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FINAL REPORT

on

ANALYSIS OF THE FEASIBILITY OF REPLACING ASBESTOS IN AUTOMOBILE AND TRUCK BRAKES

Prepared for the

Environmental Protection Agency

April 15, 1987

by

The American Society of Mechanical Engineers

This is a report of an expert panel assembled by ASME to address the technical issues associated with the removal of asbestos from vehicle friction products. This panel convened on December 3 and 4, 1986, to discuss issues of vehicle safety, friction material availability and performance, and future trends in the development of asbestos-free friction products.

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EXECUTIVE SUMMARY AND CONCLUSIONS

Due to reported health problems associated with the use of asbestos, the Office of Toxic Substances has proposed a regulation to ban the use of asbestos over a 10-year phase-down period. Since asbestos is currently a critical constituent in some vehicle friction products, the Environmental Protection Agency is interested in determining whether the proposed ban could have adverse effects on vehicle braking safety.

In order to assess the potential effects of the proposed ban on vehicle brake system operation and vehicle safety, a panel of individuals knowledgeable in the various aspects of vehicle brakes and friction materials was assembled by the American Society of Mechanical Engineers (ASME). The panel addressed technological issues associated with the removal of asbestos from friction materials, specifically:

(1) Identification of substitute brakes and systems,

(2) Influence of the ban on motor vehicle safety standards,

(3) Problems associated with replacing asbestos friction materials in aftermarket vehicles, and

(4) Pace of research and commercialization and effects on phase-out.

This report addresses the technical issues related to the proposed ban considered by the panel to be the most important.

Conclusions

The panel reached the following conclusions:

(1) **Because vehicle controllability during braking is strongly affected by friction material performance, unqualified substitution of friction materials in either vehicle disc pads or drum linings may have an adverse effect on vehicle brake balance and controllability*.**

Vehicle controllability during braking is affected by both driver and brake system performance. Generally, vehicle front-to-rear braking ratios are adjusted on a per-model basis to provide optimal braking. Too much braking on an axle results in premature wheel lock-up, and this can lead to loss of steering control (front lock-up) or spin-

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* Information supporting this conclusion is presented in Chapter 2 of this report.

out (rear lock-up). While the effectiveness of disc brakes is directly proportional to pad-disc friction levels, the effectiveness of drum brakes can be greatly affected by changes in lining-drum friction. Friction materials that exhibit reduced effectiveness also can result in brakes having insufficient torque needed to stop the vehicle. Different drum brake designs exhibit dramatic differences in effectiveness. Brake effectiveness can also be affected by the friction properties of the friction material. For these reasons, automobile and truck manufacturers have strongly opposed the immediate ban of asbestos in aftermarket friction materials for older vehicles.

(2) **No simple bench-top tests are available to evaluate the performance characteristics of friction materials or to demonstrate their compliance with Motor Vehicle Safety Standards[**].**

The qualification of original equipment braking systems is regulated under Federal Motor Vehicle Safety Standards (FMVSS) 105 and 121. For many original equipment manufacturers, these requirements represent minimal standards of performance, and supplemental qualifications are usually satisfied due to customer demand. Satisfactory compliance with FMVSS 105 and 121 requires vehicle and inertial dynamometer test facilities to evaluate brake system performance on a per-model basis. To test compliance with these requirements, vehicle manufacturers submit braking systems and friction products to numerous levels of qualification tests. Results obtained using scaled-down laboratory apparatus, such as friction material testing machines (FMTM) or friction assessment screening test (FAST) machines, have been shown to correlate poorly with vehicle test results. The performance of aftermarket friction materials is not regulated by law.

** Information supporting this conclusion is presented in Chapter 3 of this report.

(3) **Qualified, non-asbestos friction materials are not yet available for all current applications*.**

Non-asbestos friction material technology is advancing rapidly. Several new asbestos-free car, light truck, and heavy vehicle brake systems have been released for OEM applications in the past 3 years. More new vehicle brake systems will be released with non-asbestos friction materials for the 1988 model year.

Original equipment vehicle manufacturers in the United States and Europe are rapidly moving toward asbestos-free brake systems for all new cars, light trucks, and heavy trucks. Adequate non-asbestos friction material formulations presently are not available for all vehicle systems. However, with present progress continuing, most new passenger cars should be equipped with totally non-asbestos frictional systems by 1991, and most light trucks and heavy trucks with S-cam brakes, by 1992. However, a few low-volume new vehicle applications may not have acceptable non-asbestos friction materials at that time. Heavy truck wedge brake blocks, medium truck drum brake linings and many off-road vehicle brake linings may not be developed by 1992.

New classes of non-asbestos friction materials have unique compositions which may have unexpected failure mechanisms. In many cases, unique failure modes are revealed only through extensive vehicle testing.

(4) **The substitution of unqualified non-asbestos friction materials in the aftermarket poses the largest potential safety issue**.**

A large number of older vehicles in the United States have brake systems designed for asbestos friction products. The use of unproven materials in place of proven asbestos materials in existing systems could result in a loss of vehicle controllability during braking.

Currently, there are no required performance tests for aftermarket brake friction materials. In addition, most of the aftermarket, non-

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* Information supporting this conclusion is presented in Chapter 4 of this report.

** Information supporting this conclusion is presented throughout the report

asbestos material suppliers lack the facilities to evaluate their materials under dynamometer and vehicle braking test conditions.

Non-asbestos friction materials that have been developed to date have provided some new and unexpected failure modes and mechanisms due to their unique combinations of new raw materials and manufacturing processes. Mandating aftermarket non-asbestos friction materials for vehicles that were originally equipped with asbestos-based linings would lead to a potentially serious customer safety risk, unless stringent friction material qualification specification tests are included.

(5) **The majority of the automobiles sold in the United States now are fitted with front disc brakes and rear drum brakes, and this trend will most likely continue for some time*.**

Because disc brakes maintain effectiveness at high braking speeds, 4-wheel disc brakes have been used in the past on high performance European vehicles designed to operate at high speeds on unregulated European highways. This is one reason behind the European use of 4-wheel disc systems. In addition, non-asbestos drum brake materials for automobile drum brakes have been difficult to qualify in the past. For these reasons, several European automakers use 4-wheel disc brakes in conjunction with semimetallic pad materials as a means of eliminating asbestos.

Because of differences between qualification standards, cost, driver preference, and driving conditions in the United States and Europe, American and Japanese automakers are utilizing rear drum brakes. Suitable non-asbestos materials are not available for all of these applications, and industry-wide substitution of non-asbestos materials in all existing brake designs would require considerable development. It is unrealistic to assume that all automakers will redesign all passenger car and truck braking systems around disc brakes in order to utilize semimetallic materials.

The adoption of FMVSS 135 and the failure to qualify rear brake drum linings exhibiting consistent levels of friction over a wide

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* Information supporting this conclusion is presented in Chapter 5 of this report

range of performance conditions may affect the design philosophy of American and Japanese automotive engineers. Forced to ensure front bias in the system, automakers may move to using less effective disc brakes on the rear and increasing the front-to-rear braking ratio to ensure consistent performance, if proven rear lining materials are not found.

(6) **Industry gave mixed response to the proposed EPA action*.**

Numerous automobile, truck, and friction material manufacturers responded with written comments to the Federal Register announcement of the proposed EPA action. While most of the automobile and truck manufacturers were optimistic about the future availability of asbestos-free materials, they were unanimous in their opposition to a proposed phase-down schedule in which the amount of allowable asbestos would be phased out over a 10-year period. Instead, they favored a 5-year lead time prior to any ban. In addition, they were unanimously opposed to banning asbestos-containing materials for older aftermarket vehicles. Although suitable substitutes have been found for automobile front disc brakes, material qualification for rear automobile drum brakes and medium truck drum brakes is still in progress.

Friction product manufacturers gave mixed response to the issues. One manufacturer indicated that for many applications, suitable substitutes are available, although for many vehicle applications no qualified materials exist. Another manufacturer indicated that suitable substitutes were produced by their company, although no FMVSS 105 or FMVSS 121 qualification capabilities existed at their facility.

Recommended Future Work

Industry trends for the next 5 years appear to be directed toward the elimination of asbestos in all new vehicles. For these applications, the use qualified non-asbestos friction materials may not present a vehicle safety problem over the life of the friction product. However, the use

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* Information supporting this conclusion is presented in Chapter 6 of this report.

of unqualified non-asbestos materials for the aftermarket still remains a safety issue. If the eventual elimination of all asbestos in friction products is to be accomplished, additional future studies are required. Several possible research tasks are briefly outlined in the following sections.

Task 1. Determine Populations of Aftermarket Vehicle Classes and Brake System Designs in the United States

The purpose of this task would be to determine and project, over the next 10 years, the general classes of brake designs found on older vehicles (passenger cars and light trucks, medium trucks, and heavy trucks) that will require aftermarket friction materials. For example, it would be useful to determine how many passenger cars in the 3000-3500 lb weight range are fitted with duo-servo drum brake and how many utilize leading-trailing drum brakes. In addition, the population of vehicles having 4-wheel drum-brakes as opposed to rear wheel drum-front wheel disc brakes could be determined. Thus, vehicle populations would be assessed with respect to weight range, brake design, and front-to-rear braking balance.

This information would help the EPA to determine where the qualification of non-asbestos friction materials for the aftermarket would have the greatest impact on asbestos elimination. For example, if the results indicate that 80 percent of the passenger vehicles using asbestos materials are fitted with duo-servo rear drum brakes and front disc brakes, and are within the 3300-3800 lbs weight range, then the requalification of non-asbestos materials for these vehicles would have the greatest impact on asbestos elimination.

Task 2. Conduct Dynamometer and Vehicle Qualification Tests on Non-Asbestos Materials Using Representative Vehicles

The purpose of this task would be to determine whether current non-asbestos materials could be safely used in aftermarket vehicles designed for use with asbestos friction products. This task would draw upon the results of Task 1 by limiting the vehicle studies to these vehicles known

to represent the majority of vehicles now in service. In this way, the study could be conducted in a more cost-effective manner.

This experimental study would use dynamometer and vehicle tests to determine friction product effectiveness under vehicle service conditions. The ability of brake systems and friction materials to satisfy Federal motor vehicle safety standards would also be assessed.

This second task would determine (1) whether safe effective substitute materials are available ermarket applications and s among suppliers of after-

brake mechanics file

1. INTRODUCTION

The Environmental Protection Agency, under the authority granted by the Toxic Substance Control Act (TSCA), has proposed a ban on the production and importation of asbestos and asbestos-containing products. According to documents published in the Federal Register (Vol. 51, No. 19, Wednesday, January 29, 1986) the EPA has proposed several alternative approaches to eventually eliminate or drastically reduce the amount of asbestos used in the United States. The proposed actions apply to products containing asbestos, as well as raw asbestos mined or imported for incorporation into products.

The proposed ban on asbestos would have a direct effect on friction materials used in automotive, truck, transit bus and train brake systems. At the present time, many friction products contain asbestos. Asbestos provides several performance attributes for the brake lining both during its intended use as well as during its manufacture and assembly. Removal of asbestos from these materials raises the following questions:

(1) **Will asbestos-free friction products allow motor vehicles to meet current and proposed braking standards?**

Non-asbestos friction materials have added new complexities to brake system design and development because of their new, different, and sometimes unexpected functional properties. Furthermore, brake system development work becomes more difficult with the present shortage of fully evaluated, documented non-asbestos brake lining formulations. However, fully non-asbestos formulations for passenger cars, light trucks, and heavy trucks have been produced and more have been released for production. There is considerable controversy whether acceptable asbestos-free substitute friction materials have been found for some vehicle brakes, in particular some of the larger passenger car/medium truck drum brakes.

(2) **Will the use of asbestos-free materials require redesign of braking components, such as actuation cylinders, distribution valves, and reservoirs and accumulators, to permit safe use of non-asbestos brake linings?**

This question arises due to the proposed requirement for applying asbestos-free friction materials to existing vehicles that have braking systems designed for use with asbestos-containing friction materials. When non-asbestos friction materials are installed in existing vehicle systems with no alteration of the rest of the braking system, stopping distances may increase, required brake actuation forces may increase, resistance to fade may decrease, and undesirable brake stability problems may arise.

It would appear to be prohibitively expensive to replace brake system components to accommodate friction materials with different frictional characteristics because of the extensive redesign and retesting required. To assess the impact of the proposed ban, the feasibility will have to be addressed for the direct replacement of asbestos brake linings on existing vehicles with non-asbestos friction materials.

(3) **What schedule for asbestos phase-out can be implemented without compromising vehicle braking performance and safety?**

This question arises due to the possibility that in some applications acceptable substitute materials may not be available because of performance, manufacturability, or profitability issues. For some specialized vehicles, the market for friction products may be so small as to restrict the profitability of developing and manufacturing suitable asbestos-free friction materials and required associated hardware.

Objectives of this study were to:

(1) Define the technological issues associated with the EPA's

plan to disallow the use of asbestos in automobile and truck braking systems. Such issues would include:

- Identification of substitute brakes and systems,
- Influence of the ban on motor vehicle safety standards,
- Problems associated with replacing asbestos brakes on existing vehicles with alternative materials, and
- Pace of research and commercialization as they affect the proposed time for phase-out of asbestos.

(2) Collect relevant technical information required to resolve those issues.

(3) Present the findings and conclusions of the study regarding those issues where the state of existing knowledge is sufficient to make a sound engineering judgement.

(4) Define the limits of current knowledge and identify priority research topics where available information is not sufficient to draw firm conclusions.

This report addresses these and other issues created by the proposed EPA action against asbestos. Section 2 of the report describes vehicle braking systems now in use in both on-highway and off-highway vehicles. Table 1 lists the general vehicle classifications using these braking systems and vehicle examples affected by the ban. Section 3 of the report describes how friction materials are evaluated and qualified for vehicle use under Federal Motor Vehicle Standards and Society of Automotive Engineers (SAE) practices. Section 4 describes the performance of the various friction products. Section 5 covers vehicle applications affected by the proposed ban. Finally, Section 6 outlines the responses of the various industries to the EPA's proposed ban.

TABLE 1. MOTOR VEHICLES AFFECTED BY PROPOSED BAN

Vehicle Category	Example	Representative Brake Systems
On highway (low weight)	• Automobiles and light trucks	• 4 wheel drum • Rear wheel drum and front wheel disc • 4 wheel disc
On highway (high weight)	• Heavy trucks • Tractor-trailer combinations • Buses • Concrete mixers • Tank trucks	• Hydraulic drum • S-cam air drum • Wedge air drum • Air disc
Off highway	• Logging trucks • Mining trucks • Agricultural equipment	• S-cam air drum • Air disc • Wet (oil) disc

2. REVIEW OF VEHICLE BRAKING SYSTEMS

2.1 Section Summary

A review of vehicle braking systems is presented in this section and includes discussions of the performance requirements, factors influencing performance, and general design characteristics of the main braking systems. The main purpose of this section is to examine how vehicle braking performance is affected by the friction characteristics of both pad and lining materials. This is of particular importance in the aftermarket in which asbestos materials may be replaced with non-asbestos materials having different frictional properties. The main points of the section are:

- Vehicle brakes must provide consistent and dependable performance over a wide range of environmental and operating conditions, causing complex design and development challenges and necessitating performance tradeoffs.
- Brake lining friction and wear characteristics, along with thermal and mechanical properties, all affect the brake torque output, especially with high-servo-factor drum brakes. The performance of these brake systems, which are common on many American-made automobiles, is especially sensitive to the frictional properties of the brake lining material.
- Vehicle controllability and stability during braking is dependent upon the stability and consistency of the brake system. For example, an alteration in the front-to-rear braking balance due to a change in either the front or rear friction material may decrease vehicle controllability. The use of friction materials having different wear, stiffness, friction, or thermal expansion characteristics may cause a degradation in braking performance.
- Structural and vibrational behavior of brake assemblies can be significantly affected by the frictional, elastic, and structural properties of the friction materials. Brake squeal occurs when the brake and associated structural components are excited to vibrate due to friction. Some friction materials naturally damp or dissipate the vibration, while other mate-

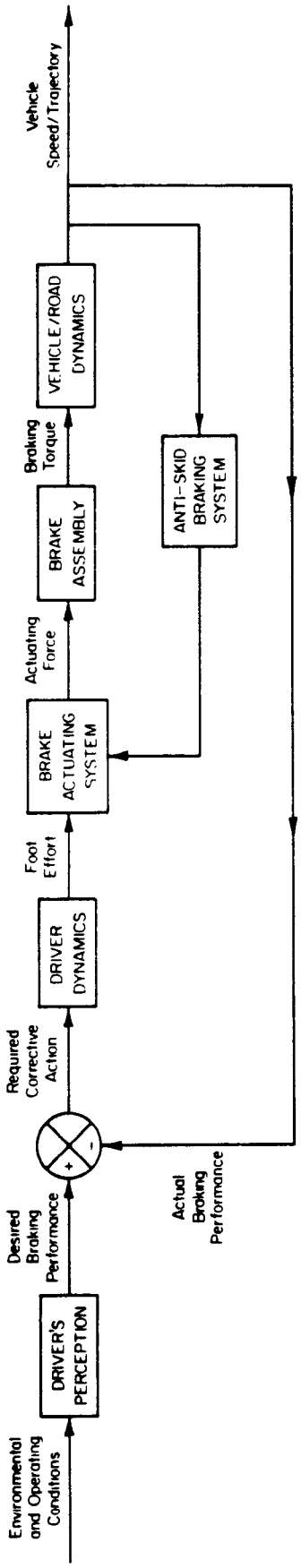


FIGURE 1. SCHEMATIC OF GENERALIZED BRAKING SYSTEM

- Accuracy of the driver's perception of the operating environment,
- Dynamic response characteristics of the driver,
- Predictability and reliability of the total brake system,
- Vehicle/road characteristics, and
- Response characteristics of the braking system.

In order to stop a vehicle safely, the brake system should provide repeatable, uniform deceleration for the same brake pedal input and provide braking force in proportion to pedal force. Further, vehicle path direction should be readily controllable by the driver during braking.

The limitation to decelerate a vehicle depends ultimately on road/tire traction, which varies with wheel slip. Maximum braking requires the brake torque to be just enough so that the resulting wheel-slip generates peak traction force available at the tire-road interface. Excessive brake torque causes a progressive increase in wheel slip and decrease in adhesion, resulting in wheel lockup and skidding. Skidding may produce an unsafe condition because directional control of the vehicle is reduced substantially and stopping distances may be increased. Rear-wheel lock-up during braking results in severe vehicle uncontrollability. For this reason, current European braking standards and proposed American braking standards require that in the event of wheel lock-up, the front wheels must lock before the rear wheels. To ensure this condition throughout the life of the friction material, both front and rear brake system performance must not be altered by friction material wear or by other changes in the material friction characteristics. Changes in the friction material properties, either due to replacing the brake shoes with different friction materials, or due to wear, prior operating history, temperature, and load effects, will change the response characteristics of the braking system.

2.3 Influence of Brake Friction Material Characteristics on Brake System Response

There are several scenarios in which an existing hydraulic or pneumatic system would require modification or redesign to accommodate changes in the properties of the brake friction material. These are summarized in Table 2. As indicated in the table, substitution of non-asbestos

friction materials for original asbestos linings requires characterization of the substitute material properties, followed by an evaluation or verification of the performance of the existing brake system with the non-asbestos materials. Due to brake system design differences, this must be done on a model-by-model basis.

For new vehicles, non-asbestos friction materials may be incorporated into a new brake system design. Depending on the characteristics of the non-asbestos friction materials, compared with those of the asbestos materials, the new brake system design could involve minor modifications of existing designs or completely new brake components.

In order to achieve adequate braking performance, brakes are designed primarily on the basis of wear, stability, brake or shoe factor, (ratio of brake torque to applied force) and pedal travel.[1] These parameters are interrelated. For example, lining material thermal expansion may require added running clearances to avoid parasitic drag. This then results in the need for greater brake pedal travel, which may lead to a master cylinder resizing. If pedal forces then become too great, a booster may need to be added or increased in size. Some of these relations are discussed in the following sections.

2.4. Influence of Brake Design on Brake Effectiveness

As mentioned previously, it is important that a vehicle have the ability to be decelerated rapidly and controllably during emergency braking. Thus the response of the vehicle to the driver's brake "commands" must be predictable, repeatable, and fast enough to stop the vehicle in a short distance, but slow enough that the driver can respond effectively with subsequent corrective braking and steering commands, e.g., to avoid skidding or "fishtailing".

The relationships between braking (frictional) torque, applied force, and the coefficients of friction have a strong influence on vehicle stability. The parameter that most strongly affects the stability of brakes is the shoe or brake factor (also called effectiveness). The brake effectiveness is defined as the ratio of the brake friction torque to the applied force and is used commonly to describe the performance of brakes.

TABLE 2. INFLUENCE OF SOME BRAKE LINING PROPERTY CHANGES ON BRAKE SYSTEM RESPONSE WITH DESIGN MODIFICATIONS TO COMPENSATE

	Change of Brake Lining Properties	Potential Response of Brake System	Needed Design Modifications
Friction Properties	• **Lower Friction Coefficients** - Front brakes - Rear brakes - Both front/rear	• **Greater Pedal Forces Required, Leading to:** - Early rear skid - Early front skid - Low brake capacity	• **Larger Booster or Small Master Cyl.** - Big front w.c. - Big rear w.c. - system redesign
	• **Higher Friction Coefficients** - Front brakes - Rear brakes - Both front/rear	• **Lower Brake Pedal Force Required, Leading to:** - Early front skid - Early rear skid - "Touchy" pedal	• **Smaller Booster/ Big Master Cyl.** - Small front w.c. - Small rear w.c. - System redesign
	• **Poor Fade Characteristics** - Green fade - Thermal fade - Water fade - Flash fade	• **High Brake Pedal Force Required For:** - Initial hot brake - Any hot brake, - Wet brakes - High speed stops	• **Recalibrate/Add Booster** - Scorch linings - Modify linings - Shield brakes - Modify linings
	• **Inconsistent Friction Level** - Green linings - Usage history - Wear depth - Within batch - Bath-to-batch	• **Varied Brake Pedal Forces Needed With:** - New brake linings - Temperature change - Mileage driven - Brake imbalance - Car-car variations	• **Change Linings/ Redesign Brake** - Modify linings - Modify linings - Modify linings - Improve process - QC improvement
	• **Environmental Sensitivity** - Water/water vapor, - Road dust - Oily contaminants - Oxide/rust effects	• **Brake Pedal Force Sensitive to:** - Humidity - Dust pickup - Road rain splash - Moist storage	• **Change Linings/ Redesign Brake** - Modify linings - Shield brakes - Shield brakes - Materials change
Mechanical Properties	• **Lower Compression Modulus**	• **Higher Brake Pedal Travel**	• **Redesign/Stiffen Actuation System**
	• **Higher Compression Modulus**	• **Noise and Uneven Effectiveness**	• **Reduce Shoe/Drum Stiffness**
	• **Higher Thermal Expansion/Growth**	• **Brake Dragging and Hot-Spotting**	• **Add Clearance or Thin Linings**
	• **Lower Tensile Strength**	• **Lining Fracture, Cast Iron Scoring**	• **Use More Rivets, Bond/Mold Linings**
	• **Lower Toughness**	• **Handling Breakage**	• **Alter Processes**

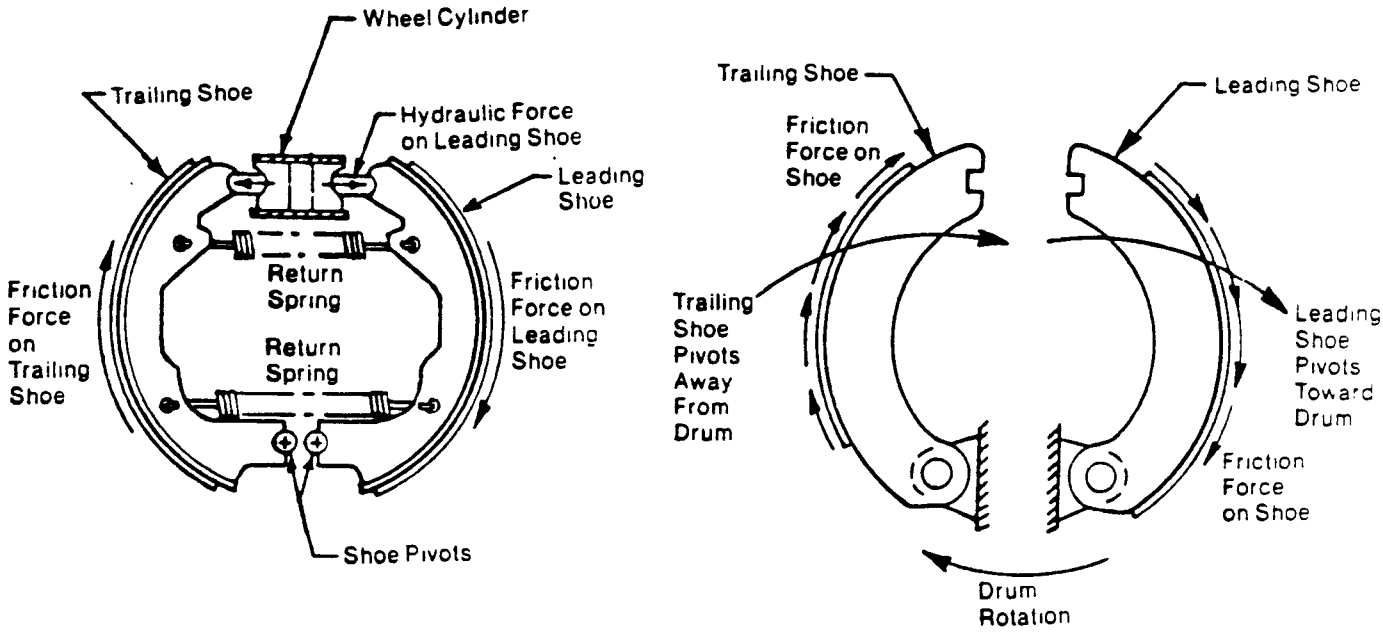
Figure 2a shows the forces acting in the shoes of a simple leading-trailing drum brake. As shown, the friction force on the leading shoe causes it to be further loaded against the drum, increasing its effectiveness, while the friction force on the trailing shoe causes it to oppose the application force, decreasing its effectiveness.

In the duo-servo design, Figure 2b, the friction force of the primary shoe is used to apply the secondary shoe, thereby markedly amplifying the application force. The increase in brake loading due to friction is referred to as self-actuation, and this phenomenon can be used to increase the brake effectiveness. This design has been and still is used extensively on American cars using asbestos-containing brake linings.

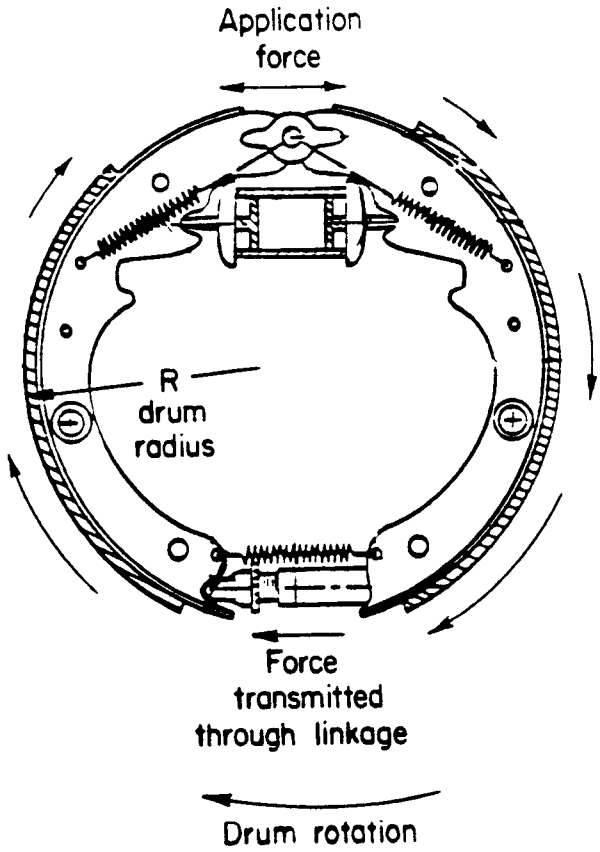
Although the phenomenon of self-actuation can increase brake effectiveness, the effectiveness is strongly influenced by the frictional properties of the lining material. Figure 3 shows the relationship between brake effectiveness and lining friction coefficients for different drum brake designs and for an automobile disc brake. Duo-servo drum brakes are widely used in American automobiles, while leading-leading systems are found on many transit buses and heavy trucks. Leading-trailing systems are also found on most heavy trucks and on many automobiles. Assuming a nominal friction coefficient of 0.4, a 12-percent change in friction coefficient can alter the brake effectiveness by approximately 44 percent for a duo-servo drum brake, 33 percent for the leading-trailing drum brake, and only 12 percent for a disc brake. Figure 3 also shows that for automobile rear drum brake systems, friction materials qualified for use with duo-servo systems may not perform satisfactorily when used with leading-trailing systems. Conversely, materials qualified for use in leading-trailing systems may precipitate rear wheel lock-up when used with a more effective duo-servo system.

Aftermarket friction materials from different manufacturers can exhibit a wide variance in friction characteristics. This can lead to variable and unpredictable brake performance, even with materials containing asbestos. Under current law, aftermarket friction materials do not have to meet Federal Motor Vehicle Safety Standards.

As more major OEM friction material suppliers phase out asbestos materials, the burden of supplying materials for the aftermarket will fall on these secondary aftermarket suppliers. Under the proposed ban on



a. leading-trailing



b. duo-servo

FIGURE 2. FORCES ACTING ON BRAKE SHOES OF TWO COMMON DESIGNS

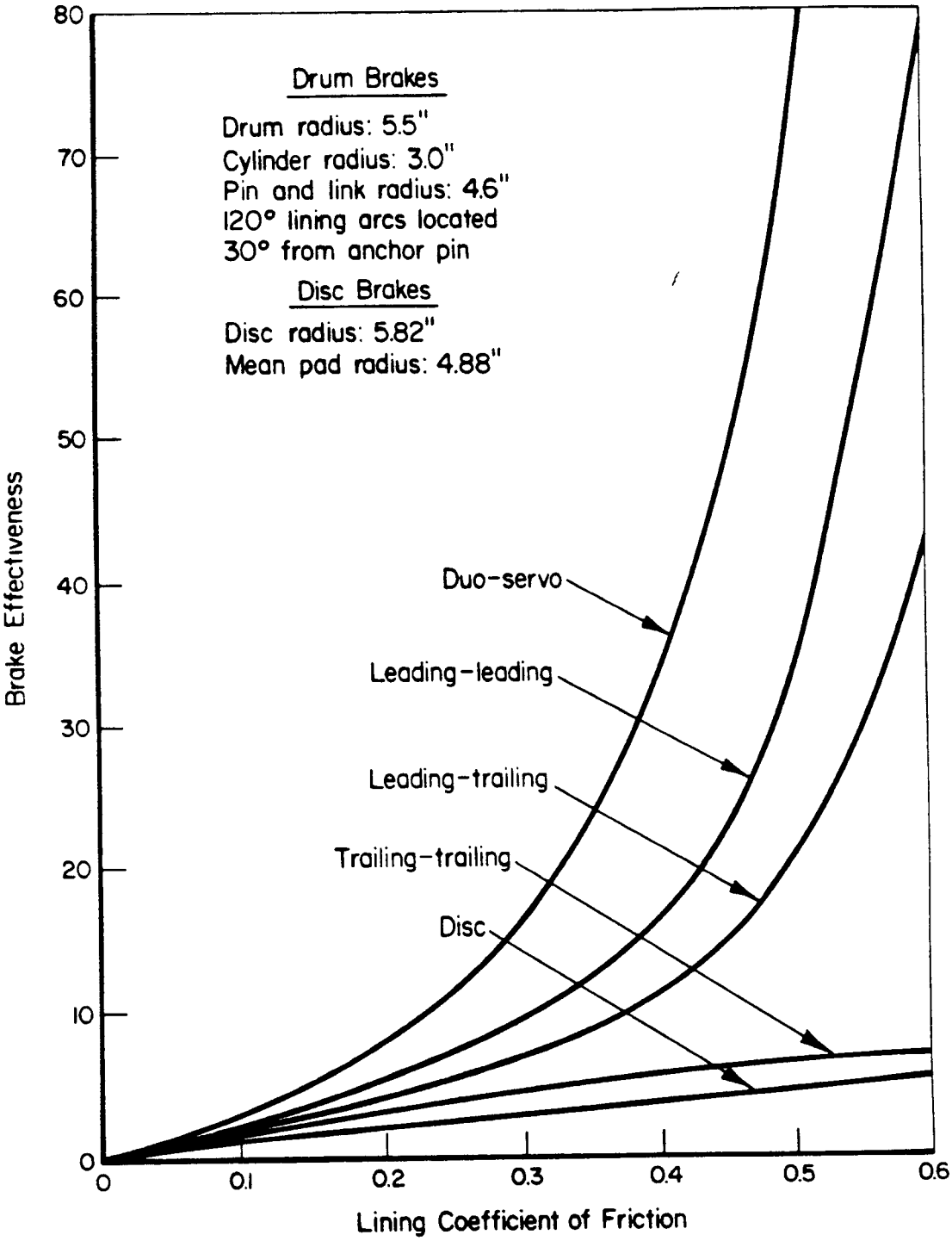


FIGURE 3. RELATIONSHIP BETWEEN BRAKE EFFECTIVENESS AND BRAKE DESIGN FOR VARIOUS LINING FRICTION LEVELS

asbestos-based linings, the brake system engineer would have two choices. First, the drum brake could be redesigned and redeveloped for acceptable performance with non-asbestos linings. Second, the designer could wait for a lining formulation to be developed that can be used directly in existing drum brake designs. This is a critical decision. Redesign of a brake assembly is costly, time consuming, and probably unrealistic. However, waiting for the development of a suitable universal non-asbestos replacement friction material--that has yet to be made--involves the risk of not having acceptable aftermarket components if asbestos-based brake linings are banned.

2.5 Influence of Brake Lining-Brake Drum Pressure Distribution on Brake Effectiveness

For drum brakes of the same design, the use of different materials exhibiting similar friction coefficients is not sufficient to ensure consistent and even braking throughout the life of the material. The use of a material that exhibits different wear or thermal properties can be sufficient to change the effectiveness of the brake system. Figure 4 shows the variation in effectiveness for the same brake design but for different brake lining pressure distributions. Note that large changes of brake effectiveness are possible for the same value of friction coefficient due to the effect of lining pressure distribution.

Several factors can lead to uneven and inconsistent brake lining-brake drum pressure distribution, but the most significant are wear and thermal distortion. Wear tends to shift the center of pressure location. Thus, substitute friction materials with different wear rates from the original asbestos materials may also influence stability by changing the center of pressure. A reduction in brake effectiveness, or an increase in brake effectiveness leading to wheel lock-up, could be possible consequences of improper friction material selection.

The profiles of the brake linings also are affected by thermal distortion. Brake lining expansion through the friction material thickness is often much greater for non-asbestos brake linings, and these friction materials also tend to be much stiffer. Therefore, the contact geometry and pressure distributions will be different, which can affect the friction

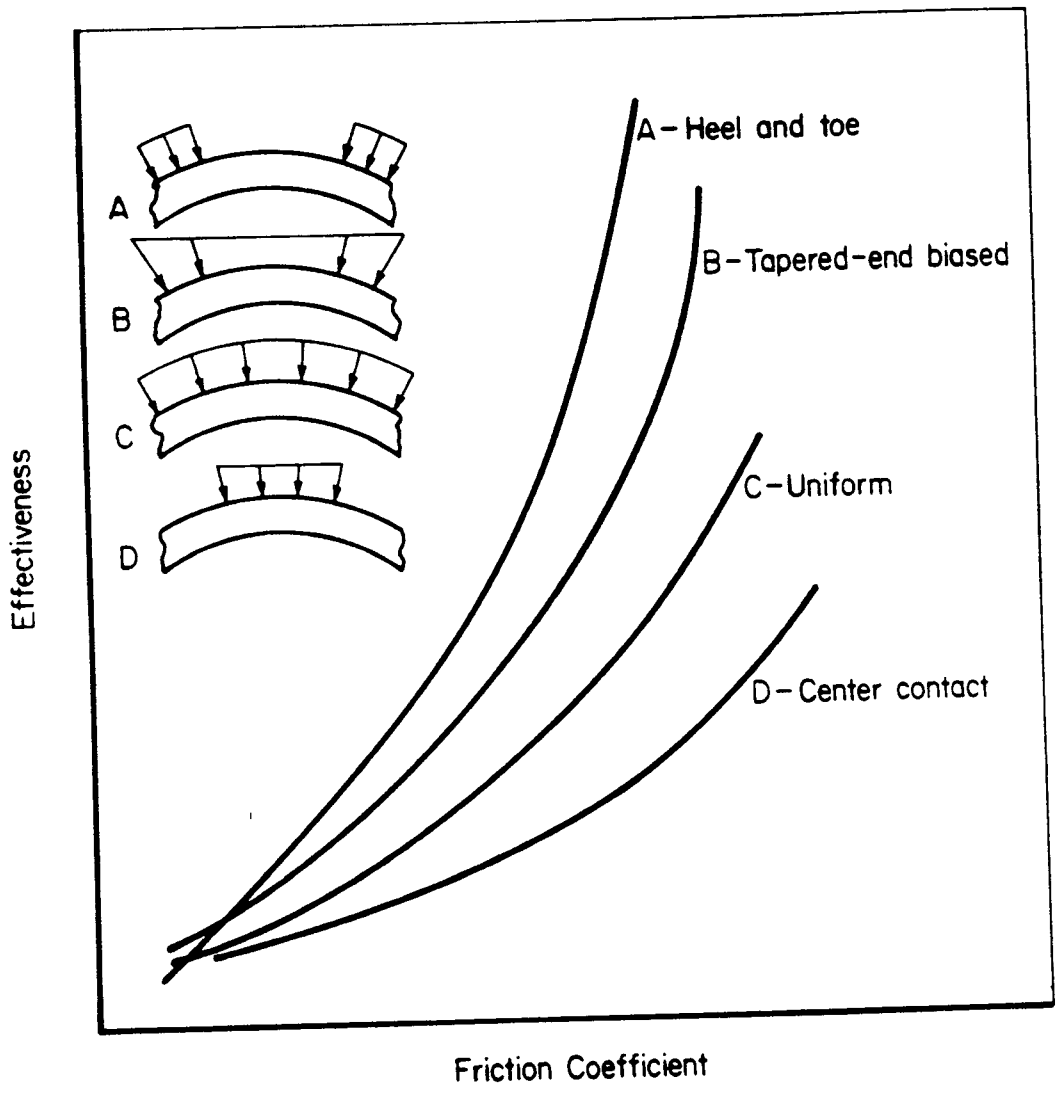


FIGURE 4. EFFECT OF LINING PRESSURE DISTRIBUTION ON BRAKE EFFECTIVENESS FOR A LEADING SHOE DRUM BRAKE

forces generated at the contact area, especially on the larger drum brake assemblies. For this reason, friction materials with higher thermal expansion rates may cause inconsistent braking performance, especially with varying brake temperatures.

An added complication results from the greater thermal expansion rate and compression stiffness of many non-asbestos friction materials. This is called hot-spotting, a thermoelastic instability that causes the lining pressure distributions to become localized, with resultant high thermal stresses and erratic friction values. The basic principles are simple, but the total system effects can be extremely complex.

For example, one particular brake lining location may have a greater clamping load than average, providing greater friction and heat generation. This causes that location to expand, further increasing its excess load. If the lining wear rate is low, this cycle can continue for some time, leading to the formation of a hot spot. Hot spotting tends to occur during low temperature brake usage, with light brake applications, and during braking from highway speeds. Since this brake usage is not severe, it can inadvertently be overlooked in the early stages of the brake development process.

2.6 Issues of Friction-Induced Vibration and Brake Noise

Vehicle braking systems generally include several structural components, e.g., calipers, pedal linkages, etc. Forces generated during braking can cause high stresses in these brake components and in vehicle-associated components, e.g., axles and suspension elements. These stresses result from the nominal braking torque as well as from thermal and other dynamic loads. Sufficiently large dynamic and thermal stresses superimposed on the nominal braking stresses might promote fractures or fatigue failures in some vehicle structures, which then could result in an unsafe operating conditions. The brake friction material properties strongly influence the dynamic behavior of the vehicle structure during braking because these properties determine the magnitude and frequency of the braking torques generated at the friction interface. For example, phenomena such as brake squeal, chatter, and groan produce structural vibrations of vehicle com-

ponents which may be either reduced or increased by substituting different brake friction materials. The influence of a particular braking material on structural vibrations depends strongly upon the specific brake system design. Therefore, replacement materials should be evaluated carefully for critical vehicle applications.

Another structural consideration occurs in attaching the friction material to the brake shoe. This can be done by riveting, bonding, or integrally molding the lining to the brake shoe. Non-asbestos linings generally are stiffer, more brittle, and more highly anisotropic, i.e., their properties are sensitive to orientation, which can provide attachment challenges.

Friction-induced vibration and noise can occur under some conditions with vehicle braking systems. The phenomenon has received considerable attention, and attempts are normally made to quantify the parameters that influence its initiation. In the final analysis, however, this phenomenon is usually evaluated experimentally on a model-by-model basis.

Although the principle of sliding friction is extremely complicated and not totally understood at the present time, it is known that friction is not a steady-state process. Vibration occurs because of this variation in friction force in the related components. It is also known that friction-induced vibration occurs via several different yet distinct mechanisms. It is possible to have more than one vibration-exciting mechanism active at a given time. This makes brake vibration corrections complex. Some non-asbestos friction materials tend to be more prone to generate friction excited oscillations, for as yet uncertain reasons. It is felt that their generally greater energy storage modulus (stiffness) and lower energy loss modulus (dampening) are probable sources of greater tendencies for vibration and noise. Asbestos is much like many strands of rope in a brake lining formulation, although much finer in size. This is believed to provide the greater inherent dampening of asbestos friction materials. Fiberglass, aramid fiber (Kevlar), steel wool, wolastonite, and other non-asbestos reinforcing fibers typically are found as single solid elements, contributing minimally to the lining damping factor.

To clarify some of the mechanisms of friction-induced vibration, the following sections discuss these mechanisms in more detail.

2.6.1 Stick-Slip

At low brake application speeds, it is possible for the brake lining and drum or disc to stick together for a short time, twisting up the vehicle suspension assembly. When the restoring torque builds up to the static breakaway value, the lining again slips against the drum/disc. This stick and slip cycle repeats rapidly, generating brake chatter, groan, or squeal vibration. This mechanism is attributed to a difference in the static and kinetic frictional torques and the spring-like restoring forces acting on brake components. The stick-slip mechanism produces a self-excited vibration with displacement-versus-time characteristics similar to a saw-shape form. This is the usual mechanism for low-speed brake chatter, although it can also exist in the form of a higher frequency squeal.

2.6.2 Negative Slope of the Friction Velocity Curve

This vibration inducing mechanism arises from a negative slope of the friction-versus-sliding velocity curve characteristic of certain materials in specific speed ranges. This causes instability in the system and excites vibrating components into nearly sinusoidal waveforms. An explanation is based on observations that the brake drum or rotor surface roughness asperities require a finite amount of time to produce equilibrium deformation of the brake lining material. The time that is available to deform the lining is decreased with increasing speed, restricting the time to compress the asperities in the friction material. Thermal effects, such as interfacial softening and changes of the chemical composition of surface layers, also have been offered as an explanation for the cause of the negative slope of friction versus velocity.

2.7 Comparison of 4-Wheel Disc Brake Systems With Front Wheel Disc-Rear Wheel Drum System

The almost standard use of front wheel disc brakes for automobiles has been due to some performance characteristics provided by this design. Because these brakes and the friction materials used with them (notably semi-metallics) can operate at higher temperatures than drum brakes, the

vehicle's braking balance can be shifted toward the front, reducing the likelihood of rear wheel lock-up during severe braking conditions. In addition, since automobile front brakes are exposed to water, disc brakes provide for more effective wet braking under many road conditions.

Many European automobiles imported to the United States have been fitted with 4-wheel disc brakes. There appears to be three reasons for implementing these brake systems. First, the effectiveness of disc brakes is less affected by friction material performance than the effectiveness of drum brakes. Since European safety standards require front brake biasing to prevent rear wheel lock-up, this situation is more readily ensured by using similar brakes on all four wheels and adjusting the front-rear pressure proportioning valve accordingly. Front brake biasing can be accomplished with vehicles outfitted with rear drum brakes, but the drum brakes require friction materials that exhibit very stable friction performance in order to ensure consistent performance (Figure 3). Second, in the absence of suitable non-asbestos linings, some European manufacturers elected to use proven semi-metallic materials and disc brakes as a means of eliminating asbestos. Third, in the United States, there is a perceived performance advantage provided by the term "4-wheel disc brakes", and so such systems are usually provided on higher priced imports. More inexpensive automobiles produced for wide-spread consumption in Europe (Fiat, VW, Renault, etc.) are still equipped with rear wheel drum brakes.

Rear wheel disc brakes have disadvantages. Currently used materials, semi-metallics, exhibit poor friction performance at low temperatures and optimum performance at high temperatures. The effectiveness of the parking brake can be adversely affected, since these brakes are usually applied when the brakes are hot and then required to hold as the brakes cool down. Also, the pad-disc normal load for the parking brakes can decrease as the pads cool down and contract from their hot, expanded geometry. The rear disc braking surfaces also are more prone to contamination by mud and road debris thrown from the front wheels.

3. EVALUATION OF FRICTION MATERIAL PERFORMANCE

3.1 Section Summary

The performance of friction materials, as applied to automotive brake systems, is reviewed in this section along with the pertinent friction material testing devices and relevant testing procedures and standards. Main points presented are:

- Friction materials are expected to perform satisfactorily over a wide range of operating and environmental conditions as an important element of the total brake system.
- Many critical performance considerations, such as fade and fade recovery, are sensitive both to the friction material and to the brake system in which it is tested. Therefore, full-system testing is required for proper evaluation.
- Friction stability can vary with both thermal and mechanical history. Therefore, short-term evaluations and those with narrow ranges of brake temperatures can produce incomplete data leading to erroneous conclusions on brake compatibility and performance.
- Laboratory specimen test machines, such as FAST and FMTM, may be appropriate for quality control tests and material screening, but they are not able to determine the acceptability of substitute friction materials or to compare different friction materials.
- Full brake inertial dynamometers, properly instrumented and utilized, can be used to screen friction materials and determine some component performance behavior. Typically, these large and expensive devices do not adequately simulate the airflow over the brake and the environmental conditions of vehicle service.
- Good brakes are those with few minor faults. Brake development testing therefore is time consuming and costly, since a wide range of conditions must be evaluated in the process of brake development.

- Federal Motor Vehicle Safety Standards (FMVSS 105, 121, and the proposed 135) are severe-usage brake tests which are only one of many standards that new (OEM) vehicle brake systems must meet. No standards need be met by aftermarket friction materials.

3.2 General Evaluation Criteria

Friction material performance for vehicle brake systems may be qualified by meeting the requirements of the Federal Safety Standards, Society of Automotive Engineers (SAE) recommended practices, along with brake component and vehicle manufacturers' standards. These experiments are directed to maximize safety, dependability, and customer satisfaction over a variety of brake operating conditions. For new vehicles, compliance with federal and state motor vehicle safety standards is only the starting point for acceptance of a brake system.

This section of the report discusses the criteria and techniques used to determine friction material suitability and performance. Full evaluation of a friction material requires installation into a complete brake system. It is only in the full brake system that many of the important brake lining attributes such as fade, fade recovery, environmental effects, and varying service factors may be properly determined.

Vehicle brakes are required to operate under a wide range of conditions, from steep downhill grades with a heavily loaded vehicle to minimal loads on interstate highways. Vehicle brakes must be completely reliable and must be minimally affected by temperature, water, or contamination. Brake actuation forces should be properly distributed, and brake friction must be consistent throughout the life of the friction material. Pedal actuation forces brakes should not exceed the capabilities of a wide range of drivers.

Vehicle braking performance can be closely related to loss of directional control in vehicles. Under skidding conditions, the tendency for wheel lockup in some brake systems can make controlling the vehicle more difficult. Commercial vehicles with lower brake effectiveness have been shown to be less likely to encounter loss of control in accidents, presumably due to lower usage speeds and reduced tendency for wheel lockup (2).

Variation in the front-to-rear brake balance, due to changes in frictional performance, may adversely affect safety through reduced directional control and stopping efficiency. The subject of vehicle brake systems is discussed in more detail in Section 2.

Section 3.2 of the report describes some of the more important friction material performance characteristics that are evaluated during original equipment manufacturer (OEM) brake system qualification experiments. These include: Fade Resistance, Fade Recovery, Delayed Fade, Effectiveness Versus Speed, Friction Stability, Wet Friction, Moisture Sensitivity, and Wear Rate. Each of these important performance characteristics will be highlighted in the following sections.

3.2.1 Fade Resistance

Brake fade refers to a loss of brake effectiveness, generally as the result of excessive brake temperatures. Such excessive temperatures may occur under hard brake usage conditions or under less stringent conditions, should component cooling be restricted. Brake fade may occur under particularly hazardous driving conditions, such as descending steep and winding mountain roads. Five types of brake fade have been described:

- **Thermal**--due to high brake system bulk temperatures,
- **Delayed**--due to resin migration during brake cooling,
- **Blister**--due to effects of near-surface lining blisters,
- **Flash**--due to high speed, high torque demand braking, and
- **Water**--due to partial lubrication from water contamination.

Figure 5 shows a performance comparison between a good friction material and a poor material. The poorer friction material exhibits a more rapid drop-off of brake effectiveness, compared with the better material. Since poor brake fade behavior could also be exhibited by high quality materials if used in inappropriate brake applications, brake lining fade behavior is meaningful primarily in the context of a particular brake lining, brake, and vehicle application. It should be noted that although these curves are continuous, the driver applies the brakes at discrete points along the curve. If the last application happens to be on the "knee" of a performance curve, then the next brake application will yield different and unexpected brake system response.

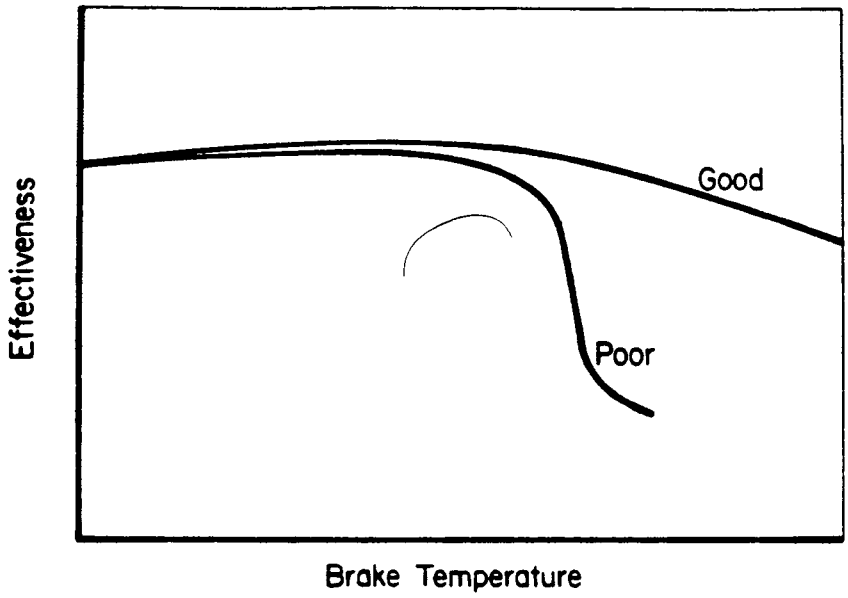


FIGURE 5. FADE CHARACTERISTICS OF GOOD AND POOR BRAKE FRICTION MATERIALS

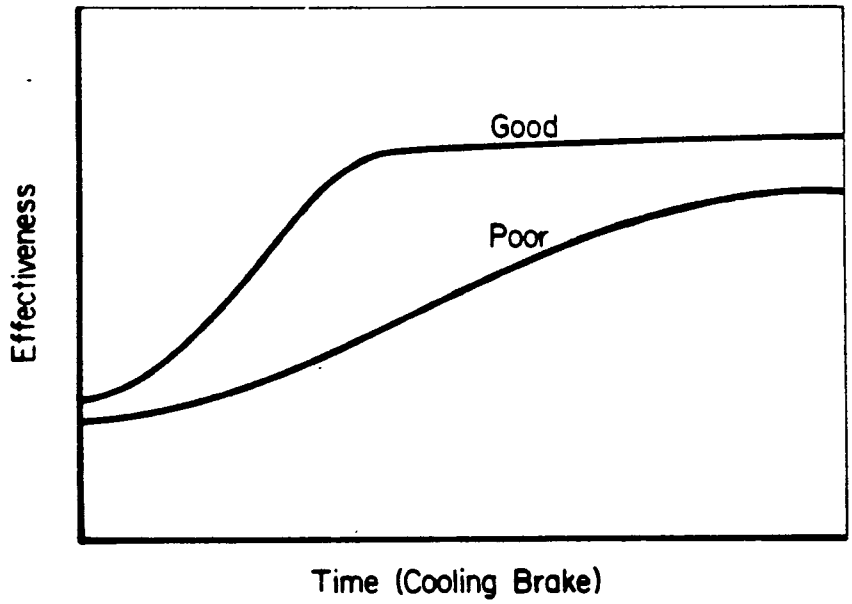


FIGURE 6. FADE RECOVERY CHARACTERISTICS OF GOOD AND POOR BRAKE FRICTION MATERIALS

3.2.2 Fade Recovery

Fade recovery refers to the ability of the friction material to quickly regain normal effectiveness after fade. This recovery is shown in Figure 6. As the brake cools with time after experiencing fade, the friction level should return rapidly to approximately the pre-fade level. Poor friction materials may exhibit slow recovery, compared with good friction materials, and may produce either a decrease or increase of brake effectiveness as a lasting consequence of the fade.

3.2.3 Delayed Fade

Delayed fade is a phenomenon which may occur with some friction materials. This phenomenon is illustrated in Figure 7. During fade recovery, brake effectiveness may drop unexpectedly, causing a temporary but potentially hazardous increase of required brake pedal force. This "delayed fade" is insidious in that it is often totally unexpected. It occurs well after a period of hard brake usage and usually with no warning signs.

3.2.4 Brake Effectiveness Versus Speed Characteristics

To ensure even braking over a wide range of stopping speeds, the brakes on each axle should exhibit similar effectiveness characteristics at all vehicle speeds. In general, brake effectiveness decreases with increasing speed. Consequently, a brake application from 60 mph usually requires greater brake pedal effort than from 20 mph. Good brake linings provide less speed spread, or difference in effectiveness at different braking speeds, and good brake systems employ friction materials that provide a proper balance of front-to-rear brake effectiveness at any speed. Figure 8 shows the general relationship between brake effectiveness and deceleration for brakes with poor and good "speed spread" performance. As illustrated, the effectiveness at 75 mph is markedly different from that at 25 mph for this brake, using a relatively poor friction material. Disc brakes are inherently less speed sensitive than high-servo-factor drum brakes, so they typically show less speed spread.

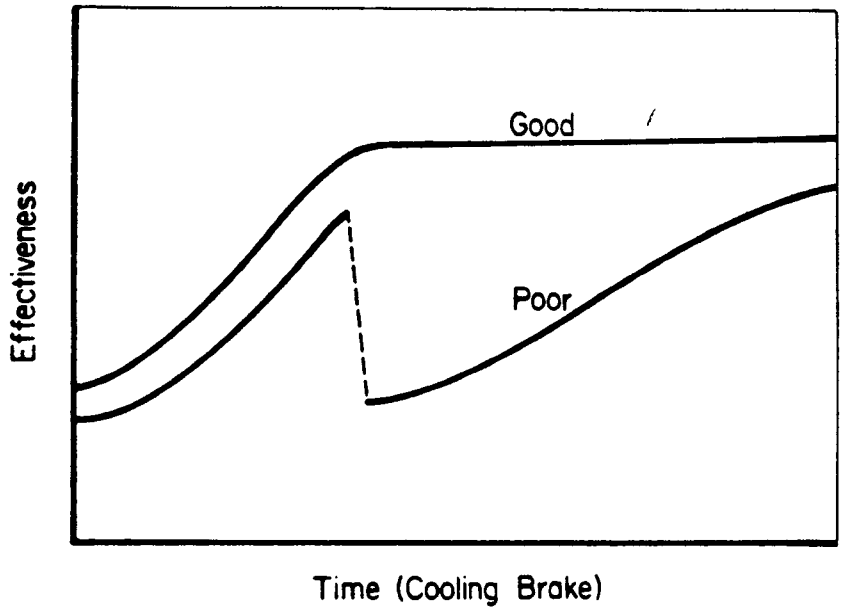


FIGURE 7. DELAYED FADE CHARACTERISTICS OF FRICTION MATERIALS

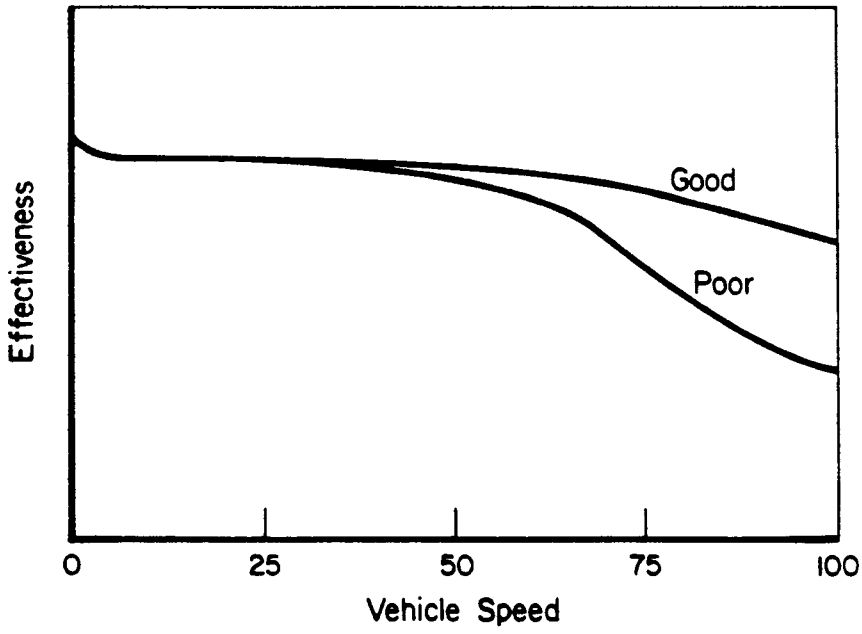


FIGURE 8. SPEED VERSUS BRAKING PERFORMANCE CHARACTERISTICS FOR GOOD AND POOR FRICTION MATERIALS

3.2.5 Friction Stability

To ensure consistent vehicle braking performance, the brake effectiveness characteristics should be stable throughout the life of the brake linings. Figure 9 shows the difference between a poor material and a good material in this regard. The brake effectiveness of poor friction materials can deteriorate with accumulated use history and wear, as indicated.

On vehicles equipped with a balanced set of friction materials on all four brakes, a gradual reduction in brake effectiveness may be marked only by a slight increase in pedal pressure to decelerate the vehicle, but brake stability will be essentially unaffected. However, on vehicles employing two unmatched friction materials on the front and rear axles, a shift in effectiveness of one braking axle relative to the other will alter braking balance and could adversely affect controllability of the vehicle during hard braking.

3.2.6 Wet Friction

The performance of vehicle brakes when wet is a significant safety concern. Disc brakes usually are less affected by water than are drum brakes largely because of the lower inherent servo factor in disc brakes. However, both disc and drum brakes can show large effectiveness losses when wet.

As expected, poor friction materials can provide a greater loss of effectiveness and take a considerably longer time to recover friction capability, when wetted, than experienced by good materials. This is shown in Figure 10. Permeability, heterogeneity, and compression stiffness are some of the brake lining properties which determine wet friction response. Complete understanding of this behavior is not known, so full brake dynamometer and vehicle tests are used to establish the wet friction behaviors of a brake system.

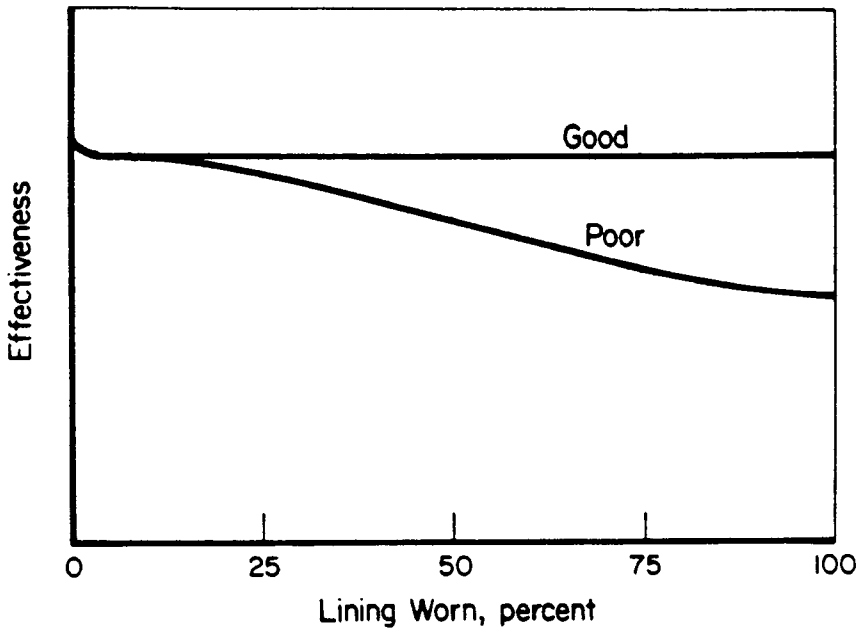


FIGURE 9. FRICTION STABILITY CHARACTERISTICS OF BOTH GOOD AND POOR FRICTION MATERIALS

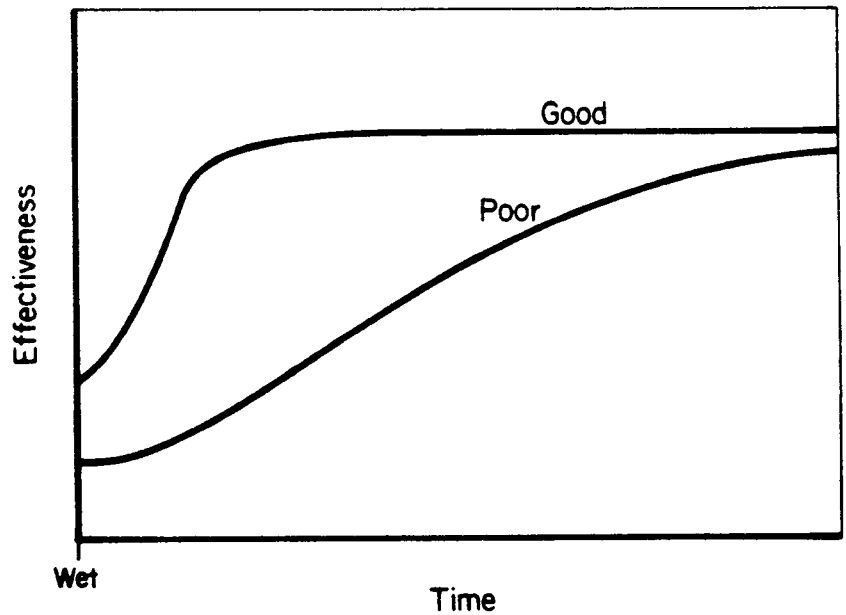


FIGURE 10. WET BRAKING PERFORMANCE FOR GOOD AND POOR PERFORMANCE BRAKING MATERIALS

3.2.7 Moisture Sensitivity

Friction materials are porous, fiber-reinforced composites that are capable of absorbing atmospheric moisture when a vehicle is parked, such as overnight. For some friction materials, this moisture has been shown to lower brake effectiveness temporarily, leading to a phenomenon called "morning sickness". Other morning sickness effects result from rusting of the cast iron disc/drum surface when a vehicle is parked for some time, causing abnormally high initial brake effectiveness. Under some conditions, it is possible for the friction material to become rust-bonded to the cast iron. Substantial driving torque may be required to break the interface free, and the rusted surface of the brake drum or disc may generate a temporarily uneven brake torque.

Figure 11 depicts the effect of moisture sensitivity on brake effectiveness. The ideal brake assembly exhibits little or no moisture sensitivity. When present, it usually persists for a few brake applications and disappears when brake heat drives the moisture from the brake lining or wear removes the surface rust.

3.2.8 Lining Wear Rate

Wear rates of friction materials depend upon temperature, prior use, speed, and load. In general, wear is directly proportional to applied normal load and speed. At moderate brake drum and disc temperatures, friction material wear rates are not affected greatly by temperature. However, at high brake temperatures, wear of the friction material may increase exponentially due to thermally induced degradation of the organic resin binder material(3).

Figure 12 shows representative wear performance for three different types of friction materials. Low quality materials may utilize an inferior binder resin (with poor heat resistance), providing a wear curve like that labelled "A". This may give acceptable wear rates at low brake temperatures, but rapid wear rates at higher brake temperatures. OEM type materials behave like curve "B", and heavy duty brake linings wear like curve "C". Note this heavy-duty lining does not improve wear life, except at the higher brake temperatures.

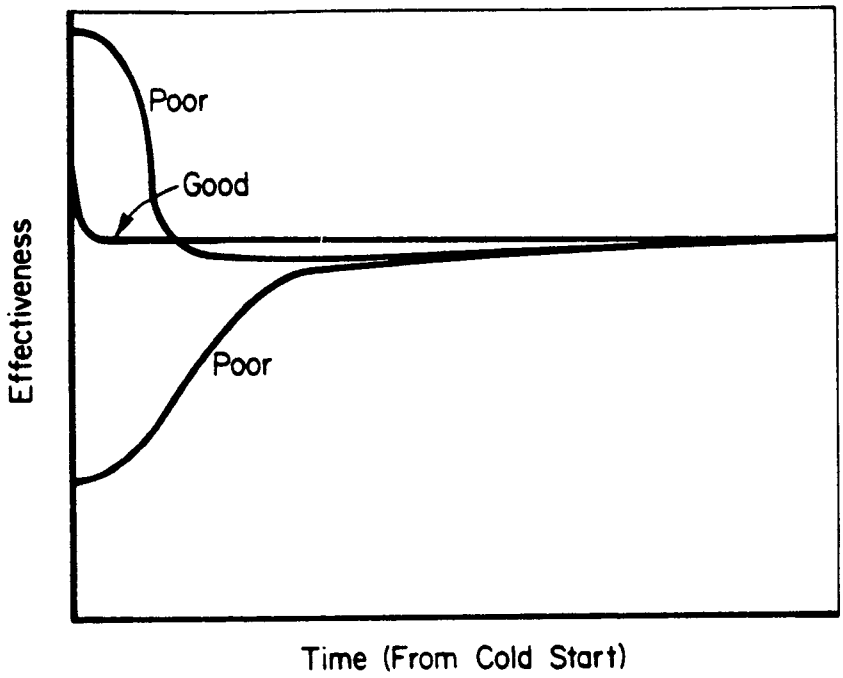


FIGURE 11. EFFECT OF MOISTURE SENSITIVITY ON BRAKING PERFORMANCE

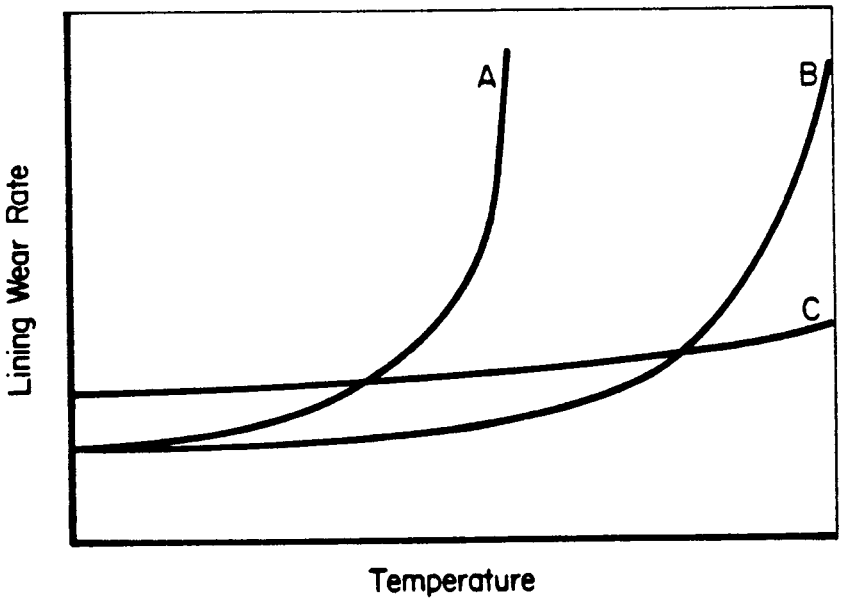


FIGURE 12. WEAR PERFORMANCE FOR BRAKING MATERIALS

TABLE 3. MACHINES FOR FRICTION MATERIAL EVALUATION (REFERENCE 3)

	Apparatus	General Test Procedure
(1)	Friction assessment screening test machine (FAST)	90 minute FAST QC test
(2)	Friction materials test (FMTM)	SAE J661a quality control machine test procedure
(3)	Girling scale dynamometer	Simulated vehicle road test
(4)	Full brake inertia dynamometer	Simulated vehicle road test

3.3.1 Friction Assessment Screening Test (FAST)

The Friction Assessment Screening Test (FAST) machine was developed by Ford Motor Company specifically for rapid "fingerprinting" of friction material specimens. It is used for in-plant quality control of clutch facings and brake linings and some specialized friction material screening and diagnostic tests. A 0.50-inch-square specimen generally is used, but lining samples up to 1.00-inch-square can be tested. The small, flat sample assures rapid specimen seating to the flat, cast iron test disc (1.5-inch thick/7.1-inch diameter). Quality control (QC) tests run for 90 minutes, with the friction drag held to a constant value. With a constant rubbing speed (880 rpm) and constant friction drag, the horsepower dissipated is also constant, providing repeatable temperature-time histories (70 to 560 F for QC). QC tests are often run on every batch of friction material as the linings are finished at their manufacturing sites.

However, the small FAST specimen precludes confidently making correlations of laboratory performance with full brake behavior. Thus this machine is used primarily for routine brake lining QC testing. Specialized characterization test procedures are mostly proprietary, and require expertise for proper evaluation.

While this machine reportedly has been used to perform friction material screening tests, it never has been recommended as a substitute for full-scale brake evaluations.

3.3.2 Friction Materials Test Machine (FMTM)

This apparatus, developed by T. P. Chase of General Motors, uses an arc-shaped 1-inch-square specimen of brake lining material, which is forced against the internal surface of a rotating, 11-inch diameter, cast iron brake drum. Auxiliary heaters and air blowers are used to provide controlled brake drum heating and cooling rates.

The FMTM is also used for quality control testing. SAE has developed a recommended practice (SAE J661a) that is classified as a quality control test procedure on the FMTM. This test requires more test time and expense than the FAST QC procedure, since it includes simulated burnish, wear, effectiveness, fade, and recovery procedures. It is used more for

periodic QC surveillance testing, than for routine production batch testing. General Motors and others also have developed specialized testing procedures for evaluating brake lining materials on the FMTM.

Based on the SAE J661a procedure, a brake lining friction rating specification has been required by some states for many years. However, this brake lining rating system has been shown to be clearly inadequate for meaningful comparative testing with different types of classes of friction materials. The SAE recommended practice J866 (revised in March 1985), includes this caution against such uses:

> **Note:** It is emphasized that this recommended practice does not establish friction requirements for brake linings, nor does it designate significant characteristics of brake linings which must be considered in overall brake performance. Due to other factors that include brake system design and operating environment, the friction coefficients obtained from this recommended practice cannot be reliably used to predict brake system performance."

Technical papers have pointed out that laboratory specimen tests, such as those which use the FMTM, do not provide acceptable correlation with actual vehicle or brake dynamometer service when non-asbestos or asbestos linings are evaluated. Different classes of non-asbestos brake linings, such as non-asbestos organic (NAO) and semimetallic (semimet), provide conflicting trends as well as different absolute values of friction on the Chase Machine[5].

3.3.3 Girling Scale Dynamometer

The Girling Scale Dynamometer is an apparatus which employs scaled-down brake components. A small brake disc is mounted on the end of a rotating shaft which carries inertia discs sized to ensure that the scaled disc pad will absorb the same amount of energy per unit area as a full-sized brake disc pad. The friction sample is pneumatically loaded against the rotating disc and a torque control system is used to produce a repetitive, constant deceleration drag.

Some brake characteristics scale by geometry and others are governed by absolute physical size. Consequently, experience is required

when using a scale device to be assured that the scaling process itself has not altered performance characteristics of the brake assembly. Therefore this device, as well as the other specimen test devices, can produce good test results only when utilized by a person with expertise in such specialized tests.

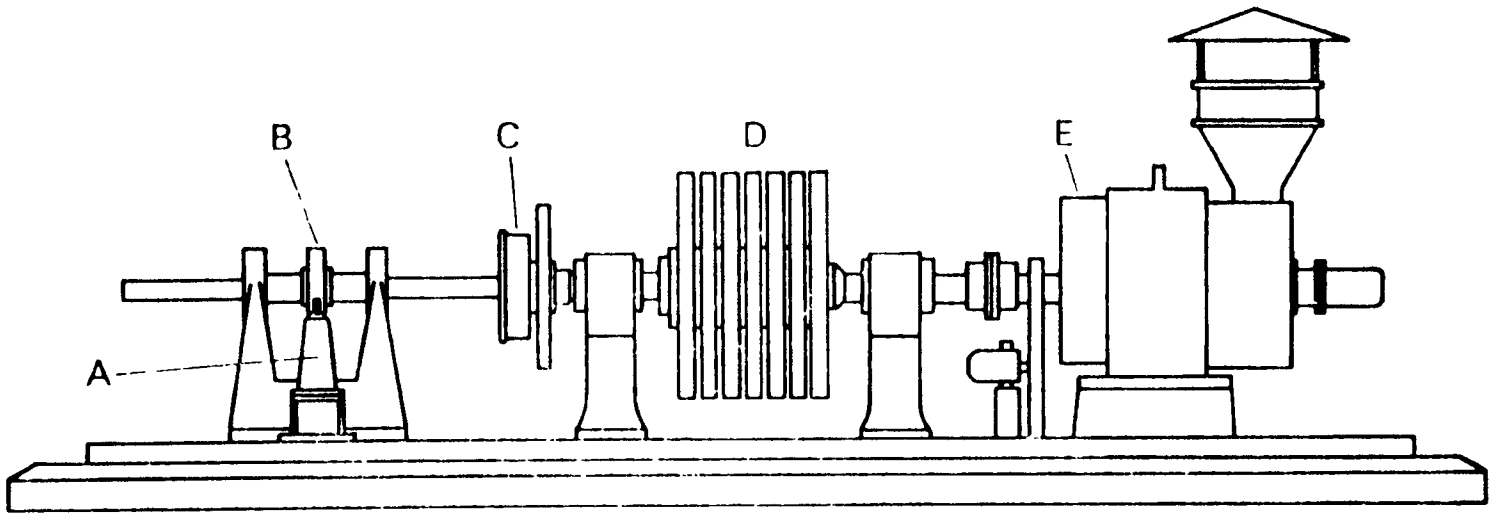
3.3.4 Full Brake Inertia Dynamometer

A full brake dynamometer simulates vehicle braking by mounting a complete brake assembly to a large rotating, inertially loaded shaft. The shaft's inertial loading is usually adjusted to simulate the actual road inertia. Figure 13 shows a schematic of an inertial dynamometer. Brake inertial dynamometers are designated by the number of ends, stations, or brake assemblies that can be tested at one time. Most are single ended for testing a single brake.

Double-ended dynamometers, while capable of simultaneous testing of two brakes, often are used as single-ended brake dynamometers so one test assembly can be installed as the other is being tested. Only a few four-ended brake dynamometers have been built. It is difficult on multiple station dynamometers to control the air flow for balanced brake cooling. Most brake dynamometers place the brake assemblies in closed ducts, both to expedite cooling and to control smoke and odor. Since faster cooling rates hasten testing, most dynamometer tests have much greater air flow and resultant cooling rates than are found in on-road testing. Consequently, brake dynamometers are used mostly for controlled wear tests, basic effectiveness tests, initial fade/recovery tests, and parking brake tests.

Full brake dynamometers are available in a range of sizes with inertial capacities ranging from "minicar" to "maxitruck". There are no standards, so almost every unit is different. Dynamometer-to-dynamometer differences in test results can be significant, even for carefully matched linings and brakes tested to the same inertia loading. Consequently, comparative brake lining test data is preferably obtained from a single brake dynamometer.

Much of the data difference between various dynamometers results from using brake lining thermocouples to control the brake test, as required



Inertia dynamometer. A: Hydraulic cylinder; B: Torque arm; C: Brake assembly; D: Flywheels; E: Motor.

FIGURE 13. SCHEMATIC OF INERTIA DYNAMOMETER

in the FMVSS 121 dynamometer procedure and as specified in most other procedures. Significant brake drum temperature variations occur with semimet and semimetallic linings, compared with conventional asbestos-based materials when control is by the lining temperature. Even different formulations of the same general type exhibit test drum temperature differences, especially if they vary in metallic content. Current brake testing practice now favors measurement of the cast iron temperature for test control. In this way differences of lining thermal conductivity do not significantly alter the temperature of the major heat sink, the drum or disc mass. Drum temperature measurement requires infrared pyrometry or thermocouple slip-ring assemblies. Most good brake dynamometers now permit one or both of these instrument refinements.

Burnishing conditions also affect the test results with most drum brake linings and blocks being sensitive to their initial usage history. When drum temperature control of the burnishing operation is provided, the test results are clearly better.

It now appears possible, with proper instrumentation and good control on the burnishing procedure, to perform meaningful friction material screening tests on full brake dynamometers.

Except for replicating airflow over the brake and environmental conditions, such as water and dust contamination, full brake dynamometers now can closely duplicate most vehicle in-service braking conditions and are invaluable for brake diagnostic testing. They can be excellent for initial brake lining screening tests. However, they are not sufficient to fully evaluate the acceptability of substitute brake linings.

3.4 Correlation of Laboratory Test Results With Vehicle Test Results

Numerous studies have been done to determine the correlation between laboratory friction material test results and actual vehicle test results[4,5,6,7,8]. In general, the only good analogy of a vehicle brake is the brake itself. Consequently, there are no specimen or scale test devices that can consistently yield test data that correlates with full vehicle performance data. This does not mean that such laboratory tests are useless--just that they should not be used to predict field perform-

ance behavior. They can and have been used to screen friction material for undesirable performance flaws.

Even tests on full brake dynamometers are difficult to correlate with on-road vehicle brake performance unless careful instrumentation and test controls are used. It should be possible to correlate full brake dynamometer test results with on-road data without need for questionable correction factors. This has been attempted by many, published by few, but not yet verified by anyone.

3.5 Federal Braking Requirements and Other Brake Tests

As indicated in previous sections, the qualification of vehicle brake systems and friction materials can involve numerous experiments to determine effectiveness, stability, fade resistance, moisture sensitivity, wet friction, and other performance parameters. Some of the brake performance criteria are determined by Federal Motor Vehicle Standards (105-83 and proposed 135 for hydraulic brakes, 121 for air brakes), while other performance standards are determined principally by the standards of the vehicle and friction product manufacturers.

This section of the report discusses the Federal Motor Vehicle Safety Standards now in effect and proposed for hydraulic and air brakes. In addition, some of the numerous SAE brake test procedures used to evaluate brake system and friction product performance will be discussed.

3.5.1 Federal Motor Vehicle Safety Standard 105

This federal standard mandates hydraulic and parking brake performance under specific vehicle operating conditions. Under the provisions of this standard vehicles under 10,000 lbs gross vehicle weight are tested to one set of procedures, while vehicles over 10,000 lbs gross vehicle weight are tested to a different set of procedures. General specifications are designed around stopping distances for braking with minimal tire skidding. Brake use tends to modify friction material performance. For this reason specifications are listed for new (pre-burnished) and conditioned (burnished) friction materials.

FMVSS 105 outlines braking requirements for vehicles braking under level, straight, dry, clean pavement conditions. Requirements for vehicle wet braking as well as parking brake performance on grades are also outlined. Table 4 lists the general categories of tests and the evaluation criteria used to determine brake performance. Specific braking requirements are outlined in the following section.

3.5.1.1 Stopping Distance Requirements. FMVSS 105 outlines a series of tests for brake effectiveness and dictates required stopping distances without wheel lock-up for passenger cars, vehicles (non-passenger cars) with GVWR of less than 8,000 lbs, vehicles weighing between 8,000 and 10,000 lbs, and vehicles with a GVWR of greater than 10,000 lbs. The procedures describe required performance for new brake linings and for burnished linings that have accumulated a specified history of brake performance. Performance requirements for partially disabled brake systems also are outlined.

Appendix A lists the procedures for evaluating braking system stopping distances under "normal" braking duty. The performance under brake fade conditions is determined by measuring the brake pedal force required to stop the vehicle under severe braking conditions.

3.5.1.2 Parking Brake Requirements. The vehicle parking brake must be capable of holding the vehicle stationary for 5 minutes on a grade (30 percent for cars, 20 percent for light trucks and vehicles over 10,000 lbs). This can be accomplished in part by using the transmission to brake the vehicle, provided the parking mechanism in the transmission must be engaged before the ignition key can be removed.

With respect to replacement friction materials, the ability of alternative materials to provide static friction levels sufficient to satisfy these criteria can only be assessed by actual vehicle tests.

TABLE 4. TESTS AND PERFORMANCE CRITERIA SPECIFIED UNDER FMVSS 105

Test	Performance Criteria	General Test Conditions
(1) Effectiveness	Stopping Distance	• Before and after burnish • GVWR and empty • With and without failures • Before and after spike stops • Before and after fade
(2) Fade tests	Pedal force and deceleration	• Pedal force needed to hold required deceleration in repeated stops to heat brakes • Pedal force during cool down (recovery) • (Did brakes return to normal?)
(3) Wet brakes	Pedal force and deceleration	• Pedal force needed to hold deceleration after brakes are wet • (Did brakes return to normal?)
(4) Parking brake	Pedal force/lever force	• Hold on grade with specified application force

3.5.2 Federal Motor Vehicle Safety Standard 121

Federal Motor Vehicle Safety Standard 121 lists the performance requirements for air braking systems. These systems are commonly used in heavy trucks, tractor-trailer combinations, off-road vehicles, and transit buses. This federal standard specifies requirements for stopping distance, brake effectiveness, fade and recovery, brake actuation time, brake release time, and parking brake operation. For these vehicles, brake loading can vary considerably, depending upon the service conditions and cargo load carried by the truck or trailer.

This section of the report will be concerned with stopping distance requirements and vehicle/dynamometer experiments needed to determine these requirements. Currently under FMVSS 121 only intercity and transit buses are required to meet stopping distance requirements. All other vehicles are exempt and do not require vehicle tests to satisfy FMVSS 121.

3.5.2.1 Vehicle Braking Experiments. Vehicle braking tests are conducted on level surfaces exhibiting different friction properties (as indicated by pavement skid numbers). For example, an 80 skid number refers to a generally dry, concrete surface, while a 30 skid number refers to a wet, polished concrete surface. Vehicle loads are adjusted to replicate heavy (loaded) or light (unloaded) conditions. Brakes are evaluated by braking the vehicle from 60 mph and 30 mph on a dry surface with a skid number of 81 and by braking the vehicle on a wet surface with a skid number of 30. Both dry and wet pavement braking are conducted under empty and fully loaded conditions.

Braking road test procedures for FMVSS 121 are listed in Appendix A. Note that in contrast with FMVSS 105 no decelerations are designated. Road tests with new brakes are preceded by a brake burnishing procedure consisting of 500 brake applications. During burnishing, brake lining temperatures are restricted to 500 F ± 50 F (Note that brake drum temperature is not controlled--see 3.2.4).

In addition to the regular system brakes, the vehicles must have emergency braking systems capable of stopping the vehicle in the event of partial brake system failure. This requirement is similar to the FMVSS

105 requirements describing brake operation in the event of partial loss of hydraulic fluid.

3.5.2.2 Parking Brake Test. The parking brakes for trucks, buses, and tractor-trailer combinations must be capable of holding the vehicle on a 20 percent grade, on a concrete surface, under both empty or fully loaded conditions in both directions. Initial brake application can be achieved using air or hydraulic activators. Once actuated the application braking loads must be maintained solely by mechanical means.

3.5.2.3 Dynamometer Testing for FMVSS 121. FMVSS 121 describes procedures for inertia dynamometer evaluation of friction materials. These procedures require the installation of a complete air brake assembly on the inertia dynamometer. Since stopping distance requirements cannot be measured using an inertia dynamometer, brake performance is determined by measuring brake torques and deceleration rates as a function of air pressure in the actuator. Dynamometer inertia is determined by using the inertial equivalent to the vehicle load on each axle.

The dynamometer test sequence for determining brake retardation, brake power, and brake recovery is listed in Appendix A. Trailers are only required to pass brake retardation requirements. Service line pressure and calculated brake retardation factor are used to determine acceptability of the materials.

3.5.3 Proposed Motor Vehicle Vehicle Safety Standard 135

This standard would replace FMVSS 105 for hydraulic brakes for passenger cars only. It contains a shortened test procedure designed to be more harmonized with European regulations. Requirements posed by the new standard which may affect friction material qualification are described in the following sections. This proposed standard can be found in Federal Register, May 10, 1985, Vol. 50, No. 91, pp. 19744 through 19760. Later revisions are in FR, Jan 14, 1987, Vol. 52, No. 9, pp 1474 through 1474.

3.5.3.1 Front Brake Biasing. Under FMVSS 135 standard, brake balancing would have to be adjusted to ensure that in the event of a braking situation resulting in wheel lock-up, the front wheels will lock first, for both a lightly-loaded vehicle and a fully-loaded vehicle. Currently, FMVSS 105 does not specify a wheel lock-up sequence. The braking situation involves careful selection of friction materials exhibiting stable, repeatable friction performance coupled with a properly adjusted proportioning valve. A vehicle designed witgh front-bias braking could become unsafe over time if the brake balance significantly changed.

3.5.3.2 Control Forces for Brake Application. Under the proposed standards, the allowable pedal forces required to brake the vehicle under specified stopping conditions will be reduced. Lower control forces may necessitate redesign of brake components on some cars to provide greater mechanical advantage, particularly to meet the requirements for performance with a failed power assist unit.

3.5.3.3 Parking Brake Performance. Under the proposed standard, the test gradient would be reduced from 30 percent to 20 percent, and a dynamic test has been added. The allowable control force for applying the parking brake would be reduced. This particular requirement may not place additional restrictions on friction material performance. A grade reduction from 30 percent to 20 percent represents a 30 percent reduction in load applied via gravity in the direction of slope. In contrast, the proposed reduction in allowable control force for the parking brake is between 10 and 20 percent.

3.5.4 SAE Recommended Practices for Evaluating Brake Systems and Friction Materials

The Society of Automotive Engineers (SAE) has developed about 26 recommended practices for checking the performance of brake lining systems. These standards cover automobile, truck, and trailer brake system tests using both vehicles and dynamometers.

Prior to the adoption of FMVSS 105 and 121, the SAE procedures were intended to give some suggested standard guidelines to brake system

evaluations. The enactment of FMVSS 105 as a requirement for brake system certification shifted the emphasis of these SAE procedures to the role of supplementary tests that could be used to further qualify vehicle brakes and braking systems.

Table 5 lists some of the SAE brake test code procedures. Various SAE documents outline test procedures, while others outline performance requirements for various vehicle classes.

TABLE 5. SELECTED SAE VEHICLE BRAKE TEST CODES

SAE Code	Description	Comments	Vehicle Affected	Approval Date
J661a	Laboratory procedure for evaluating friction	Generally shown to have poor correlation with vehicle performance		5/1953 - revised 9/1971
J667	Laboratory procedure for evaluating friction material performance using an inertial dynamometer	First SAE recommended practice for inertia dynamometer testing		4/1952 - revised 6/1961
J843d	Vehicle test procedure for evaluating brake system performance	Intended to replicate conditions of vehicle tests required by FMVSS 105	Passenger cars and light duty trucks	1/1963 - revised 3/1973
J201	In-use vehicle test procedure for brake system of cars, light trucks, and passenger vehicles up to 10,000 GVWR	An inexpensive quick test designed to examine, in a cursory fashion vehicle parking brakes and service brakes; set up for state inspection stations	Passenger cars and light duty trucks	4/1976
J212 JUN80	Laboratory test procedure for dual-end inertia dynamometer	Laboratory (inertia dynamometer) version of SAE J843b	Passenger cars and light duty trucks	6/1980
J880 MAR85	Brake system rating test code	Rates power absorption capability of heavy duty vehicle brakes	Commercial vehicles	3/1985

4.0 PERFORMANCE ATTRIBUTES OF FRICTION MATERIALS NOW IN USE

4.1 Section Summary

This section presents some performance characteristics of known asbestos and asbestos-free friction materials and discusses the feasibility of replacing the asbestos-based brake linings that are currently used.

Main points brought out in this section include:

- Friction materials are proprietary formulations, made from specific combinations of binder resins, reinforcing agents, fillers, and friction modifiers to provide acceptable performance in some brake applications.
- Chrysotile asbestos-based friction products have been highly developed and refined over the past 80 years. Their field performance attributes are well known.
- Non-asbestos friction materials presently are under intensive development, but most have been conceived within the past decade. Limited field service data is available.
- Four classes of non-asbestos friction products exist: non-asbestos organic (NAO), resin-bonded metallic (semimetallic), sintered metallic, and carbon-carbon. Only the semimetallic and NAO materials have shown promise for common automotive brake lining applications. Semimetallic linings are not readily applicable to drum brakes, except for heavy truck brake blocks.
- Non-asbestos organic linings offer the best potential for most automotive friction material applications. However, development of NAO materials is hampered by a lack of understanding of the new raw materials; specifically their special processing requirements and their full-service performance behavior. Since lining formulation is a proprietary process, there is very little information interchange on non-asbestos lining technology.
- No performance requirements exist for aftermarket friction products. Consequently, non-asbestos brake linings are

commercially available, but they lack field service data to assure satisfactory performance for the full range of automotive applications.

4.2 Introduction to Friction Material Formulations

Little has been published about the specific formulations of friction materials, since they are considered to be proprietary compositions by the friction material manufacturers. This section of the report reviews the more common forms of both asbestos and non-asbestos lining materials and presents data regarding performance under vehicle or simulated vehicle braking conditions.

Friction materials for automobiles contain four general types of ingredients: reinforcing agents--usually fibers, friction modifiers, fillers, and binders. Most automotive friction materials use thermosetting resins in their binder systems. These resins, often of the two-step (Novolac) phenolic type and generally modified for both processing and functional purposes, provide the matrix to bond the various constituents together. Internal pressures generated during processing and fade testing can reach 1000 psi, so binder resins require good tensile strength at elevated temperatures. Binder resins provide more than just structural attributes to the brake lining. Thermal stability, friction level, fade, fade recovery, dimensional stability, wear life, and other performance characteristics of the brake lining are determined, at least in part, by the choice and amount of binder resin.

Reinforcing agents provide the structural elements to support the friction material in service. Brake linings experience a range of loadings that require strength, stiffness, and toughness. The reinforcing agents contribute to the stiffness and strength of the friction material composite. Usually these agents are fibrous and most often provide other attributes to the brake lining, such as wear resistance and improved dimensional stability.

Since chrysotile asbestos has been used as a reinforcing agent in friction materials for about 80 years, its performance attributes are fairly well known. Chrysotile asbestos was chosen because of its unique combination of physical, thermal, mechanical, tribological, processing,

and economic properties. It is a unique mineral, processed to provide the desired fiber length distribution and fiber "openness" (degree of fiber fluffing or opening of the fiber bundles) needed for specific applications. Usually two or more grades of chrysotile asbestos are blended to produce the desired properties for the brake lining.

Non-asbestos friction materials use a blend from several hundred potential fiber and other structural agents that have been tried in brake linings. No one fiber replaces asbestos, so a "fiber cocktail" is developed to provide the needed processing, structural, functional, and permeability attributes for the brake lining at an acceptable cost.

Friction modifiers and fillers, as the names suggest, are added to provide the needed performance modifications and cost control to the binder/fiber system. Hundreds of organic and inorganic constituents may be used, in varying amounts, distributions, and particle sizes to achieve the intended results. Since friction material formulation is more of an art than science, it is common for these materials to be sequentially added to the formulation to "correct" different performance shortcomings in the lining development process.

The asbestos-free friction materials have four developmental classes: non-asbestos organic (NAO), semimetallic (semimet), sintered metallic, and carbon-carbon. Semimetallic and NAO linings appear to be the best suited for most automotive brake applications, but all four types will be discussed in Section 4.4.

4.3 Asbestos-Based Friction Materials

Asbestos has been used in brake linings and other friction products since the turn of the century, when metals, leather, and wood no longer were adequate. The predominant type of asbestos used in brake linings is chrysotile, a hydrated magnesium silicate. The ultimate chrysotile fibril is about one millionth of an inch in diameter, so a fiber bundle about the size of a human hair may contain a million fibrils. The larger fiber bundles, called "crudes" constitute the visible asbestos in a friction material. Smaller fibers, especially when fully wetted by the binder resin, are virtually impossible to see in the brake lining. Many lengths and fiber diameters are used in making the asbestos-based friction

materials, usually by selection of an appropriate commercial grade or grades and by proper blending. Asbestos provides many desirable attributes to the linings, both in manufacture and in service usage.

During the mixing and molding process, asbestos helps to hold the materials together. This is referred to as "green strength" in the preforming and molding operations. During molding, and also during usage, the asbestos provides permeability to the lining, letting internally generated volatiles escape before they can produce high internal pressures and possibly blister or crack the brake linings.

Chrysotile asbestos, being hydrated, loses this water as the temperature rises. At around 650 degrees Celsius (about 1200 degrees F) this dehydroxylation causes about a 14-percent weight loss to the asbestos. At slightly higher temperatures, the chrysotile asbestos converts to an amorphous or glassy phase. One common product of this conversion is called forsterite. In this converted phase, the chrysotile asbestos normally has been transformed from a fiber to a very fine powder. At very high temperatures, forsterite can deposit in smeared layers over the disc or drum braking surfaces, but this is quite uncommon and undesired.

Each vehicle application requires friction materials exhibiting different frictional and mechanical properties. Passenger car and light truck drum brake linings, called segments, usually contain from 30 to 70 percent by weight of asbestos. If held together with a liquid resin, these are referred to as wet mixes. Such materials are commonly roll-molded to their basic cross-sectional shape, but also may be formed by extrusion or other molding processes. When a powdered binder resin is used, the mix is referred to as a dry mix. These generally require an initial molding or briquetting operation to produce the required shape. Both are cured by heat in a process that is both time and temperature dependent.

A wide range of friction, wear, and other properties can be built into such materials, particularly with over 70 years of formulation development time. Asbestos provides good static friction properties, important to drum brakes with integral parking brakes, and is easily formed, by many processes, to make durable and dimensionally stable segments.

Passenger car and light truck disc brake linings are almost exclusively made with powdered binder resins in dry mix processes that

involve being individually molded to nearly final dimensions. Asbestos content usually is a bit lower and longer fiber lengths are used in disc brake linings because of their greater temperatures and pressures in service usage. The permeability, or "breathing" characteristic, of chrysotile asbestos is important to disc brakes to prevent rapid friction loss with increasing temperatures and during hard, high speed stops.

Heavy truck drum brake linings are called blocks and are generally molded in slabs. Longer fiber length asbestos and added crude fiber content is needed in these blocks, for reasons similar to those for disc brakes. Truck blocks are thick, about 0.75 inches (19 mm) so they require sufficient permeability to release volatile materials from manufacturing as well as from hard brake usage. Inadequate "breathing" causes blistered or delaminated brake linings. Truck brake blocks have been continuously refined over the years, with special formulations for most of the unique usage conditions.

4.4 Non-Asbestos Friction Materials

Less than twenty years have been devoted to the development of non-asbestos brake linings, with the most intensive effort over the past ten years. Various alternative fibers have been studied since cotton was replaced by asbestos 80 years ago. However, none provided the requisite performance to challenge asbestos until the semimetallic linings were developed for hard service disc brake usage in the 1970's.

Concerns about asbestos fiber toxicity, increasingly stringent air quality standards, and rising insurance costs all stimulated the development of substitute materials. Substantial progress appears to have been made in the past few years, as many new vehicle models have been released with fully asbestos-free brake systems. Several aftermarket friction products have been advertised as asbestos-free, but little is known of their actual service performance characteristics.

Dynamometer and vehicle performance test data for non-asbestos friction materials are not available, so a complete evaluation of these materials was not possible. A variety of non-asbestos materials is available for aftermarket applications. No replacement friction materials, except qualified OEM linings, are known to have undergone qualification

tests under FMVSS 105. In addition, most aftermarket suppliers lack the facilities required to conduct FMVSS 105 and FMVSS 121 test procedures.

The following discussion, though not complete, provides at least an introduction to the different types of non-asbestos friction materials that are presently available or under development. Some of their basic functional characteristics are also given, when sufficient information was available.

Despite substantial engineering efforts, non-asbestos replacement friction materials are not available, at a proven quality and performance level that is equivalent to that of the original brake linings, for vehicles which originally were released with asbestos-based brake linings.

Non-asbestos friction materials technology is advancing rapidly, with many new car, light truck, heavy truck, and off-road brake systems being released for new vehicle production. Materials are under development for all four general classes.

4.4.1 Semimetallic Friction Materials

Semimetallic and resin bonded metallic (RBM) are all names for this popular class of friction material. Semimetallics utilize steel wool, some form of iron powder, graphite, binder resin, and various other constituents in their formulations.

Semimetallics have been used as disc brake linings on passenger cars and light trucks for about a decade. Presently they are the most common friction material used with original equipment manufacturer (OEM) disc brakes in the United States. Although originally produced with a resin-asbestos backing layer, most semimetallic linings now use no backing layer, or one of a non-asbestos organic (NAO) composition. Semimetallic linings also have had limited usage in heavy truck drum and disc brakes.

These friction materials are usually hot-pressed to finished dimensions. Consequently, they are not readily made into drum brake segments, due to the needed large lining curvature. Since semimetallics also tend to be low in strength and stiffness, they are better suited to the thicker disc brake lining and heavy truck block configurations.

Semimetallic linings have several unique performance characteristics. For one, they have a high initial wear rate, at least until a

ferrous transfer layer is built up onto the drum or disc cast iron surface. This formation is rapid at high temperatures, but can be quite slow for brakes that operate at low temperatures, low speed, and light pressures. Lining wear life is greatest for moderate temperature service. Poor lining life can result from very low usage temperatures, so brakes are often designed to run hotter with semimetallic linings. Most friction materials have a lower friction level at higher rubbing speeds, but semimets do not. These materials have nearly constant friction levels from about 30 mph to beyond 100 mph, providing potential front-to-rear brake balancing difficulties for some systems. While the friction is nearly constant at high speeds, the lining wear rate is not. Semimetallic linings have high wear rates, per unit work done, at higher rubbing speeds. Thus they seldom are used for racing car applications.

Water affects many friction materials greatly, but has very little influence on semimetallics--unless accompanied by oil. Water and oil can act to reduce the friction of semimet materials in contact with cast iron discs. Since road splashing generally contains some oil, this can cause a loss of friction. Disc brakes are less water sensitive than are most drum brakes and often run warm enough to dry quickly, so water effects usually are not critical or long lasting. Cool and humid ambient air conditions affect semimetallic linings significantly, causing a temporarily low brake effectiveness called "morning sickness".

4.4.2 Non-Asbestos Organic Friction Materials

Non-asbestos organic (NAO) materials utilize a combination of fibers and other ingredients to fulfill the functions that chrysotile fibers had performed in resin-asbestos linings. Aramid (DuPont's Kevlar), fiberglass, mineral wool, wollastonite, steel wool, and processed mineral fiber are some of the common reinforcement fibers used along with the binder resin and various fillers and friction modifiers in NAO brake linings.

NAO brake lining formulations presently are used in some OEM drum brake applications for passenger cars and light trucks and increas-

ingly are used in brake blocks on heavy truck drum brakes. NAO disc brake linings have been released for many OEM disc brake applications. Development efforts of NAO drum brake segments for the remaining OEM applications remains active.

This class of friction materials offers the greatest hope as an effective asbestos replacement, but also provides the greatest problems to develop. Literally hundreds of fibers and reinforcing agents have been used, generally in combination with several others. Finding the best combination for lining processability, friction level, friction stability, wear life, fade resistance, recovery, contamination sensitivity, and mechanical properties is a formidable task, even using statistically designed experiments. Since there is essentially no technical communication or cooperation among the lining suppliers, each is working virtually independently at this task. It appears likely that new NAO materials will be developed that are superior to the best of the asbestos-based linings. Presently, NAO materials tend to be hard, brittle, low in permeability, highly anisotropic, and prone to hot spot, blister, and crack in service.

4.4.3 Sintered Metallic Friction Materials

Usually sintered, these heavy-duty materials typically are of iron or copper base, but they may generally contain inorganic filler and friction modifiers as minor constituents.

Sintered ferrous drum brake linings were released for a few OEM passenger car applications two decades ago. They tend to be environmentally sensitive, both to temperature and moisture, which limits commercial applications. However, they are used for special service aftermarket automobiles, some severe service commercial vehicles, and aircraft disc brake applications.

Sintered copper-based friction materials have been used in heavy duty brakes and clutches for around three decades. Often with another metal, forming a bronze, and a refractory, such as mullite, these materials can perform well in hard service usage. However they too are environmentally

sensitive and can cause severe galvanic corrosion in wet environments, when used against the typical grey cast iron countersurface materials. Aircraft disc brakes and heavy duty truck/tractor clutches are present uses for the sintered bronze friction materials.

No known new application of these relatively old and well developed friction materials has resulted from the search for asbestos substitutes, largely due to their cost and sensitivity to light-duty environmental conditions(9).

4.4.4 Carbon-Carbon Friction Materials

These materials are space-age composites of carbon (graphite) fiber, held in a matrix of amorphous carbon using a costly and time-consuming manufacturing process.

Military aircraft, race cars, and some commercial aircraft now sometimes use the carbon-carbon friction materials for both the stationary and rotating elements of disc brakes. High cost and environmental sensitivity limit additional applications(9).

4.5 Aftermarket Vehicle Considerations

4.5.1 Drum Brakes

Brake design also affects the suitability of using some friction materials. The duo-servo drum brake used in older U.S. vehicles usually employs two different types of linings, with different friction properties, on a single brake to maximize overall brake performance. Aftermarket friction materials must be capable of replicating original design friction levels and friction stability to achieve acceptable vehicle braking performance.

The leading-trailing drum brake used on the rear axle of the new, smaller front wheel drive vehicles does not require friction materials with such stringent friction stability properties. In both applications,

the static friction properties of the material are important due to the use of rear drum brakes as parking brakes.

4.5.2 Disc Brakes

Disc brakes generally operate at higher temperatures than do drum brakes, and the friction material used for this application must exhibit stable friction behavior over a wide temperature range. U.S. passenger cars and light truck disc brakes which used asbestos-phenolic friction materials were designed to operate at lower temperatures than do present vehicles that use semimetallic linings. These asbestos-based linings generally had higher friction, especially at the lower brake temperatures, than do the semimetallic linings.

4.5.3 Factors Affecting Substitution of Friction Materials

The use of asbestos-free materials as direct substitutes in vehicles designed for asbestos-based linings may be restricted for the following reasons:

(1) Braking balance between front and rear brakes may be adversely affected.

With few exceptions, semimetallic and NAO linings presently are the only non-asbestos friction materials available for use on disc brakes. Use of semimetallic linings would decrease the front brake effectiveness, especially at the lower temperatures. Since many of the front brakes were designed to operate at lower temperatures than are optimal for semimetallics, the semimetallic linings would not provide proper friction and wear behavior for many users.

The available NAO rear brake linings differ in their friction properties, especially in the low temperature region, and also may be humidity sensitive. Front-rear brake balance at low temperature could be unsatisfactory,

unless matched front and rear linings both were installed during brake servicing. Regrettably, many users have only one set of linings replaced at a time. This offers a substantial opportunity for unbalanced braking between the front and rear brakes.

No known balanced non-asbestos brake lining sets are available for the aftermarket applications that originally were asbestos-based. The front-rear balance with replacement asbestos-free linings probably will be sensitive to the brake temperature, vehicle speed, and brake line pressure.

(2) **Parking brake capacity may be reduced.**

Many of the non-asbestos organic (NAO) drum brake linings provide low effectiveness at low temperatures. In addition, they also generally have high thermal expansion coefficients and are stiffer in compression. This can lead to a loss of parking brake capacity both from the lower effectiveness values and from larger losses of input cable forces, due to lining contraction.

(3) **No meaningful brake lining effectiveness ratings exist.**

NAO friction materials are currently produced domestically in both brake pad and brake drum configurations. Tables 6 and 7 list current U.S. producers of brake pads and linings for passenger cars and trucks[10]. Only a third of the manufacturers of NAO brake linings for light and medium vehicles are outfitted with the facilities needed to evaluate friction products under true vehicle test conditions or simulated vehicle tests (full brake inertia dynamometers). Similarly, only a third of the manufacturers of heavy vehicle drum brake blocks have appropriate test facilities for evaluating their NAO friction materials. All of these suppliers rate their linings using a rating methodology that has been shown to be deficient (see Section 3.2.2).

TABLE 6. PRODUCERS OF BRAKE LININGS FOR LIGHT AND MEDIUM VEHICLES

Company	Location	Market	Products: Disk Brake Pads: Asbestos	Products: Disk Brake Pads: Semi-Metallic	Products: Disk Brake Pads: NAO	Products: Drum Brake Linings: Asbestos	Products: Drum Brake Linings: NAO	1983 Sales (million dollars)	Employees	Comments
Abex Corp.	Winchester, VA	OEM and aftermarket	X	X		X	X	12	200	
Bendix Corp.	Troy, NY	OEM and aftermarket	X	X	X	X	X	75	1,200	Aftermarket products contain asbestos
Friction Div. Products, Inc.	Trenton, NJ	OEM and aftermarket		X		X		10-12*	N/A	1 million disc pads 400-500 thousand drum pieces produced per month
General Motors (Delco Moraine Division)	Dayton, OH	OEM and aftermarket	X	X				400	4,800	OEM for GM and Saab
General Motors (Inland Div.)	Dayton, OH	OEM and aftermarket				X	X	N/A	N/A	Also produces semi-metallic drum brake lining
H. Krasne Mfg. Co. Inc.	Los Angeles, CA	Aftermarket for imported cars	X	X				N/A	N/A	
Lear Siegler, Incorporated	Danville, KY	Primarily aftermarket: some OEM for medium trucks	X	X				50*	400*	
Nuturn	Smithville, TN	OEM and aftermarket	X	X		X	X	12	200	
Auto Friction Corp.	Lawrence, MA	Aftermarket, imported and domestic vehicles	X	X		X	X	8	100	
Brake Systems, Inc.	Stratford, CT	OEM and aftermarket	X	X	X	X	X	N/A	N/A	

TABLE 6. PRODUCERS OF BRAKE LININGS FOR LIGHT AND MEDIUM VEHICLES (Continued)

Company	Location	Market	Products: Disk Brake Pads: Asbestos	Products: Disk Brake Pads: Semi-Metallic	Products: Disk Brake Pads: NAO	Products: Drum Brake Linings: Asbestos	Products: Drum Brake Linings: NAO	1983 Sales (million dollars)	Employees	Comments
U.S. Automotive Mfg. Co.	Tappahannock, VA	Aftermarket	X			X		N/A	N/A	
Carlisle	Ridgeway, PA	Aftermarket			X	X				
Chrysler	Wayne, MI	OEM and aftermarket	X	X	X	X				
Virginia Friction Products	Walkerton, VA	Aftermarket	X	X	X	X				

* Figures provided by company representatives

Sources: ICF 1986 Survey of Primary and Secondary Processors of Asbestos Products. Telephone conversations with company representatives.

Sales and employees -- Ward's Directory of 51,000 Largest U.S. Corporations and Ward's Directory of 49,000 Private U.S. Companies. 1984. Petaluma, CA: Baldwin H. Ward Publications.

TABLE 7. PRODUCERS OF BRAKE LININGS FOR HEAVY VEHICLES

Company	Location	Market	Disc Brake Pads	Drum Brake Blocks				1983 Sales (million dollars)	Employees
			Semi-Metallic	Asbestos	NAO	Full-Metallic	Metallic (Asbestos-Free)		
Abex Corp.	Winchester, VA	OEM and aftermarket		X	X			12	200
Bendix Corp. Heavy Vehicles Systems	Cleveland, TN	Aftermarket	X	X	X	X	X	N/A	N/A
Carlisle Corporation	Ridgway, PA	OEM and aftermarket	X	X	X	X	X	25	400
H.K Porter Co.	Huntington, IN			X	X			18	300
Nuturn	Newcastle, IN	OEM and aftermarket		X	X			12	200
Ordnance Parts and Engineering	Fort Worth, TX	OEM and aftermarket, primarily military vehicle		X				2*	N/A
Brake Systems, Inc.	Stratford, CT	OEM and aftermarket			X			N/A	N/A
Scan Pac	Mequon, WI	OEM and aftermarket			X			N/A	N/A
Wheeling Brake Block Mfg. Co.	Wheeling, WV	OEM and aftermarket			X			5	100
Raymark	Crawfordsville, IN	OEM and aftermarket		N/A	N/A	N/A			
Standco Ind.	Houston, TX	N/A		X					
Palmer Prod.	Louisville, KY	N/A		X	X	X			
Friction Prod.	Medina, OH	OEM and aftermarket							

* Figures provided by company representative

This test, with 1 inch square specimens, can give particularly misleading friction data for some NAO and semimet brake linings.

The brake lining/drum or disc/pad system is a tribological system in which alterations in either the pad surface or the rotor surface affect system frictional behavior. Under elevated temperatures, cast iron surfaces can form iron oxides or develop transfer films which exhibit lower coefficients of friction than do plain cast iron surfaces. The abrasive nature of asbestos-phenolic friction materials acts to continually remove these surface films, thus restoring system friction and brake effectiveness. Semi-metallics, on the other hand, depend on a transfer film that is known to exhibit low friction under cold and moist conditions.

4.6 Direct Comparison of OEM and Aftermarket Brake Linings

Complete brake dynamometer and vehicle performance data are not generally available to use for comparisons of different friction materials, making it difficult to support or refute claims made about the availability of acceptable, asbestos-free replacement brake linings. When available, interpretation and evaluation of the test data can be difficult.

The next two sections present both dynamometer data and vehicle test data that highlight observed performance limitations posed by the use of non-asbestos friction materials.

4.6.1 Dynamometer Test Data

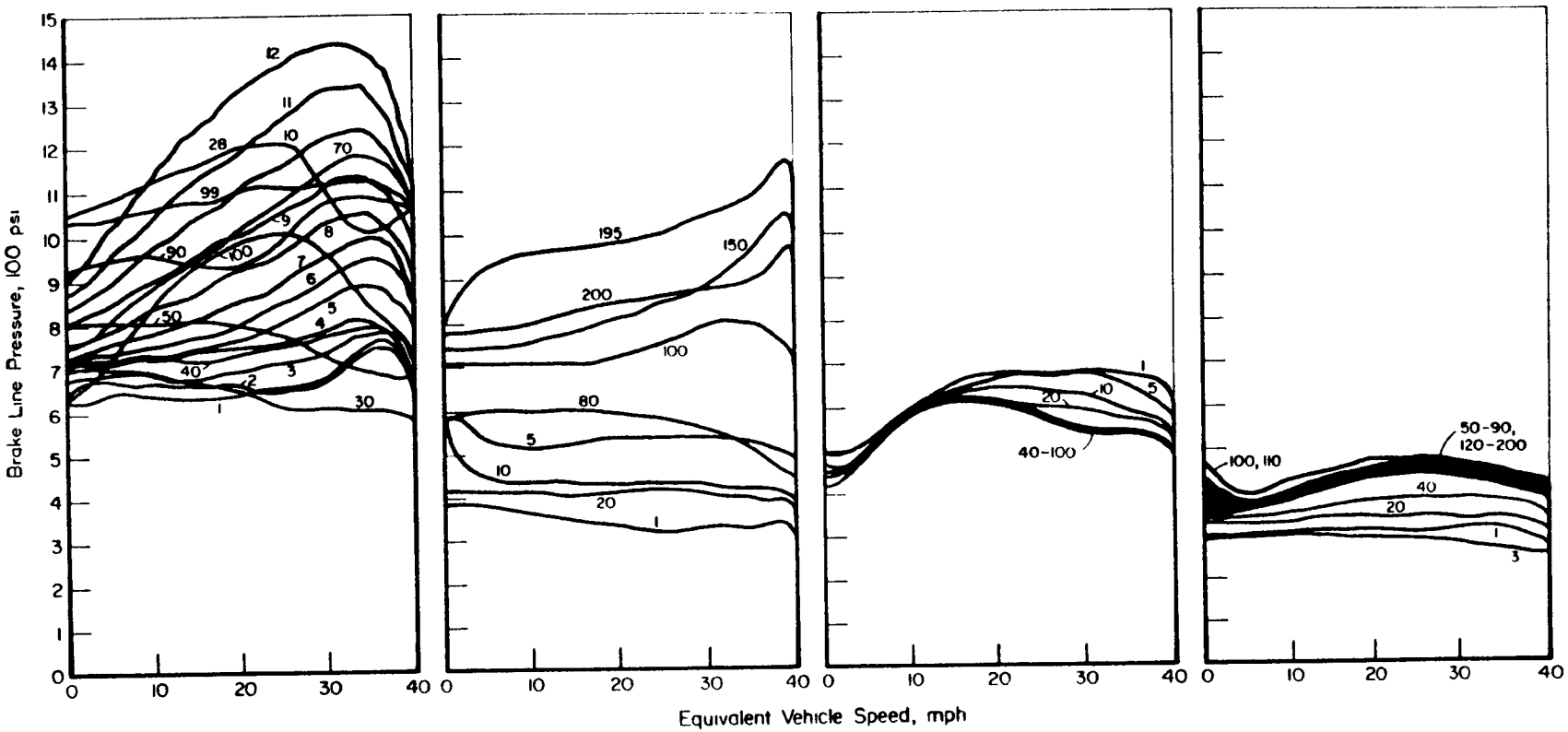
One example set of data follows which supports the claim that no acceptable asbestos-free friction materials have yet been developed for certain drum brakes. In this case a full brake dynamometer was used to test four different sets of drum brake linings on a 12-inch duo-servo drum brake with a 3-inch lining width. Identical procedures and matching test components were used, so the brake linings were the only known variables[11].

The linings tested have been coded, a condition for the availability of this test data. For simplicity of presentation, only the initial lining burnish test data is shown.

Figure 14a shows this data for Lining A, a NAO drum brake lining set. The test data is presented as brake line pressure versus equivalent vehicle speed. The brake line pressure relates to the amount of brake pedal effort exerted. All brake stops, after stop/3, were performed from the same initial brake drum temperature of 300 degrees F. All of the stops were from the same initial speed (40 mph) and controlled to provide an equivalent of 8 feet per second per second deceleration--a "normal braking" application. Note the wide range of pressures required to make the same stop. Even after 100 burnish applications, the required hydraulic pressures varied by a factor of two for adjacent stops. Also, the required brake pressures for this normal type of brake stop were almost to the limit for the power brake booster.

Brake lining A would be unacceptable for any OEM brake usage on this brake assembly. However, this lining formulation was released for production application on a different, smaller-sized drum brake. With a smaller brake and attendant thinner linings, lining A met all of the service requirements for an OEM brake lining. This demonstrates how the acceptability of a friction material is not just dependent upon the properties of the brake lining, but also depends on the specific choice of brake, vehicle, and use conditions.

Figure 14b shows performance curves for a NAO material B. Lining B was a candidate NAO material, but was not released for production. It used a different non-asbestos fiber system from that used in A. This lining provided, on average, higher brake effectiveness, but with a greater range of brake application pressures for the same test. Although not illustrated here, other test data for this lining show it to have an undesirable "morning sickness" with very high initial effectiveness for the first few cold stops. A lining like this on the rear drum brakes, used with a semimetallic front disc brake lining, would provide a vehicle brake system with a very strong tendency for rear wheel lockup (skidding) when cold.



Note: Numbers on curves represent stop numbers in test.

FIGURE 14. COMPARISON OF DYNAMOMETER TEST RESULTS FOR FOUR DIFFERENT FRICTION MATERIALS, 300 F AFTER BURNISH, 12 x 3 DUO SERVO DRUM BRAKE (REF 11)

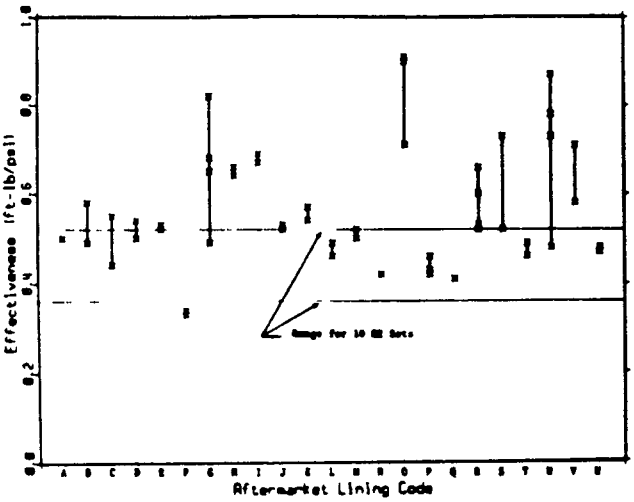
Figure 14c shows performance curves for a material C. Lining C, a "premium quality" aftermarket asbestos-based lining set, has been used for many years. Note the narrow band of brake line pressures for this burnish sequence. In particular, the stops from 40 through 100 were virtually identical. This consistency of brake effectiveness, although not guaranteed by the use of asbestos-based friction materials, is not yet available from any known NAO drum brake lining on this size of drum brake. Lining C had slightly higher (about 25 percent) lining wear rates than the two non-asbestos materials shown.

Figure 14d shows performance curves for asbestos material D. Lining D was the OEM released material for this brake system. It had the highest average effectiveness of the four linings and also the narrowest band of brake line pressures. In this case, the second 100 burnish-stop data was included to illustrate the consistency of performance that can be obtained from this brake. About 45 brake applications were required to obtain steady-state frictional behavior. After these, the test data were very repeatable, and the variation of effectiveness with speed was quite acceptable for a duo-servo drum brake.

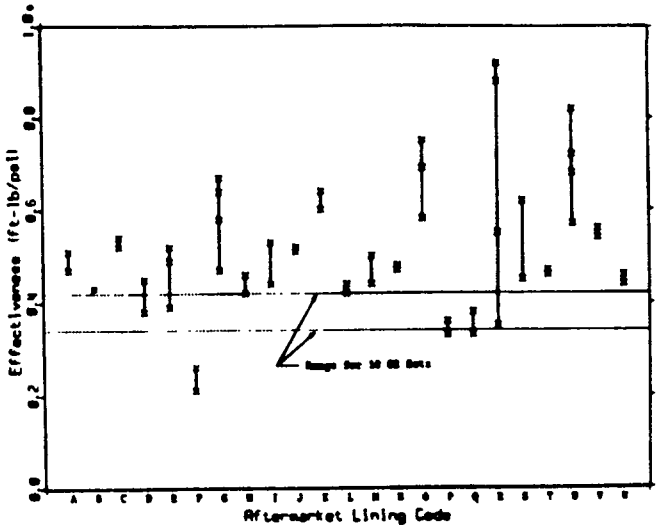
4.6.2 Vehicle Test Data

For a vehicle test study conducted by the National Highway and Traffic Safety Administration (NHTSA), the performance of aftermarket brake linings was compared to the performance of OEM linings[12]. These experiments were conducted using a compact size passenger car equipped with front disc brakes with semi-metallic pads and duo-servo drum brakes on the rear. Twenty-three different aftermarket rear drum linings were obtained by purchasing them from automotive service centers and automobile parts outlet stores. These materials were identified with a letter code of A through W.

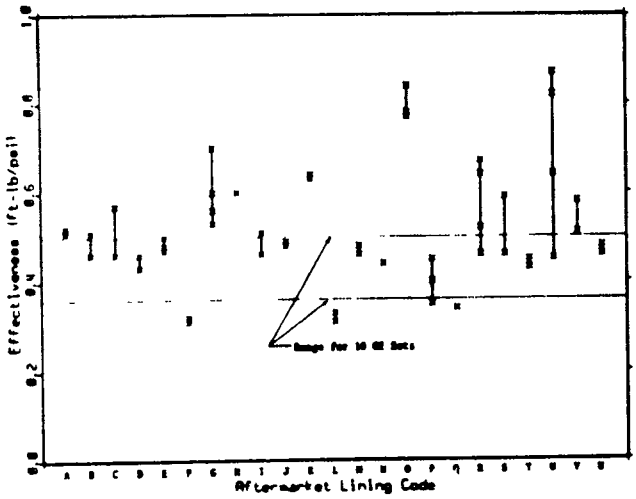
Experiments were conducted under conditions similar to those specified in FMVSS 105 (see Appendix A). To generate data representative of OEM lining performance, 10 sets of OEM-qualified linings were also obtained and tested to generate a comparison baseline.



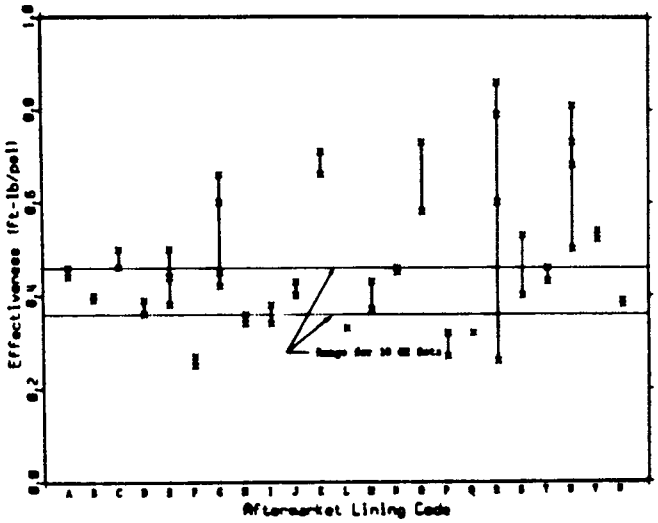
a. 30 mph pre-burnish rear brake effectiveness results



c. 30 mph post burnish rear brake effectiveness results



b. 60 mph pre-burnish rear brake effectiveness results



d. 60 mph post burnish rear brake effectiveness results

FIGURE 15. VEHICLE TEST RESULTS COMPARING THE PERFORMANCE OF AFTERMARKET FRICTION MATERIALS (REF 12)

Figure 15 shows the measured brake effectiveness for the various aftermarket linings under four different test conditions. At least two separate sets and as many as four separate sets of the same linings were tested; variations in performance are illustrated by the range in effectiveness exhibited among different sets of identical materials. Figures 15c and 15d indicate the wide range of effectiveness variability among the aftermarket materials. Lining material "R" exhibited the highest variability in effectiveness. This material was the only non-asbestos material tested of the 23 aftermarket materials tested. This data is consistent with the dynamometer test results presented in Figure 14. The remaining 22 test results also illustrate how wide variations in effectiveness can exist even for asbestos materials.

4.7 Issues of Consumer Acceptability of Non-Asbestos Materials

Consumer acceptability of non-asbestos friction materials, as with asbestos friction materials, will be affected by material wear performance and by the tendency to induce brake noise. Excessive brake wear could lead to sooty tire sidewalls, while brake noise continues to be an annoyance to many consumers.

Some brake materials used for front disc brakes have created a "dirty wheel syndrome" from wear debris[13]. Also known as "dusting", this situation arises when fine, sooty wear debris is deposited on the outside wheel and the surfaces. This situation makes routine tire maintenance more undesirable since the black film is tenacious and usually makes the car owner's hands dirty. To prevent this situation, some car owners switch to aftermarket disc pads that are advertised as being "dusting resistant". Auto owners apparently assume that these materials are equally effective as braking materials as other materials more prone to dusting.

Aluminum "shields" are also available to shroud the disc and prevent debris from being deposited on the outer wheel surfaces. These shields are mounted between the disc and wheel of the brake and wheel assembly. Two adverse situations may arise from the use of such shrouds. First, the discs may operate at higher temperatures due to the decreased

convection and radiation from the disc surface. Second, the wheel lug nuts may eventually loosen due to plastic deformation of the aluminum shroud in the vicinity of the lugs.

The "dirty wheel syndrome" has been reported more often by owners of German luxury automobiles, such as BMW and Mercedes, for many years. Owners of such vehicles tend to be more fastidious about the car's appearance than owners of other less expensive vehicles which utilize other materials. It is now becoming more of a problem on American and Japanese cars as more non-asbestos materials are utilized.

Nevertheless, the various techniques used by owners to eliminate the problem more clearly illustrate the public's viewpoint that vehicle brakes are largely unaffected by consumer neglect or tampering. OEM-qualified non-asbestos materials that exhibit excessive brake squeal or "dusting" could be replaced by materials provided by an unregulated aftermarket supplier, that need not meet any certification.

5. REVIEW OF VEHICLES AFFECTED BY PROPOSED BAN

5.1 Section Summary

The purpose of this section was to examine the various vehicle classes using friction materials and identify trends in braking systems in the various vehicle classses. The following observations were made:

- The overwhelming majority of American passenger cars are now designed with front disc brakes and rear drum brakes. There is not a significant trend toward wider use of 4-wheel disc brakes. American manufacturers are directing efforts toward developing suitable asbestos-free lining materials for rear automotive drum brakes.
- Because disc brakes maintain effectiveness at high braking speeds, 4-wheel disc brakes have been used in Europe on some high performance vehicles before asbestos became a concern. Now some European manufacturers use 4-wheel disc brakes and semi-metallic brake pads as a means of eliminating asbestos from passenger cars. Differences in consumer acceptance between Europe and the United States, specifically brake wear and brake noise, may restrict the use of 4-wheel disc systems in the United States.
- Trends in light truck braking systems follow those in passenger cars.
- Most medium trucks (American, European, and Japanese) use drum brakes on all four wheels. Acceptable qualified substitutes for current asbestos lining materials have not been found in many cases. These drum brake systems use segments, a thin lining material similar in geometry to automobile brake linings. However, the relatively severe braking requirements of this application prevent a simple retrofit of automobile materials to the medium truck market. A small percentage of medium trucks are now being produced with disc brakes and semi-metallic pads.
- Acceptable substitutes for asbestos materials have been found in some cases in the heavy truck segment. These

brake systems use thick molded brake blocks which are bolted or riveted to shoes. Some non-asbestos materials have been found to exhibit sufficient mechanical strength and frictional properties for this application.

5.2 Brake System Trends in Passenger Cars, Trucks, and Equipment

For this study, motor vehicles have been divided into three classes: passenger cars, on-highway trucks, and off-highway vehicles. Motorcycles, transit buses and trains, and aircraft have not been included.

The overwhelming majority of vehicles in the United States are, as expected, passenger cars (Table 8). The majority of the 1984 American passenger cars were fitted with a rear-drum and front disc brake system; 33 percent of 1984 imported automobiles were fitted with 4-wheel disc brake systems[14]. Medium and heavy trucks continue to use traditional drum brakes. Light trucks use front disc brakes with rear drum brakes.

5.2.1 Passenger Cars

Passenger cars are the largest single market for friction products in the U.S. As indicated previously, there were about 130 million registered passenger cars in 1984 in the United States.

Prior to 1965, almost all American passenger cars were equipped with 4-wheel drum brakes with asbestos linings. In 1965, some vehicles (Lincoln Continental and Chevrolet Corvette) were equipped with front disc brakes. Widespread use of front disc brakes across most product lines of American manufacturers began in the early 1970s.

There are a substantial number of vehicles that have drum brake systems designed for use with asbestos friction materials. In 1984, there were still 11.5 million cars in operation that were manufactured prior to 1970, and the majority of these presumably were fitted with 4-wheel drum brakes. Prior to 1982, the majority of automobiles with front-wheel disc brakes had been designed for use with asbestos brake pads. Since the mean life of passenger cars is now about 7.6 years[15], automobiles fitted with brakes designed for use with asbestos friction products will continue to be in operation for several more years. Vehicles manufactured in 1986

TABLE 8. NEW VEHICLE SALES AND VEHICLE REGISTRATION FOR 1984 (REF. 15)

	U.S. Calendar Year Sales (Millions)
Passenger Cars	10.4
Domestic	8.0
Imported	2.4
On Highway Trucks	4.1
Light	3.8
Medium	0.06
Heavy	0.20
Off-Highway Vehicles	
Farm equipment	0.17*
Construction equipment	0.05**

* 1986 estimate
** 1985 estimate

with asbestos friction materials can be expected to require aftermarket brake components for at least another 11 years.

Current American automobiles are almost exclusively designed with front wheel disc brakes. As shown in Table 9, American manufacturers do not appear to be embracing 4-wheel disc brakes as a means of changing the braking characteristics of automobiles. Currently, American manufacturers appear to be retaining rear wheel drum brakes. These brakes are attractive for the following reasons:

(1) Easier implementation of parking brake mechanism,
(2) Less susceptability to debris,
(3) Less susceptibility to corrosion,
(4) Less weight, and
(5) Less cost.

At the present time, there appears to be no distinct performance advantage under American driving speeds to rear wheel disc brakes other than reduced time required for maintenance. The use of rear disc brakes also simplifies the setting of front-to-rear braking balance.

The current trend among American automakers is to implement asbestos-free brake lining and brake pad materials in new major model changeovers. Brake systems on existing models are never routinely redesigned. New models, such as the Ford Taurus, are equipped with semi-metallic front disc brake pads and non-asbestos organic rear drum linings. Rather than redesign brake systems with 4-wheel disc brakes using semi-metallic pads, American automobile manufacturers have elected to retain rear drum brakes and direct development efforts toward new, non-asbestos rear drum linings. Qualification of non-asbestos materials through vehicle testing may take 2 years or longer, assuming a suitable material exists for a specific vehicle application. The redesign of a vehicle's rear brake system from drum brakes to disc brakes could take 5 to 7 years, with little guarantee of significantly improved performance.

5.2.2 On-Highway Trucks

On-highway trucks are generally classified with respect to gross vehicle weight class, i.e., by the vehicle curb weight plus cargo. Trucks can be considered single chassis vehicles or can be used in tractor-trailer

TABLE 9. LIST OF 1985 AMERICAN AUTOMOBILES EQUIPPED WITH 4-WHEEL DISC BRAKES (REFERENCE 16)

	Number of Units Sold With 4-Wheel Disc Brakes	Percentage of output
General Motors	164,301	3.6
Ford	46,608	2.7
Chrysler	0	0
American Motors Corporation	0	0
Volkswagen of America	82,797	100
Honda	0	0

combinations. Eight weight classes currently exist, although for the purposes of this study, the following classifications are used:

Classification	GVW Class	GVW Range (lbs)
Light	Group 1	6,000 and less
	Group 2	6,001 and 10,000
	Group 3	10,001 - 14,000
Medium	Group 4	14,001 - 16,000
	Group 5	16,001 - 19,500
	Group 6	19,501 - 26,000
Heavy	Group 7	26,001 - 33,000
	Group 8	33,001 - over

New truck registrations for 1984 indicate that light trucks make up approximately 94 percent of the total truck population, which reflects the popularity of small pick-up trucks and mini vans. In contrast, medium trucks account for about 1 percent of the population, while heavy trucks make up the remaining 5 percent[14].

The following sections outline current brake systems and trends in vehicle brake materials for the three classes of on-highway trucks.

5.2.2.1 Light Trucks. The "light truck" designation refers to both pick-up trucks and compact vans used in light hauling and passenger transport. About 3.9 million light trucks were sold in 1984 in the U.S. As of 1984, almost 31 million light trucks were registered in the United States.

Trends in light truck braking systems follow closely those of passenger cars. In 1984, more than 94 percent of light trucks manufactured in the United States were equipped with front wheel disc brakes. Ford and GM 1987 light trucks are using variable proportioning valves for rear brakes or anti-lock systems to improve braking under a wide range of truck loads. Calibration of a variable proportioning valve is affected by changes in rear brake lining material. In this respect, trucks brakes are following European passenger car trends in that design steps are being taken to ensure front wheel brake biasing.

Many light truck brakes manufactured in the United states are now using asbestos-free semimetallic materials in the front disc brakes and non-asbestos organic linings for the rear drum brakes. In 1986, the Ford Aerostar and Ranger models were fitted with all non-asbestos friction materials. The automotive industry is in the process of converting existing light truck models over to asbestos-free friction products.

Although new truck brake systems appear to be heading toward asbestos-free friction materials, a large population of older vehicles requiring aftermarket friction products still exists. Between 1970 and 1982, the median age of light trucks was 7.1 years(15).

5.2.2.2 Medium Trucks. The "medium truck" designation generally refers to single chassis trucks with a GVW of between 14,001 lbs and 26,000 lbs. These trucks usually are used as enclosed delivery trucks or open, flat-bed trucks. Manufacturers usually provide the engine, drive-train, cab, and chassis, which are custom modified to suit the customers' needs. Brake systems on this truck classification can be either hydraulic or air operated, depending upon customer selection and intended service. The majority of the systems are hydraulic due to lower initial costs associated with these systems. In 1982, there were 1.4 million medium trucks in service in the United States(14,15).

Current manufacturers and marketers of medium trucks in the United States are Ford, General Motors, Chrysler, Mack, and Mercedes-Benz, and others. These manufacturers typically purchase axle and brake assemblies from "foundation" axle and brake manufacturers and assemble them, along with the engine and chassis, into the finished truck. These brake systems are almost exclusively drum brakes on both the front and rear brakes. These brakes use strip linings similar to automotive drum brakes. However, due to the more severe braking conditions found in these trucks, qualified asbestos-free materials have not been found for some medium trucks.

Disc brakes for medium trucks are now under development, although the number now in service is very small(17). Some of the advantages cited for truck disc brakes are light weight and increased ease of maintenance. However, problems with excessive rotor and pad temperatures continue to limit their use in potentially severe braking conditions. European medium

trucks produced by IVECO (Italy) and Saab-Scania (Sweden) are exclusively fitted with hydraulically actuated drum brakes[17,18,19].

5.2.2.3 Heavy Trucks. The "heavy truck" designation refers to either single-chassis trucks or segmented tractor-trailers having a GVWR of greater than 26,000 lbs. In general, the single chassis trucks have hydraulically-actuated brake systems, while the brakes of tractor-trailer combinations are generally air actuated.

Large truck brake systems are almost exclusively drum type, either of the leading-trailing type (Figure 3a) or the leading-leading type. For these severe braking requirements, thick block segments rather than thin strips of friction materials are bolted or riveted to shoes. Some success has been achieved in qualifying non-asbestos block materials for heavy truck applications. This success has been due in part to the ability to mold the non-asbestos materials into rigid blocks possessing sufficient mechanical strength.

The use of disc brakes in the heavy truck market has received some attention, but the overwhelming majority of the systems is still centered around the use of drum brakes. Because drum brakes still offer some performance advantages over disc brakes, a complete conversion to disc brakes in this vehicle market is not expected.

Qualification of non-asbestos materials for truck and trailer service is progressing through the combined efforts of foundation brake manufacturers, truck manufacturers, and friction product manufacturers. Most of the aftermarket friction product manufacturers do not possess the facilities to evaluate the performance of their products under vehicle service conditions.

5.2.3 Off-Highway Trucks and Equipment

Farm equipment and construction equipment have braking needs different from those of on-highway trucks. Braking speeds will be lower and required brake torques will be higher.

Examples of off-highway equipment include road scrapers, road graders, excavators, haulers, cranes, mobile drilling rigs, and other large

pieces of equipment. Farm equipment can range from small tractors to large harvesting combines.

Qualification of friction products for these applications is usually the responsibility of the foundation brake manufacturer and the equipment manufacturer since no Federal braking requirements exist. Materials found to perform satisfactorily through years of customer and manufacturers' experience are rarely changed since the usage conditions and equipment change only slightly.

The development of qualified asbestos replacements for this market segment may be difficult due to the extended time required for development, coupled with the relatively small market represented by the farm and construction equipment industry.

5.3 Current European and Japanese Experience in Brake Design and Friction Material Selection (Automobiles and Light Trucks)

The bulk of the European import automobile and truck market is comprised of vehicles manufactured in Germany, Great Britain, France, Sweden, and Italy. As indicated previously, most of the recent imported European automobiles are fitted with front wheel disc brakes which use semimetallic asbestos-free friction pads. There is a strong trend among European automakers to use 4-wheel disc brakes, along with semimetallic materials. Table 10 lists the European automakers and the percentage of their product lines that are equipped with 4-wheel disc brakes. Although the percentage of new European 4-wheel disc brake imports is high (80 percent), the total number of units imported is small compared with United States automobile production.

European drivers have different preferences with respect to brake performance than do American drivers. In general, Europeans are more tolerant of brake squeal and brake wear than are American drivers, and materials judged acceptable from a standpoint of stopping performance alone may not be acceptable to the American public. In addition, the European safety standards are different from those in the United States but are difficult to compare directly. Generally, the ECE/EEC regulations allow lower levels of braking efficiency than do the United States regulations, but they do require calculations to show that the "design intent" brake balance is front bias, i.e., front wheels lock first. The emphasis

TABLE 10. LIST OF 1984 EUROPEAN-MANUFACTURED AUTOMOBILES EQUIPPED WITH 4-WHEEL DISC BRAKES (REF. 14)

	Number of Units Sold in the U.S.	Percentage With 4-Wheel Disc Brakes
Germany		
Mercedes-Benz	58,017	100
Volkswagen	64,405	100
BMW	64,525	58.6
Audi	54,590	15
Porsche	14,708	100
Great Britain		
Jaguar	18,044	100
France		
Renault	10,277	0
Peugeot	14,792	100
Italy		
Alfa Romeo	3,399	100
Sweden		
Volvo	96,422	100
Saab	25,146	100
TOTAL	424,325	83

of front biasing makes 4-wheel disc brakes attractive because the effectiveness of disc brakes are less affected by slight changes in friction material performance. Automakers can help ensure that the brakes are front biased in spite of unforseen friction product behavior by using proportioning valves to force the front discs to handle most of the vehicle braking.

Virtually all of the Japanese automobiles imported to the United States are fitted with front disc brakes, although some models are also equipped with 4-wheel disc brakes. Table 11 lists the percentages of Japanese vehicles equipped with 4-wheel disc brakes. In 1984, only 20 percent of the 1 million units sold in the United States were so equipped.

The eventual adoption of FMVSS 135 and the failure to qualify rear automotive brake drum linings exhibiting consistent levels of friction over a wide range of performance conditions may affect the design philosophy of American and Japanese automobile engineers. Forced to ensure front bias in the system, automakers may eventually move to using less-effective disc brakes on the rear axle and increasing the front-to-rear braking ratio to ensure consistent system performance, if proven rear drum lining materials are not found.

TABLE 11. LIST OF 1984 JAPANESE AUTOMOBILES SOLD IN THE UNITED STATES EQUIPPED WITH 4-WHEEL DISC BRAKES (REF 10)

	Number of Units Sold	Percentage With 4-Wheel Disc Brakes
JAPAN		
Honda	374,819	17.9
Nissan	372,633	32.7
Toyota	306,900	24.9
Subaru	148,880	0
Mitsubishi	39,104	>0
Isuzu	17,233	>0
Mazda	128,197	0
TOTAL	1,387,766	>20

6.0 SUMMARY OF INDUSTRY RESPONSES TO PROPOSED BAN

6.1 Section Summary

Various concerns representing automobile manufacturers, truck and equipment manufacturers, friction product producers, and environmental groups responded with written comments to the Environmental Protection Agency's proposal outlined in the Federal Register. Table 12 lists the respondents.

In general, respondents commented on numerous facets of the proposal, but the comments most pertinent to this study were those dealing with issues of brake performance, application availability, and feasibility of the proposed phase-down schedule. The comments of respondents have been categorized in the following sections with respect to the issues addressed.

Table 13 summarizes in a very general sense the responses of the various industries and groups to the main features of the proposed EPA ban.

6.2 Concerns of Respondents to Issues of Brake Performance

The comments of the respondents to this issue are summarized in Appendix B. The automobile and truck manufacturers were consistent in their opposition to the proposed ban on asbestos in aftermarket friction products. These manufacturers contend that vehicle safety may be compromised if unproven friction products are used in place of vehicle-tested products containing asbestos. One truck manufacturer (Navistar) claims that brake and friction product qualification can take up to 48 months, so the time and cost of re-qualifying materials for other aftermarket products would be prohibitive.

Some manufacturers question the long-term performance of some asbestos-free materials and subsequently feel that further development will be necessary before a phase-out can be feasible. Ford Motor Company indicated that friction products must be qualified under long term conditions more stringent than federal motor vehicle safety standards in order to determine the sensitivity of materials to "hot-spotting" and "morning sickness". Rockwell International inferred that current non-asbestos

TABLE 12. LIST OF RESPONDENTS TO FEDERAL REGISTER NOTICE REGARDING PROPOSED EPA ACTION

Automobile Manufacturers

Japanese Automakers

Toyota Technical Center, U.S.A., Inc.
Subaru of America, Inc.
American Honda Motor Company, Inc.
Mitsubishi Motors Corporation
Nissan Research and Development, Inc.

American Automakers

Chrysler Corporation
General Motors Corporation
Ford Motor Company
American Motors Corporation

European Automakers

Volkswagen of America
Mercedes-Benz of North America, Inc.
Austin Rover Group Limited

Trade Associations

Automobile Importers of America, Inc.
National Automobile Dealers Association
Motor Vehicle Manufacturers Association

Environmental Lobbyists

National Resources Defense Council, Inc.

Truck and Equipment Manufacturers

Foundation Brake and Axle Manufacturers

Rockwell International

Truck Frame and Chassis Builders

Navistar International Corporation
Freightliner Corporation

Farm Equipment

John Deere and Company

Friction Product Manufacturers

OEM Compounders

Allied/Bendix Corporation
Abex Corporation

Aftermarket Suppliers

Wagner
Scan-Pac
Original Quality, Inc.

Trade Association

Friction Materials Standards Inst.

Fiber Suppliers

DuPont

TABLE 13. SUMMARY OF RESPONDENTS' COMMENTS TO PROPOSED EPA PLAN

	Brake Performance	Substitute Availability	Feasibility of Proposed Phase Down
Automobile Manufacturers	• aftermarket for older vehicles should be exempt	• materials for front disc brakes available • materials for rear drum brakes not qualified sufficiently	• phase-down plan opposed • 5-year lead time prior to ban favored
Truck and Equipment Manufacturer	• aftermarket for older vehicles should be exempt	• materials for heavy on-road and off-road vehicles not available or qualified as yet	• phase-down plan opposed • 5-year lead time prior to ban favored
Friction Product Manufacturers	• performance of some materials still needs qualification (Allied/Bendix) • performance of substitutes as good or better than asbestos (Scan-Pac)	• many vehicle applications have no qualified materials (Allied/Bendix) • substitutes available for all applications (Scan-Pac)	• many substitutes will be available within 5-years (Allied/Bendix) • substitutes now available (Scan-Pac)
Environmental Lobbyists	--	• substitutes available for all applications	• immediate ban on current and aftermarket asbestos friction materials

materials designated for off-highway heavy-duty applications give unacceptable performance and durability.

Friction product manufacturers gave mixed reports concerning product performance. Allied/Bendix indicated that development work was still progressing, and substitute formulations need to be evaluated using vehicle tests and dynamometer tests. Scan-Pac, on the other hand, claimed to have products available for all heavy-duty vehicle applications, although no in-house inertia dynamometer or vehicle test facilities are available at Scan-Pac's facility for qualification of materials.

6.3 Concern of Respondents to Issues of Friction Material Availability

The comments of the respondents to this issue are summarized in Appendix C. U. S. and Japanese automobile manufacturers indicate that non-asbestos front disc brake pads are now being used extensively on new car models. Chrysler indicated that all but one vehicle manufactured by Chrysler is fitted with semi-metallic front brake pads, while General Motors acknowledged that for front disc brakes, asbestos-free replacement materials are now available for new model cars. Asbestos-free rear drum brake materials are still not available for automotive applications.

Volkswagen indicated that in model year 1987 all products will be fitted with non-asbestos linings, while Daimler-Benz indicated that new 300 series models will be fitted with asbestos-free friction materials. Daimler-Benz did indicate that brake systems of other vehicles in their product line are undergoing lengthy and extensive redesign and requalification to be fitted with non-asbestos materials.

Since most heavy duty truck and equipment brakes use drum brakes, the concerns of truck and equipment manufacturers were different from those of the automobile manufacturers. Since truck life is considerably longer than automobile life, aftermarket availability for older vehicles remains a strong concern. Freightliner and Rockwell indicated that friction product suppliers have been unable to provide qualified non-asbestos linings for heavy-duty on-highway and off-highway applications. John Deere indi-

cated that replacement materials have not been qualified for use in tractor transmission clutches and axle brakes.

Friction product manufacturers gave mixed reports concerning the availability of asbestos-free materials for the various applications. Allied/ Bendix indicated that they had been successful in developing asbestos-free products for some applications, although many vehicle applications currently remain without qualified asbestos-free materials. Scan-Pac and DuPont both indicated that substitute materials are available for all applications, although Scan-Pac has concentrated on providing materials for aftermarket heavy vehicle applications. However, both Scan-Pac and DuPont lack the facilities to conduct vehicle or dynamometer tests required for FMVSS certification.

6.4 Concerns of Respondents to Feasibility of the Proposed Phase-Down Schedule

The comments of the respondents to this issue are summarized in Appendix D. The automobile industry, both domestic manufacturer and importers, voiced unanimous concern over the proposed timetable for asbestos phase-out. The following were major points made by this industry:

(1) The years 1981, 1982, and 1983 were years of severe recession in the automobile industry. Therefore asbestos-usage quotas based on asbestos usage during these years are excessively restrictive.

(2) The proposed rating is unfair to auto importers, who voluntarily restricted imports during 1981, 1982, and 1983.

(3) Option 1, which allows a five-year lead time to develop and qualify new asbestos-free materials, is preferable than the proposed staggered phase-down effort.

(4) If FMVSS 135 is adopted, more lead time may be required, depending upon exact provisions of FMVSS 135.

Truck and equipment manufacturers, whose products rely upon drum brake materials, were opposed to the proposed immediate reduction in allowable asbestos in friction materials. Navistar, Freightliner, and Wagner supported a plan in which most asbestos use was banned after a 5-year lead time. Modifications of this provision would allow the use of asbestos in

materials for which no replacement material was qualified. John Deere requested an exemption for all materials used inside a machine housing, such as clutches and sealed axle brake units used on John Deere tractors.

The friction product manufacturers gave mixed reports concerning the proposed phase-down schedule. Allied/Bendix indicated that reliable alternatives for original equipment materials will be available within 5 years. DuPont and Scan-Pac, on the other hand, indicated that acceptable substitute materials now exist. Both companies lack the facilities to qualify materials and systems under Federal safety standards.

The National Resources Defense Council (NRDC) supports an immediate ban on all asbestos in friction products, both new and aftermarket. They contend that viable substitutes are available today.

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APPENDIX A

Vehicle and Dynamometer Test Procedures for Qualifying Friction Materials and Brake Systems Under FMVSS 105 and FMVSS 121

TABLE A-1. SUMMARY OF TEST PROCEDURES FOR FMVSS 105

No.	Sequence	Procedure	Stopping Distance Per Vehicle Group, ft A	B	C	D
1	Instrumentation Check	Check instrumentation by making not more than 10 stops from 30 mph at a deceleration of not more than 10 ft/sec/sec				
2	First (preburnish) Effectiveness test	Make 6 stops from 30 mph, then make 6 stops from 60 mph	57 216	65 242	69 267	88 388
3	Burnish brake linings (at GVWR)	Procedure 1: Vehicles with GVWR of 10,000 lbs or less Make 200 stops from 40 mph at a deceleration rate of 12 ft/sec/sec. Use approximately 1 mile rest interval in between brake applications Procedure 2: Vehicles with GVWR of over 10,000 lbs Make 500 "snubs" at 10 ft/sec/sec (maintain brake temperatures less than 500° F)				
4	Second effectiveness test	Make 6 stops from 30 mph, then make 6 stops from 60 mph, then make 4 stops from 80 mph (GVWR > 10,000 lbs)	54 204	57 216	57 194	81 388
5	First reburnish	Make 35 stops from 40 mph at a deceleration rate of 12 ft/sec				
6	Test parking brake	• Measure force required to actuate hand brake lever • Position vehicle on incline and observe position-holding ability				

Note: Unless otherwise specified, brakes on hottest axle are between 150-200 F at start of test stops

TABLE A-1. SUMMARY OF TEST PROCEDURES FOR FMVSS 105 (Continued)

No.	Sequence	Procedure	Stopping Distance Per Vehicle Group, ft A	B	C	D
		• Empty and loaded conditions evaluated under 20 percent and (light trucks and vehicles over 10,000 lbs) and 30 percent grades (passenger cars)				
7	Third effectiveness test	• Make 6 stops from 60 mph under lightly-loaded conditions	194	216	242	388
8	Partial failure	• Under lightly-loaded conditions, disable either the front brakes or rear brakes • Make 4 stops from 60 mph • Restore disabled half, disable 2nd half, repeat stops • Repeat procedure for vehicles at GVWR	456	517	517	613
9	Inoperative brake power and power assist units	• Disable power assist • Make 4 stops from 60 mph • at GVWR only	variable requirements			
10	First fade and recovery (at GVWR)	Procedure 1 - Vehicles With GVWR 10,000 or Less				
		baseline: • Make 3 stops from 30 mph at 10 ft/sec /sec deceleration and measure control force readings				
		fade: • Make 5 stops from 60 mph at 15 ft/sec /sec deceleration, followed by 5 stops at maximum attainable deceleration between 5 ft/sec/sec and 15 ft/sec/sec at 0.4 mile intervals				
		recovery: • Drive 1 mile at 30 mph to prepare for recovery tests • Make 5 stops from 30 mph at 10 ft/sec /sec deceleartion at 1 mile intervals				

Note: Unless otherwise specified, brakes on hottest axle are between 150-200 F at start of test stops

TABLE A-1. SUMMARY OF TEST PROCEDURES FOR FMVSS 105 (Continued)

No.	Sequence		Procedure	Stopping Distance Per Vehicle Group, ft A	B	C	D
			Procedure 2: Vehicle With GVWR of More Than 10,000 Lbs				
		baseline	• While in neutral, make 3 "snubs" from 40 mph to 20 mph at 10 ft/sec /sec deceleration				
		fade	• While in neutral, make 10 "snubs" from 40 to 20 mph at 10 ft/sec /sec deceleration at 30 second intervals				
			• Drive 1.5 miles at 40 mph to prepare for recovery tests				
		recovery	• While in neutral, make 5 "snubs" from 40 mph to 20 mph at 1.5 mile intervals				
11	Second reburnish		• Make 35 stops from 40 mph at a deceleration rate of 12 ft/sec/sec	--	--	--	--
12	Second fade and recovery (at GVWR)		• Repeat procedure for first fade and recovery, except increase fade stops to 15 for vehicles < 10,000 lbs GVWR and to 20 for vehicles > 10,000 GVWR				
13	Third reburnish		Make 35 stops from 40 mph at a deceleration rate of 12 ft/sec/sec	--	--	--	--
14	Fourth effectiveness test (at GVWR)		• Make 6 stops from 30 mph, then make 6 stops from 60 mph • Make 4 stops from 80 mph (vehicles with GVWR < 10,000 lbs) • Make 4 stops from 95 or 100 mph (passenger cars only)	57 216	65 242	65 267	88 388

Note: Unless otherwise specified, brakes on hottest axle are between 150-200 F at start of test stops

TABLE A-1. SUMMARY OF TEST PROCEDURES FOR FMVSS 105 (Continued)

No.	Sequence	Procedure	Stopping Distance Per Vehicle Group, ft A	B	C	D
15	Water recovery (at GVWR)	• Make 3 stops from 30 mph at 10 ft/sec/sec deceleration • Drive at 5 mph for 2 minutes through a 6-inch deep water trough • Leave water trough, accelerate to 30 mph • Make 5 stops from 30 mph at a deceleration of 10 ft/sec/sec				
16	Spike stops (at GVWR)	• Make 10 successive stops from 30 mph using a control force of 200 lbs applied in not more than 0.08 sec. • Make 6 stops from 60 mph	216	242	267	388

Vehicle Group Description:
A - passenger cars
B - non-passenger cars with GVWR of less than 8000 lbs
C - vehicles with 8000 < 10,000
D - vehicles with GVWR > 10,000. (school buses over 10,000 lbs must meet all requirements. All other vehicles over 10 K have to meet partial failure (8) and inoperative brake (9) requirements only.

Note: Unless otherwise specified, brakes on hottest axle are between 150-200 F at start of test stops

TABLE A-2. SUMMARY OF ROAD TEST PROCEDURES FOR FMVSS 121 (all vehicles except "non-school" buses are exempt from these requirements)

Sequence	Procedure
Burnish brake linings	• Make 500 brake applications at 10 ft/s/s deceleration, 1 mile intervals or 500 F brake temperatures • Readjust brakes if necessary
Road tests - effectiveness	Under GVWR and unloaded, make following stops: • From 20 mph with service brakes* • From 60 mph with service brakes • From 20 mph with emergency brakes • From 60 mph with emergency brakes

*These stops to be conducted on dry and wet pavement

TABLE A-3. SUMMARY OF DYNAMOMETER TEST PROCEDURES FOR FMVSS 121 (tractors, trucks, buses trailers)

Sequence	Procedure	Evaluation Criteria
Burnish brake linings (all vehicles)	• Make 200 stops from 40 mph at 10 ft/sec/sec	Brake temperatures, T 315 F < T < 385 F
	• Make 200 additional stops from 40 mph at 10 ft/sec/sec	Brake temperatures, T 450 < T < 550
Brake effectiveness/ retardation factor (trailers only)	• Make 7 consecutive stops from 50 mph with increasing brake air chamber pressure	• Calculated brake retardation force force at each air chamber pressure
Fade and recovery (all vehicles)	• Decelerate from 50 mph to 15 mph at 9 ft/sec/sec at 72 second intervals deceleration rate; repeat 10 times	• Service air pressure must be below 100 psi
	• Hot stop from 20 mph at 14 ft/sec/sec	• No pressure limit
	• Make 20 consecutive stops from 30 mph at 12 ft/sec/sec deceleration rate (at 60 second intervals)	• Service air pressure must be below 85 psi and above 20 psi

APPENDIX B

CONCERNS OF RESPONDENTS TO ISSUES OF BRAKE PERFORMANCE

Automobile Manufacturers

Mitsubishi

- Replacement parts should be exempt.
- Must evaluate and consider:
  - Adoption of larger brake booster
  - Increase of pad area
  - Adoption of ventilated disc brakes
  - Adoption of larger brakes
- FMVSS 135 proposed by NHTSA is considered to be more stringent than FMVSS 105.
- "Judder" is currently a problem for clutches.

Chrysler

- Aftermarket materials for older vehicles should be exempt for safety reasons.

General Motors

- Aftermarket is serious concern for safety reasons. Therefore, aftermarket for older vehicles should be exempt.
- Essential that EPA collaborate with NHTSA on this rulemaking.
- Considering safety, we are obligated to continue production of parts for servicing vehicles throughout their useful life.

Example of System Changes That Might Occur with a Lining Change

Assume that a replacement lining has 20 percent less friction than the original:

- A larger wheel cylinder would be specified to achieve the required torque output.
- A larger wheel cylinder results in more fluid displacement and may require a master cylinder change to obtain the proper pedal travel.
- Larger master cylinder may make pedal effort too high necessitating a booster change.
- Testing of the vehicle may indicate insufficient parking brake capability due to the reduced friction necessitating a park brake cable change.
- Increased cable forces may result in parking brake strut buckling during abuse tests, necessitating a foundation brake redesign.

Mercedes-Benz

- Exemption (indispensible) for replacement parts.
- FMVSS-105 is in the process of being reconsidered by NHTSA; impact may cause further delays.

A safe braking system is a well balanced design. Influencing one of its parameters alone, e.g. by replacing asbestos in friction materials, necessitates reconsideration of the complete system. Immediate availability of substitutes is not given for all applications.

Ford

- Complex issues must be researched, including:
  - Thermomechanical stability (hot-spotting and banding)
  - Brake fluid displacement
  - Fluid boil (semi-metallic and metallic linings)
  - "Morning sickness" (effects due to moisture)
  - Different friction levels.
- Exemption for parts replacement for older vehicles.

Austin-Rover Group

- Unrealistic lead times.
- Friction materials have a major effect on safety.
- Exempt replacement parts for vehicles produced before rule goes into effect.

Toyota

- Oppose applying rule to replacement parts for earlier models.

National Automobile Dealers Association

- Shouldn't rush brake development work.
- OSHA standards cover danger to maintenance people.

AMC

- FMVSS-135; more stringent braking requires are currently under study.

Motor Vehicles Manufacturers Association

- The safety and effectiveness of motor vehicle braking will be reduced.
- The cost in terms of deaths and dollars from motor vehicle braking losses should be included with the potential impact assessment.
- Problems with new friction materials:
  - Rotor scoring
  - Noise
  - Lining cracks
  - Absence of consistent and reliable braking performance data
- Safety must not be compromised.

Truck and Equipment Manufacturers

Wagner

- CAFE requirements
  - Resulted in significant redesign of vehicle and brakes
  - But current vehicle population of pre-CAFE must be operated safely
- There are presently no data on brake performance from actual vehicle tests using:
  - Semi-metallic disk brake friction materials
  - New substitutes
- Safety - health effects do not consider the safety related risks associated with possible inferior braking performance.
- No or little available test data.

Navistar

- Need both fleet tests and dynamometer tests to qualify friction materials.
  - Dynamometer tests run per FMVSS-121
  - Fleet tests run per IH Fleet Test Phase
- Qualification takes about 48 months

Freightliner

Technical problems to be calculated further before non-asbestos linings can be used universally:

Wear rate - At extremely high temperature.

Speed sensitivity - Generally less sensitivity at low speeds than at high speeds.

Static friction characteristics - Much lower and can create difficulty in complying with Federal MVSS-121 for parking.

Durability - Some are more susceptible to cracking and crumbling.

Low speed noise and chatter

Heat Conduction and corrosion resistance - needs further evaluation.

Rockwell International

Brake tests used to qualify materials:

- Our internal test requirements
- Requirements of our brake customers
- FMVSS-121 - highway, air
- SAE J-1152 - off-highway vehicle
- SAE J-1473 - off-highway vehicle
- Specific industry standards for
  - Agriculture
  - Rail
  - Military specifications

Off-highway heavy duty applications:

- Unacceptable durability and performance problems
- Higher friction requirements for off-highway vehicles
- Several non-asbestos lining characteristics require more development, including:
  - Low unburnished performance
  - Low after-burnish performance
  - Greater speed sensitivity at speeds ≥30 mph

Changes in FMVSS's can have a monumental impact when attempting conversion to new brake lining materials.

John Deere

- Agricultural, industrial and garden tractors have much longer lives than traditional consumer products. Therefore service is demanded for several decades. Major concerns are:
  - Identical friction coefficient, fixed design
  - High safety risks, risk/risk concept
  - Low replacement part volume
  - Sizeable inventory of old agricultural tractors routinely provide service parts for machines build 20 to 35 years ago.

Friction Product Manufacturers

Allied/Bendix

- Direct substitution of new materials for asbestos fibers resulted in
  - Poor friction levels
  - Friction instability
  - Increased noise
  - Front-to-rear vehicle brake imbalance

- Substitute formulations need to be evaluated using
  - Vehicle tests (J843d)
  - Inertia dynamometer tests

Scan-Pac

- Industrial friction products - for non-asbestos friction products performance is the same as, or better, than asbestos friction products.

- Now use SAE J661a to evaluate materials:
  - Coefficient of friction versus - Wear test at 900 F

APPENDIX C

CONCERNS OF RESPONDENTS TO ISSUES OF FRICTION MATERIAL AVAILABILITY

Automobile Manufacturers

General Motors

- OK for front disc brakes (replacements available).
- No substitute for rear drum brakes.
- Especially difficult problem for heavy-duty trucks.

Chrysler

- Currently, all but one vehicle that Chrysler manufactures has semi-metallic front disc brake pads. However, even these require an asbestos-containing underlayer material for cushioning affect.
- Brake design criteria:
  - FMVSS-105
  - Lining life of 50,000 miles
  - Noise free operation
- Tests
  - Controlled laboratory tests narrow field of candidates
  - Field tests
- Forcing the use of asbestos-free materials will compromise motor vehicle safety.

Mitsubishi

- Replacement parts should be exempt. New materials may require a design change of related parts.
- No substitute as yet for rear drum brake linings.

Honda

- Should address any vehicle manufactured after the effective date. Not applicable to replacement parts.
- Retrofitting would require replacing other parts and is not cost-effective and reduces safety.

Volkswagen

- Will have asbestos-free brake linings across its entire product line beginning in 1987 model year.

Mercedes-Benz

- Rear brake pads and parking brake linings are asbestos free on all Mercedes-Benz passenger cars.

- New 300-series are currently equipped with asbestos-free brake pads on all wheels.

- Currently have asbestos-free clutch linings on all cars.

The other asbestos containing systems would have to be redesigned so as to accommodate non-asbestos friction materials. This process of redesigning and testing is extremely time consuming and has not yet led to results that satisfy our criteria. The problems encountered are basically the following:

- The brake factor level as compared to customarily approved linings is either too high or too low.

- The brake factor scatters--in a non-permissible range--as a function of miles travelled, speed and temperature.

- Hi wear of pads and discs.

- Insufficient mechanical strength.

- High thermal conductivity.

- Low corrosion resistance.

These problems are less significant for rear brakes because the requirements regarding rear brakes are different from those for front brakes.

Ford

- No practical substitutes for
  - Duo-servo car and light truck drum brake linings
  - Engine manifold gaskets

- Motor vehicle safety must not be compromised. Even a slight increase in traffic fatalities would eliminate any benefits.

American Motors Corporation

- Allow the use of asbestos in replacement parts for existing vehicles.

Truck and Equipment Manufacturers

Wagner

- Considerably more progress made in manufacturing non-asbestos pads for disc brakes than for strip linings for drum brakes.

- Some manufacturers of strip friction for drum brakes who restrict sale of non-asbestos material to OEM customer. No aftermarket sales.

- Drum brakes have changed to non-self energizing (need higher coeffi-

Allied/Bendix

- Bendix has, in fact, been successful in developing asbestos-free products for select applications but not all applications.
- Aftermarket is of most concern.
- Automobile front disc brakes is a very severe application for front wheel drive cars.
- Rear disc brakes - may be able to use a cost-effective, asbestos-free organic disc pad.
- Non-asbestos organic drum brake linings first installed on US 1984 light trucks and then on 1986 passenger cars.
- Some of this technology has recently been transferred to use on medium size trucks.

Friction Materials Standards Institute

- Semi-metallic disc brake pads are now on front brakes of passenger cars and light trucks most have them.
- Aircraft brakes are non-asbestos.
- Non-asbestos developed for:
  - Clutch facings in heavy duty area
  - Passenger cars
- The industry is working on substitutes for
  - Light, medium and heavy truck drum segments
  - Truck/trailer blocks

Scan-Pac

- Manufacture non-asbestos friction materials for industrial application.
- Non-asbestos products since 1977:
  - Lawn and garden tractors
  - Snowmobiles
  - Snow throwers
  - Industrial clutches
  - Electric brakes
  - Hoists/winches/cranes/shovels
- Asbestos-free products perform as well as, and in most cases better than, asbestos products.
- Federal Express fleet of 390 IVECO vans have shown good results; last 4x as long.

- 25 vehicles - Heavy duty truck fleet (18 wheels) better performance than asbestos lining, 60 percent longer life.

- School bus fleets/transit buses.

DuPont

- Viable substitutes in friction products are currently available:
  - Automotive disk and drum brake linings
  - Truck brake blocks
  - Industrial brakes (reinforced with aramid) and other fibers

- 75 percent of new cars have non-asbestos brake linings.

- Clutch, manual transmission in use in Europe (non-asbestos); Automatic transmission in use in U.S.

- DuPont believes substitutes are available for gaskets also.

Environmental Lobbyists

National Resources Defense Council

- Semi-metallic disk brakes are in use
  - In U.S., (GM)
  - In Europe, Saab, Volvo and Jaguar.

- DuPont - aramid-fiber products.

- In Sweden is it illegal to replace brakes on vehicles if an asbestos-free brake is certified as satisfactory by the brake or vehicle manufacturer--two-thirds of new cars sold in Sweden are equipped with asbestos-free brakes.

Nissan

- Need longer lead time:
  - Light-duty vehicle, front brakes -- at least 5 years
  - Light-duty vehicle, rear brakes -- at least 6 years
  - Light-duty trucks -- impossible to say
  - Clutch linings -- at least 6 years
- Rule should not apply to replacement parts.
- Rule should only apply to major vehicles redesigned (as new models are introduced).
- EPA should devise a flexible exemption procedure.

Chrysler

- Believe they can comply with time table of Alternative 2 except for trucks.
- Truck brakes will be asbestos-free at end of 10-year period specified in Alternative 2.
- EPA should publish guidelines for exemptions.
- Exempt aftermarket.
- Proposed schedule:

Product Category	Time
Construction products, clothing	2 years
Passenger car brakes; all transmission applications	7 years
All other cases in motor vehicles	12 years

- Modification of Alternative 2 represents most practical approach.

General Motors

- Brake testing process can require up to 5 years.
- Exempt aftermarket replacement for older vehicles.
- In 1979, GM made goal to eliminate asbestos from brakes by 1985.
  - Largely met on front disc brakes
  - Not met on rear drum brakes due to:
    - squeal
    - wear
    - friction stability
- 70 percent reduction is too severe after first year.

- Recommend that a ban not take effect until after a period 10 years; and that the EPA permanently exempt aftermarket brake linings.

Volkswagen

- Beginning in 1987 model year, no asbestos brake linings on VW.
- Proposes Fixed Time Limits for new vehicles.

Product	FTL
Clutch	4 years
Transmission	4 years
Gaskets	4 years
Front disc brake pads (light duty)	4 years
Rear drum brake lining (light duty)	6 years
Medium and heavy duty brakes	10 years

Exemption allowed if non-asbestos substitutes not available.

No permits needed.

- Exempt replacement parts.

Mercedes

- Ban only after 5 years.
- Including possibility of exceptions:
  - Indispensible with respect to replacement parts
- Gaskets, particularly cylinder head gaskets, may need even longer lead time.
- Alternative 1 is preferable over Alternative 2.
- If FMVSS-105 is revised, this might result in further delays.

Ford

- Introduce changes during model redesign.
- Ford supports reasonable fixed time table for removal of asbestos products, coupled with a procedure for exempting where no reasonable alternatives exist.
- Exemption for parts replacement.

Austin

- Anticipates lead time of 5 years to remove asbestos from its vehicles.

- Unrealistic lead times.
- Alternatives 1 or 2 would be more equitable.
- Exempt spare parts for earlier models.

Toyota

- Opposed to applying rule for replacement parts to earlier models.
- Against proposed phase-down over 10 years.
- Prefer staged ban.
  - Friction products--5 year lead time
  - Gaskets--10 year lead time
  - Insulators--5 year lead time

National Automobile Dealers Association

- EPA should consider a simple, streamlined model-year-based ban on new vehicle parts.
- Avoid regulating replacement parts.
- EPA should consider
  - Ban beginning in a given model year for new vehicles
  - No regulation of replacement parts
- EPA and manufacturer should determine year(s) of ban on different products.

American Motors Corporation

- Recommends
  - More realistic timetable
  - develop guidelines for exemption
- EPA should ban asbestos use in specific products, such as disc brakes, rather than a product category, such as friction material.
- Develop guidelines for exemptions.
- Lead time needs can only be adequately addressed under a product-specific regulation. This is major reason AMC opposes the phase-down scheme proposed by EPA.

Motor Vehicles Manufacturers Association

- Schedule for implementation must be contingent upon the availability of suitable substitute materials so that safety and braking performance are not compromised.
- Lead times proposed are unrealistic.
- MVMA supports "an exemption process for essential uses without substitutes".

- MVMA supports "an exemption process for essential uses without substitutes".
- EPA should propose exemption procedure.
- Exemptions for aftermarket required.
- MVMA requests that EPA allow at least two full years between promulgation and the effective date of any regulatory action.
- Individual member companies will provide additional comments on this matter of timing.

Truck and Equipment Manufacturers

Wagner

- Phase-down proposed in Option 3 10 year period represents too great a highway safety risk.
- Brake strip friction material must be exempted from Option 3, and 5 year options 1 and 2.
- Recommend EPA establish mechanism for exemption procedure.
- Request (1) an exemption on drum brake strip lining, and (2) extension of 5-year ban option for disc brake pads used on older vehicles.

Navistar

- 3-1/2 to 4 years lead time to develop and incorporate new material into any product.
- One-year not enough lead time for brake linings.
- Exemption required for replacement parts.
- Navistar supports Alternative 1 (5 years) if certain modifications are made:

Year	Percent
6	30
7	24
8	18
9	12
10	6
11	0

- Alternative 2 - comments same as for Alternative 1.

- Recommends
  - Lead time of 5 years plus 5 year phase-down.

Freightliner

- Oppose EPA's primary proposal to immediately begin to phase out asbestos as impractical and practically impossible.

- Support EPA's alternate proposal number 1 which provides 5 years before asbestos friction products would be banned.

- Requests EPA proceed with Alternative 1. Allows friction materials to remain on the market for 5 years--adequate time for all commercial vehicle applications.

Rockwell

- Proposed schedule for phase-down:
  - Within a reasonable period, non-asbestos will replace asbestos in most of the heavy duty or highway truck and trailer market.
  - Definitive time constraints cannot be expected to phase out or ban asbestos linings for heavy-duty off-highway vehicles with severe brake requirements and a few very heavy duty on-highway truck applications until higher friction, non-asbestos qualification materials are developed.

John Deere

- A first-year reduction of 70 percent is too fast to reallocate asbestos for critical remaining uses.
  - Most reductions contemplated by the regulations took place during the base years
  - Life cycle tests require 6 months of lab tests plus 2 years of field tests

- The regulation does not consider the necessity of providing quality service parts for repair of existing machinery.

- Recommendation
  - Exemptions be provided for asbestos used inside a machine housing
  - 70 percent reduction be changed as follows (for new parts)

Year	Percent
1	40
2	50
3	70
10	100

  - Replacement parts over long period of time.

Friction Parts Manufacturers

DuPont

- Europe is ahead of U.S. in conversion of disc brake and manual clutches to substitutes.
- Viable substitutes are currently available for any application in friction products and gaskets.
  - Substitutes are technically equivalent or superior
  - Initial cost is generally higher, but this is offset by increased value in use.

Allied/Bendix

- Believe safe reliable alternatives will be developed for all original equipment friction materials within 5 years of the effective date of regulation.
- 10 years for aftermarket.
- New model vehicles is "best time" to introduce these products.

Friction Materials Standards Institute

- Need time to develop and test satisfactory products.
- Particular problem for aftermarket.
- Highway safety in paramount.
- An immediate ban cannot be supported because of the importance of safe braking systems on the nation's highway.

Original Quality

- Will take many years to develop a racing substitute at temperatures between 350 C and 1000 C.
- 5 to 10 years or even longer for current racing disc brake pads.
- We favor a disc pad ban in 10 years.

Scan Pac

- They already have acceptable material for industrial and automotive use--light through heavy trucks, buses, off-road, construction, farms, etc.

Environmental Lobbyists

National Resources Defense Council

- Ban on the use of asbestos in the brakes of all new cars and trucks and in all replacement brakes in existing motorized vehicles.
- Replacements are available today.