometer tests to determine if the shoe meets the minimum acceptable requirements. The dynamometer friction and wear tests include a grade test series measuring retarding force, shoe wear, and wheel temperature produced by a constant brake shoe load at 25 mph wheel speed for 45 minutes, a light braking stop test series, each measuring gross stopping distance for five initial speeds with a constant shoe force, a static friction test measuring the torque required to start wheel movement with a given shoe force, a shoe wear test, and a spark test. The minimum coefficient of friction acceptable for the light and heavy brake tests are 0.32 and 0.27 respectively. The minimum static coefficient of friction acceptable is 0.38. The full specification can be obtained from the AAR.

The AAR brake shoe test is the only industry-wide specification on brake shoes. The AAR specification is not easy to meet, however, and is therefore considered a good measure of a quality brake shoe. Although it not law, very few railroads would purchase a composition brake shoe that does not meet the AAR specification. The U.S. Department of Transportation has no regulations or specifications on brake shoes or disc pads for rail vehicles.

No government regulations or railroad industry specifications exist that cover the performance of rail car disc brake pads. As with brake shoes, however, many rail car manufacturers and railroads have their own vehicle tests for new products. Some use the breakaway test, which basically entails pulling a rail car up to a set speed, removing it from the locomotive, and then applying the brakes and measuring instantaneous deceleration rates, brake shoe forces, and stopping distance.

Each individual transit authority has their own rapid transit car specification. The specification used by the U.S. Department of Transportation for its State of the Art Car rapid transit car may be representative. This specification requires a 105,000 pound car with an initial speed of 40 mph to have a maximum distance to stop of 450 feet in service friction braking and 425 feet in emergency friction braking. At 80 mph initial speed it requires 425 and 2200 feet respectively. The complete specification can be obtained from the U.S. Department of Transportation.

E. Aircraft Brake Lining Tests

No government regulations exist exclusively on performance of brake lining materials for use on aircraft. However, regulations do exist covering the entire braking system of the aircraft, of which the friction material is an important component. Any friction material for use on any brake, on any airplane, must qualify by tests outlined by the U.S. Department of Transportation's Federal Aviation Administration. These tests for small aircraft can be found in the Code of Federal Regulations, Title 14- Aeronautics and Space, Chapter 1- Federal Aviation Administration. In Part 37, Section 37.172, a dynamometer test is outlined requiring 35 design landing stops at a deceleration rate of 10 ft/sec^2. As a measure of wear, only one change of segments is allowed during this test series. A taxi and park test is included in Part 23, Section 23.735, which specifies the kinetic energy that the brake system must be capable of handling and specifies that the brake must be capable of holding the aircraft stationary with take-off power on the critical engine. Section 23.75 outlines the horizontal stopping distance required for a landing.

The airplane manufacturer frequently runs his own dynamometer and field tests. At least one manufacturer, for example, requires the segments to pass 100 stops instead of the 35 called for in the test of Section 37.172.

XI. CONCLUSIONS

This study of the markets for improved brake friction materials and the technical requirements and constraints associated with such improvements leads one to the following conclusions.

Passenger Cars and Light Trucks

This industry is probably the most cost conscious of any that were studied in this survey. A new brake lining material with improved coefficient of friction stability would be desirable, but any cost increase would have to be minimal. A brake lining material, incorporating the following improvements, but equal in cost to conventional linings, however, would penetrate the brake lining market for this industry:

- Reduced wear
- Reduced drum wear
- Elimination of noise (disc brake applications).

Trucks and Trailers

An improved friction material equal in performance to conventional brake linings, but having the following improved properties, would be quite advantageous to this industry:

- Reduced fade, more stable coefficient of friction at elevated temperatures.
- Reduced lining wear
- Reduced drum wear

- Capability of meeting present FMVSS121 regulation and proposed regulation of 245 ft stopping distance at 60 mph.
- Equality in price to conventional linings, or no more than 40% increase.

A price increase of 40% over conventional lining materials would necessitate considerable improvement in each of the other categories listed above, for a new lining material to be accepted by the trucks and trailer industry.

Buses

A definite market exists for a new brake lining material for use by the busing industry. This material must be equal in performance to conventional linings and exhibit the following improvements:

- Reduced noise
- Reduced fade, more stable coefficient of friction at elevated temperatures
- Reduced lining wear
- Reduced drum wear
- Comparable in price to conventional linings or no more than 40% increase.

The bus industry seems to be actively seeking brake lining materials with the above improvements. A new lining with these qualities is definitely needed but must be cost effective in relation to drum and lining wear.

Agricultural, Construction, and Industrial Equipment

A considerably more detailed study of these industries would be required to make an accurate determination of friction material properties required of a new brake lining material. However, the industrial equipment sector could definitely provide a significant market for a new brake lining material that incorporates the following improvements:

- Reduced wear
- Significant reduction in or elimination of asbestos content.
- Tolerable cost increase; material should be cost effective in relation to wear rates.

Rail Cars

Brake Shoes--A new friction material that is at least equal in performance to currently used composition rail car brake shoes and has a significant improvement in any or all of the following characteristics with no more than a 40% price increase would make a marketable rail car brake shoe product:

- Reduced wheel wear
- Reduced wheel thermal damage
- Reduced brake shoe wear

In addition, a significant improvement in any of the following characteristics without any price increase would make a marketable brake shoe:

- Reduced coefficient of friction fade
- Reduced shoe icing
- Reduced braking noise.

Disc Pads--A new friction material that is at least equal in performance to currently used composition rail car disc brake pads and has a significant improvement in either or both the following characteristics with a price increase would make a marketable rail car disc pad product:

- Reduced pad wear

- Reduced disc wear

In addition, a significant improvement in any of the following characteristics without a price increase would make a marketable disc pad:

- Reduced coefficient of friction fade
- Reduced braking noise

Aircraft

A new friction material that is at least equal in performance to currently used organic composition small airplane disc pads and has a significantly higher coefficient of friction with a maximum 100% price increase would make a marketable airplane disc brake segment product.

APPENDIX
LIST OF TERMS

Braking:

The conversion of the energy of motion (kinetic energy) of a vehicle mostly into heat energy. The heat may be calculated by the formula $KE = \frac{1}{2} mv^2$ where KE is the kinetic energy, m is the mass, and v is the velocity of the vehicle.

Brake Lining:

Brake lining is a friction material used for stopping or retarding the relative movement of two surfaces.

Coefficient of Friction:

The effect of friction between any two materials can be measured and represented by a relationship which is known as the "coefficient of friction." This relationship is the ratio between two measured forces and is always represented by a fraction in which the numerator is less than the denominator. The denominator of the fraction is the normal force pressing the two surfaces together. The numerator is the frictional force resisting the motion of one surface over the other when a force is applied parallel to the contacting surfaces. The coefficient of friction determined when one surface slides over the other is the dynamic coefficient of friction; the coefficient of friction determined when one surface does not slide over the other with maximum force parallel to the surfaces is the static coefficient of friction.

Friction Material:

A product manufactured to resist sliding contact between itself and another surface in a controlled manner.

Ranges of Friction:

Friction material is given a friction rating (coefficient of friction) with the notation whether the value is for dry or wet (oil) operation and whether it is dynamic or static friction. In dry operations, friction material may be said to be available in the range of 0.1 to 0.60. A material whose friction is less than 0.1 is usually regarded as a bearing material.