ALLIED

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June 26, 1986

Registered Mail
Return Receipt Requested

Document Control Officer - TS-793
Office of Pesticides and Toxic Substances
Environmental Protection Agency
Room E-209
401 M Street, SW
Washington, DC 20460

Re: Comments on Toxic Substances Control Act
EPA Document Control Number: OPTS-62036
Asbestos Proposed Mining and Import Restrictions and
Proposed Manufacturing, Importation and Processing
Prohibitions; Proposed Rule (51 FR 3738, January 29, 1986)

Dear Sir:

Allied-Signal appreciates the opportunity to submit comments in response to EPA's Notice concerning the Proposed Rule for Asbestos under Section 6 of the Toxic Substances Control Act (TSCA).

In the United States, Allied-Signal has over 200 manufacturing locations in 34 states, in 1985 had sales of over $9.1 Billion, and currently employs about 145,000 employees. We believe the proposed Asbestos Rule could have a significant effect on Allied-Signal and, in particular, on one of our key businesses, i.e. Friction Materials. The United States based Bendix Friction Materials Division is a major supplier of asbestos containing and non-asbestos containing friction material products. In addition, the Allied Automotive Sector Divisions Jurid Werke in Europe and Jurid do Brasil are original equipment friction material suppliers on vehicles imported into the United States. These Jurid plants plus Bendix Mintex Proprietary, Ltd. (Australia) also supply replacement friction material parts for the United States aftermarkets. As such, we offer the following comments to the EPA with the view that enlightened regulation is important to the protection of health, safety and the environment, as well as to the continuation of an important business in the United States. The friction materials business provides products and services critical to the safety of the public during transportation, as well as employment for several thousand people in several states.

I. Risk Assessment

- Allied-Signal appreciates the public and marketplace concerns relating to the continued use of asbestos and asbestos containing friction materials.

- Asbestos is a generic name used to describe several naturally occurring minerals which have similar, but not necessarily identical, crystalline structures, chemical compositions, and biological effect properties. The asbestos fiber of choice for use in friction materials for passenger cars and trucks has been chrysotile asbestos. This is largely due to its specific physical and chemical properties which have yielded the critical friction characteristics necessary for safe, reliable performance in stopping a moving vehicle. The chrysotile asbestos fiber, however, is not suitable by itself for this product application. Processes have evolved that react the chrysotile asbestos fiber with other very specific materials in a formulation that creates a tightly bonded organic matrix that locks the chrysotile asbestos fiber into this matrix in the cured compound. It is the combination of these materials in the bonded matrix that produces specific physical and chemical properties that result in the necessary friction characteristics for a particular application. These friction materials must then be engineered into a system that is specifically designed for each passenger car and truck model application. One cannot simply substitute a friction material designed, formulated and engineered for one very specific application for another application without significant potential impact on the braking capability of the vehicle. It is largely for this reason that the extensive search for substitutes for chrysotile asbestos is a complicated and costly research, development and engineering process. Any proposed EPA regulation on banning or phasing down the use of asbestos in friction materials must take this technological challenge into account. We do not believe EPA should trade a debatable risk for the very real problem of unreasonable risk that may result from unreliable or unsafe braking system characteristics.

- The Bendix Friction Materials Division, Jurid Werke, Jurid do Brasil, Bendix Mintex and the Allied Automotive Technical Center of Allied-Signal have had extensive research programs for over 10 years to develop non-asbestos friction material products. These efforts have been successful in developing alternatives for some applications, particularly for certain new model vehicles. The research programs continue unabated at a high level to further develop non-asbestos friction materials for other new model and existing model applications. However, criteria established as part of Allied-Signal's Product Responsibility Program include that the Corporation will develop and commercialize only those products which can be produced safely and with high quality, and that are reliable and safe for their intended application.

- EPA's starting point for proceeding with regulation under Section 6 of TSCA is a finding of unreasonable risk. EPA has assumed that exposure to chrysotile asbestos fiber is similar quantitatively to exposure to other forms of asbestos fibers, and that the toxicological properties of chrysotile asbestos fibers are identical to other asbestos fibers. It is from these assumptions that EPA has estimated the risk level to employees in different occupations and workplaces, and determined that current controls will not preclude unreasonable risk from occurring or continuing.

- The scientific literature contains many reports of significant differences in the toxicological properties of and biological effects in people exposed only to chrysotile asbestos fibers vs those people exposed to other asbestos fibers. The American Conference of Governmental Industrial Hygienists (ACGIH) has recognized these differences by assigning different Threshold Limit Values (TLV's) for each form of asbestos, recognizing chrysotile asbestos as significantly less of a problem. Further, as mentioned above, the chrysotile asbestos fibers are mixed with several other reactive materials. This specific formulation, after processing and curing, results in the chrysotile asbestos fiber being bonded and locked tightly within an organic matrix that must resist significant degradation over time to assure reliability of performance. Scientific studies have shown that decomposition products of friction materials, when formed from the high temperature and pressure of brake applications, are, for the most part, not fibrous and not identified as free chrysotile asbestos fibers and separate from the bonded matrix. Thus, garage mechanics who may perform brake changes, including relining and grinding operations and may not use the hygiene control procedures recommended by the Friction Materials Standards Institute, including use of local exhaust ventilation, are not exposed to measurable and identifiable free chrysotile asbestos fibers, but rather to a dust of a very different compositional nature. The unbonded chrysotile asbestos exposure levels, in the Bendix Friction Materials Division's United States manufacturing operations, are tightly controlled through engineering design supplemented by local exhaust ventilation and filtration systems and are well in compliance with OSHA and ACGIH standards. In fact, the Corporation has implemented such systems in operations worldwide. Allied-Signal believes that these risk assessment factors do not warrant an immediate ban while the research programs continue to identify safe and reliable substitutes for use in friction materials. Thus, EPA may wish to re-examine its risk estimates and the determination of unreasonable risk.

II. Risk Management Approach: Asbestos Substitution

- In spite of the facts noted in the risk assessment, there has been considerable movement in the marketplace away from friction materials containing asbestos. We fully expect that the market-place pressures that place a demand for non-asbestos products will continue. Allied-Signal has, over the past decade, implemented extensive and costly research programs to develop reliable and effective friction materials that are asbestos free. The Bendix Friction Materials Division has, in fact, been successful in developing asbestos-free products for select applications and expects to continue to be successful in the research and development programs for other applications.

- If the EPA, in its unreasonable risk determination, concludes it is still appropriate to proceed with a ban and/or phase-down on the importation and processing of asbestos for friction materials, Allied-Signal believes safe, reliable alternatives will be developed and commercially available for release by vehicle or brake manufacturers for all original equipment friction material uses within 5 years of the effective date of such a regulation. However, Allied-Signal also believes that it will take significantly longer (at least 5 additional years) to develop adequate substitutes for the asbestos containing friction materials used in the aftermarket.

- The current design criteria for new model passenger cars and trucks assume that the friction material will be of the non-asbestos type, and, as such, the systems are being engineered with the different physical and chemical properties of the non-asbestos material in mind. For the aftermarket, the introduction of an asbestos-free friction material into a system originally designed for asbestos based friction material may result in very different braking characteristics from those initially desired due to the change in physical and chemical properties. Thus, retrofitting in the aftermarket is of much greater concern for the long term substitution of non-asbestos for asbestos friction materials.

III. <u>Regulatory Framework For Asbestos Manufactured, Imported Or Processed For Original Equipment Friction Materials</u>

For regulatory control purposes, Allied-Signal could support a properly designed regulatory approach to banning and/or phasing down the future manufacture, importation or processing of asbestos for use in disc pads, drum segments and brake blocks, designed for use in <u>original equipment</u>, if the following factors were taken into account:

A. "Free market forces" are expected to be sufficient to encourage manufacturers of friction materials to identify and commercialize suitable substitutes for the asbestos. Therefore, no additional regulatory restrictions should be imposed for a period of 5 years from promulgation of the final regulation and initiation of the compliance schedule. This would enable Allied-Signal to compete in an increasingly international world market where certain applications still require the use of asbestos in friction materials for product safety and integrity reasons. However, major new product design criteria would stipulate the use of non-asbestos friction materials. We believe regulatory interference in free market forces during this 5 year period will not significantly increase the already high level of research, development and engineering activity to develop an asbestos-free product. Such interference will have a negative effect on our ability to compete on a world level which will subsequently have a long term negative effect on the RD&E funding necessary for the continued commercialization of substitutes for asbestos.

B. From year 6 of the initiation of the final regulation, there could be a required reduction of the total quantity of asbestos permitted to be imported (as raw material and in finished articles) for use in friction materials to 30% of a base year (1981 through 1984). This would continue to be reduced linearly to total elimination after year 10.

C. The regulation should stipulate that there will be a "State of Technical Achievement Review" process at year 3 and at year 5 to assure that research, development and systems engineering have indeed been able to identify safe, reliable substitutes. We fully expect to be able to achieve these.

D. It is critical to United States based industry that EPA and OSHA work cooperatively in the regulatory control of asbestos. If EPA indeed plans to proceed to ban or phase-down the use of asbestos, then OSHA needs to allow flexibility in achieving anticipated lower permissible exposure levels to asbestos fibers (i.e. utilizing administrative controls and respiratory protection on an interim basis) instead of costly engineering controls while the asbestos phaseout is proceeding.

E. The EPA regulations must apply to all friction material products containing asbestos on an equal basis. This would include imports of finished articles as well as domestically produced friction materials.

F. The permit system that EPA is contemplating for companies that import or process asbestos into finished products must be a simplified notification process only that will not require significant effort on the part of companies nor require significant review by the EPA. We believe this system should go into effect between years 6 through 10, and again stress the need for that system to be simple.

G. Allied-Signal does not concur with the transferability or banking concepts for permits since we believe that it will lead to far greater administrative complications for EPA and industry without measurable benefit to the EPA, industry or the public.

H. Labeling of products containing asbestos should be required, but the labeling should be required on the carton within which the asbestos product is packaged. Labeling of individual disc pads, drum segments or brake blocks containing asbestos would be technically complicated and would probably not survive in a legible fashion during extended brake usage. The cartons containing Bendix Friction Material products are currently labeled in accordance with OSHA labeling requirements and we support the continuation of that system. In addition, in conformance with OSHA's Hazard Communication Standard, Material Safety Data Sheets advising of the presence, hazards and control of asbestos in a resin bonded matrix are communicated to all Bendix Friction Material customers.

IV. Regulatory Framework For Asbestos Manufactured, Imported Or Processed For Aftermarket Friction Materials

Allied-Signal could support a regulatory required ban or phase-down on the manufacture, importation or use of asbestos in friction materials designed for use in the aftermarket. However, the problem in achieving technological breakthroughs in developing substitutes that provide effective, reliable characteristics for braking systems designed years ago for use with friction materials containing asbestos is a much more difficult task. To assure the safety of the users of passenger cars and trucks who may be required to use non-asbestos friction materials in a braking system designed for use with asbestos containing friction materials, it is imperative to assure "like for like" substitution in the aftermarket. All factors bearing on performance characteristics (including quality, reliability, fitness for specific use, system safety, and product integrity) must be assured for mixed components in a system not specifically engineered for the different physical and chemical characteristics of non-asbestos friction materials.

1. For disc pads in the aftermarket, there is a need to provide an asbestos-free product across the entire product spectrum. We anticipate less difficulty in substituting an aftermarket asbestos-free disc pad for those original equipment systems currently being designed for use with asbestos-free products. However, we anticipate much greater difficulty in being able to substitute an aftermarket asbestos-free product as replacement in an original equipment system that was originally designed for use with asbestos. This is especially true for cars built in the mid-1960's and early 1970's. Nevertheless, Allied-Signal could support a regulatory ban and/or phaseout of the manufacture, importation and processing of asbestos if the following criteria are included in the regulation:

A. No regulatory controls (i.e. maintenance of the "free market") should be imposed for a period of 5 years following the promulgation of the final regulation and initiation of the compliance schedule.

B. During year 6, the total quantity of asbestos permitted to be used should be reduced to 50% of that allowed in a base year (1981 through 1984) from which further reductions would be factored in.

C. From year 7 through year 10, the residual 50% would be reduced by an appropriate percentage such that there would be a linear reduction to zero after year 10. It will likewise be important to have a "State of Technical Achievement" review at year 3 and year 5 of this phase-down period. While we expect success in our research and development programs, the safety of the consumer using and depending on the braking system for his automobile or truck should be paramount in EPA's aftermarket brake risk assessment and risk management criteria.

D. EPA and OSHA must coordinate and concur in their regulatory measures during the phaseout such that interim measures, including administrative procedures and protective equipment, could be used to meet OSHA's anticipated reduction in permissible asbestos exposure levels.

E. Imported products must be regulated equally with products manufactured in the United States. Otherwise, manufacturing of finished friction materials may be transferred to other countries having a different set of regulatory controls on asbestos. This would jeopardize jobs in the United States.

F. The permit system, that EPA is contemplating for companies that import or process asbestos into finished products, must be a simplified notification process. We believe this system should go into effect between years 6 through 10, and be applicable on a product by product evaluation basis.

G. Allied-Signal does not believe the transferability or banking concepts EPA has suggested for these permits add any advantages and therefore recommend their deletion from regulatory proposals affecting the aftermarket as well as original equipment.

H. Labeling of packages or cartons containing the friction material with asbestos is required under current OSHA regulation. There should be no additional requirements to label each individual disc pad.

2. For rigid and flexible drum segments in the aftermarket, we anticipate much greater technological difficulty in being able to create a "size for size" replacement of asbestos with non-asbestos drum segments at competitive prices. At the present time, our goal is to develop competitively priced, asbestos-free friction materials for use on all drum brake applications. Our research programs have shown that significant differences still exist in performance characteristics between our current asbestos-free and asbestos type friction materials (associated with operating temperatures and "fade/recovery" conditions).

Because of these differences and the effect of the force multiplying action (mechanical advantage) on the safe operation of these asbestos-free materials in the duo-servo brake design, Allied-Signal is convinced that further experimental work is necessary to develop asbestos-free products suitable for use on non-servo and duo-servo brakes, especially when there is a chance (due to dimensional similarity) of a mechanic installing a product designed for non-servo use where the one designed for duo-servo use is intended.

Of course, we must engineer materials which have the desired structural integrity, friction level and long life properties the car owner now obtains with the current asbestos product, and yet be processed economically.

Our existing manufacturing equipment was designed to utilize the processing characteristics associated with asbestos fiber. We must now refocus our efforts to maximize the processability of substitute materials.

Nevertheless, we could support a regulatory phaseout and/or ban providing the factors as enumerated above in IV(1) (A-H) for the disc pads in the aftermarket are applied. It would be especially critical to have the "State of Technical Achievement" review since there is less confidence in having adequate substitutes to meet this specific need. During the 10 year phaseout period, it is especially important to have built-in regulatory flexibility to modify the percent reduction after 5 years and possibly after 10 years, but this can be accomplished on an exception basis. A built-in review at year 8 should identify the need for extending out the 10 year phaseout period.

3. For brake blocks in the aftermarket, Allied-Signal continues to have some difficulty in achieving commercial success with adequate non-asbestos substitutes on a "like-for-like" basis. In this product line, this is largely due to the variability in products coupled with less control. In this particular market segment, replacement parts are chosen largely on the basis of "price only". Nevertheless, we could support a regulatory ban and/or phaseout of the use of asbestos for this particular application provided the criteria as enumerated in III (A-H) above for original equipment would apply.

V. Status of Development of Asbestos Substitutes In Friction Materials

EPA has specifically asked for comments on whether adequate substitutes are available for all asbestos applications. EPA has implied that there are such substitutes currently available for friction materials. While we agree with EPA that there are adequate substitutes available for certain friction material applications, it is inappropriate to assume that adequate substitutes are available for all applications. This point is expanded on in the attached update on the technology of developing asbestos-free friction materials.

VI. Recordkeeping Requirements

EPA has proposed certain recordkeeping requirements in the proposed rule. If EPA adopts Allied-Signal's recommended regulatory approach, no recordkeeping requirements would be imposed during the first 5 years of the 10 year phase-down period. This would enable manufacturers of friction materials to focus their energy and resources into the research, development and systems engineering necessary to commercialize safe, reliable non-asbestos substitutes for asbestos in friction materials. Of course, OSHA's recordkeeping requirements relating to controls in the workplace would continue to be in place. Beginning during year 5 for implementation in year 6, identification of the base year for those companies that import or process asbestos would commence. Recordkeeping requirements would be appropriate to determine the total quantity of asbestos imported or processed during years 6 through 10 to verify the phase-down. These data could be required to be submitted to EPA and/or inspected by EPA. Copies of labels on packages and other recordkeeping requirements for the OSHA standard would continue to be maintained.

Allied-Signal appreciates the opportunity to work with the EPA in striving to find the appropriate regulatory framework for assessing and managing the risks present in the manufacture and use of products containing asbestos. We hope EPA recognizes that finding adequate substitutes for asbestos for use in friction materials is a technologically complicated and costly process.

Great strides have been made in the past 10 years to develop non-asbestos friction materials and we are optimistic that great strides will continue to be made in our research, development and engineering programs. We remain dedicated to the task of identifying asbestos substitutes, provided such substitutes are safe and can be used in such a way as to not compromise the safety of passengers who are dependent on reliable, effective, quality braking systems and components in their passenger cars and trucks. This would apply for new models as well as in support of older models.

Thank you for the opportunity to comment on the proposed regulation.

Sincerely yours,

Joel B. Charm

Joel B. Charm
Director, Corporate Product Safety
and Integrity
(201) 455-4057

/gbl
attachment
cc: K.W. Cole, Washington Office

SUMMARY

	ORIGINAL EQUIPMENT						AFTERMARKET					
	Brake Blocks Year	%	Disc Pads Year	%	Drum Segments Year	%	Brake Blocks Year	%	Disc Pads Year	%	Drum Segments Year	%
1. Allied Signal will		up to								up to		up to
support the ban if	1-5	100							1-5	100	1-5	100
we can use asbestos	6	30	Same		Same		Same		6	50	6	50
in our product lines	7	24	as		as		as		7	40	7	40
equal to a percentage	8	18	at		at		at		8	30	8	30
of our "base year"	9	12	left		left		left		9	20	9	20
consumption as indi-	10	6							10	10	10	10
cated.	11	0							11	0	11	0
2. Technical review to	Yes		Same		Same		Same		Same		Yes	
determine if the	Year 3 &										Year 3	
industry is "on target"	Year 5										Year 5	
with non-asbestos											Year 8	
programs.												

3. EPA and OSHA must concur in phase-out program coupled with administrative/protective equipment requirements for the work place. (Engineering controls should not be required.)

4. Permit system (required for Years 6-10) must be a simplified notification procedure only.

5. Permit must not be transferable nor "bankable."

6. Phase-down requirements must be applied equally to domestic manufacturers and importers.

7. Present "OSHA" warning label on carton should be adequate (versus labeling "the product").

AN UPDATE ON DEVELOPING
ASBESTOS FREE FRICTION MATERIALS

by

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Troy, New York
June, 1986

ABSTRACT

Friction materials for automotive brakes are complex composites containing three general types of ingredient materials: reinforcing fibers; modifiers that adjust or maintain friction level, wear rate, and noise properties; and organic binders. Historically, the foundation or major constituent of automotive friction materials has been asbestos fiber, so chosen because of thermal stability, friction level, reinforcing properties, availability, and relatively low cost.

Numerous substitutes for asbestos in conventional organic materials have been evaluated, including both naturally occurring and synthetic materials. Direct substitution of these alternative materials in conventional formulations has resulted in poor friction levels, friction instability, roughness, structural failure, increased noise, mating surface deterioration and/or front-to-rear vehicle brake imbalance. Complete reformulation, not simple substitution, is necessary to meet the numerous, complex performance requirements of consumers, vehicle and brake manufacturers, and government standards, such as FMVSS 105-75 and FMVSS 121.

In the 1960's, a new class of friction materials, called semimetallics, was developed to meet severe braking requirements, primarily in heavy-duty disc brake and extreme duty truck block applications. Semi-metallics operate satisfactorily against the ventilated cast-iron rotors in the smaller brakes of downsized cars, as well as against the solid rotors found in the lighter brakes of new front wheel drive vehicles. Semimetallics rely on steel fiber and powder metallurgy techniques for reinforcement, and do not require asbestos. The improved performance of

semimetallics compensates for their higher costs due to more expensive ingredients, higher specific gravity, and more costly processing requirements. Overall development took more than ten years from introduction to significant customer acceptance.

The characteristics of the original semimetallic formulations made them extremely difficult and costly to process as a drum lining segment. Consequently, during the early 1980's a new class of asbestos-free friction materials was developed, specifically for small drum lining applications. These new-type friction materials are also more costly, (initially), due to the use of man-made fibrous ingredients, amortization of processing equipment and the techniques associated with the new machines. However, the segments are now being used on rear drum brakes by the major USA based vehicle manufacturers and the trend is already in place for additional applications as new models are introduced in the next several years. It should be noted that low wear characteristics of this new class of materials yields as lower "total life" cost to the vehicle owner in spite of their higher initial costs.

This paper is based on information originally presented at a July 14, 1980 EPA/CPSC workshop in Arlington, Virginia by Messrs. Jacko, Brunhofer and Aldrich and compares the situation then, the industry's expectations and the Bendix accomplishments to date.

INTRODUCTION

Automotive brakes can be viewed, quite simply, as energy transformers. During a brake application, the friction material (stator) makes contact with the rotating drum or disc (rotor), creating a friction force resisting the relative motion between the two bodies. The energy of motion is transformed into heat energy, which is dissipated, primarily, through the rotating member.

As one might expect, the friction material must operate in a rather hostile environment. Lining soak temperatures in excess of 400°C (750°F) are not unusual, and temperatures at the contact interface can exceed 850°C (1650°F). The nature of the on-the-road operating environment (dust, mud, salt, water, etc.) complicates the problem. The friction material must possess an optimized balance of characteristics, and maintain those characteristics throughout 20,000 to 40,000 miles of vehicle operation.

The fundamental characteristics of friction materials are listed in Table 1. Friction level must be adequate and stable over a wide range of operating speeds, application pressures, and temperatures, regardless of the conditioning and age of the material and vehicle load. Of particular interest are the fade/recovery characteristics, i.e., the ability to resist friction level deterioration when subjected to extreme elevated temperatures (the fade) and then to return to the pre-fade friction level on cooling (the recovery). The friction material must have good wear properties for long life, but it must also not cause excessive wear or grooving on the mating disc or drum. Excessive compressibility, noise and roughness (chatter, vibration, pulsation) must be avoided, and sensitivity to moisture must be minimized. Finally, the friction material must be capable of being manufactured with consistency at a reasonable cost.

Detailed definitions of these characteristics, and their interaction and interdependence, have been discussed at length by Aldrich and Jacko (1). In general, attempting to improve upon one characteristic often results in the deterioration of other characteristics. The development of friction materials is therefore a complex, interactive process seeking an optimized combination of interdependent characteristics.

The existence of numerous brake designs provides another level of complexity in designing friction materials. Linings for drum brakes require a wide range of properties. The duo-servo drum brake (at one time the most popular U.S. design) requires two different types of linings, designated primary and secondary, each of which needs different properties of strength, wear resistance, friction level and friction stability. The non-servo drum brake (used on the rear axle of many new sub-compact vehicles) requires a friction material which encompasses the best characteristics of the primary and secondary in a single formulation, with emphasis on low temperature properties and static friction capability. The large hydraulic and air-operated drum brakes utilized on medium and heavy trucks require, in general, the maximum properties of the smaller vehicle linings but at significantly higher operating temperatures. The arcuate form of drum brake linings places additional restrictions on the formulation, because of processing requirements.

Disc brakes demand a totally different set of operating conditions for the friction materials. Disc brakes generally operate at significantly higher temperatures than equivalent drum brakes, and the front disc brakes run hotter than the rear drum brakes on the same vehicle (Table 2). The friction material for disc brakes must be specifically designed for these higher temperatures, and must possess a very stable coefficient of friction and better wear characteristics across the temperature range. Friction-material formulations must also be tailored to the specific needs of the particular vehicle application. Numerous parameters such as vehicle weight, front-to-rear brake balance, actuating system design, and duty cycle affect the capability of a particular lining formulation to perform satisfactorily.

The existence of numerous complex performance standards emanating from consumers, associations, manufacturers, and government agencies provides an additional set of parameters that friction materials must meet. Significant differences can exist between friction materials used as original equipment in new vehicles and friction materials available as replacement parts in the aftermarket. Each vehicle manufacturer has a unique, extensive set of test and acceptance standards to ensure the safety, durability, and performance of its products and the components used therein. Government-instituted requirements exist at the federal, state, and local levels. Federal requirements include those promulgated by the Department of Transportation (vehicle performance), the Occupational Safety and Health Administration (manufacturing work practices), and the Environmental Protection Agency (manufacturing practices and raw materials).

In order to meet the many characteristics outlined thus far, friction materials for automotive brakes have developed as complex composites containing three general types of ingredient materials: reinforcing fibers; modifiers that adjust or maintain friction level; wear rate and noise properties; and organic resin binders. Historically, the type of friction materials used in most automotive applications has been conventional organic friction material. The foundation or major constitutuent of conventional organic friction material has been asbestos fiber, so chosen because of its unique combination of characteristics. Asbestos fibers provide reinforcement, possess a high coefficient of friction, and more importantly, have excellent thermal stability. The openness of the fiber, its adsorptiveness, and its compactibility enhance the processing and uniformity requirements. Finally, asbestos fibers have been available in a variety of grades at a relatively low cost.

Once the friction material has been cured, the asbestos fibers are locked into the matrix. During brake operation, the high temperatures generated at the interface convert more than 99.7% of the asbestos to non-fibrous residues (primarily olivine) in the wear debris (2), and less than 0.02% asbestos becomes airborne (3,4).

The conventional organic formulations and the processes by which they are made have been dependent upon and tailored to the physical and chemical properties of asbestos. Two courses of action were open for elimination of asbestos from automotive friction materials:

1. Attempt to substitute an alternative fiber system for the asbestos in conventional formulations, with subsequent and modification of composition and process techniques. Bendix quickly learned that this concept was not effective.

2. Develop a new generation of friction materials, designed from the start, without asbestos. Industry trends toward improved vehicle and brake system quality standards (customer satisfaction and reduced variability in light weight, fuel efficient cars) have resulted in the development of new formulations and processing techniques which meet these demands.

SEMIMETALLIC DISC PADS

Properties

In the 1960's, a new generation of friction materials, called semimetallic, was developed to meet severe braking requirements which organics could not meet. Class A organics (typical U.S. materials), which perform well in low and moderate temperature duty, are prone to fade and exhibit compressibility and poor wear resistance at high temperatures. Class B organics (typical European and Japanese materials) provide good high-temperature wear and friction levels, but have poor low-temperature wear resistance, produce rotor scoring and/or wear, and are prone to being noisy. Semimetallics were initially developed for these extreme, high-temperature applications (5).

Semimetallics rely on steel fiber and powder metallurgy techniques for reinforcement. Various property modifiers are added to enhance performance to desired levels, with a resin binder holing the materials in a uniform solid mass. Semimetallics may contain metallic powder, sponge iron particles, ceramic powder, steel fiber, rubber particles, graphite powder, and phenolic resin (6,7). Some manufacturers utilize a backing layer of a different composition which can contain asbestos.

Problems Overcome

Inherent in the uniqueness of the semimetallic formulations and their performance properties were a number of significant problems which required resolution. Concentrated development effort was required to resolve both processing and performance related issues. Processing issues included: the uniformity of the raw materials mixtures, the ability to form and handle the in-process material, and the ability to consistently manufacture high-quality parts. Performance issues included: material strength, cold friction properties, initial wear resistance, and attachment to the backing plate. The development effort on semimetallic friction material has been continuous, not only to further improve its characteristics and properties, but also to overcome the problems inherent in accommodating new vehicle applications.

Semimetallics gained acceptance because they were able to solve some of the problems that could not be overcome using Class A or Class B organics. The improvements/advantages are listed in Table 3. The key element is the attainment of overall excellent properties at both low and high temperatures. Semimetallics cost more because of more expensive ingredients and a costlier process, but the improved performance capabilities offset these factors. An increased usage of semimetallics has occurred over the past few years. The shift to front wheel drive, plus the downsizing of vehicles, with resulting smaller front brakes and higher operating temperatures has given impetus to increased use of semimetallics (8). It is expected that the trend toward asbestos-free semimetallic disc pads will continue.

SEMIMETALLIC DRUM BRAKE LININGS

An obvious first alternative to conventional asbestos/organic drum brake linings was the use of semimetallic material for drum linings. In fact, one of the initial applications for semimetallics was for 3/4" thick blocks in air brakes on heavy-duty trucks used in the logging industry -- an extremely severe application.

Significant research and development effort had been expended on semimetallic drum brake linings. However, the basic nature of semimetallics does not possess the necessary "green strength", is difficult to bend into the arcuate shape, and is more brittle in its cured form and therefore subject to cracking.

Due to the problems listed above, Bendix decided not to expend R & D funds in this type of friction material application and directed its resources towards non-asbestos organic drum brake linings (See Page 11).

ALTERNATE FIBERS/REINFORCERS

Properties

Alternative fiber systems in conventional organic formulations represented the first course of action open to friction-material manufacturers . Table 4 is a summary of the properties of some of the various materials which could be considered as alternate reinforcements. Since conventional organics and semimetallics have traditionally been reinforced with asbestos and steel fiber, respectively, these fibers are also included in the table for comparative purposes. The data in Table 4 were obtained from the material manufacturers' literature and extensive characterization data developed at Bendix. Characterization included scanning electron microscopy and x-ray energy spectroscopy (SEM/XES). The selection of suitable alternate materials must also consider the health and safety implication of the substitute fiber system. After considerable study of existing information, Bendix has chosen substitute materials which, in our judgement, are free from serious health implications.

Processing Conditions

Current organic friction materials have been developed around the unique properties of asbestos. Asbestos fiber bundles "open" during mixing and entrap the friction modifiers and resin, giving a consistent mix. The compactability of asbestos facilitates forming at room temperature with moderate pressure.

The non-asbestos fibers are much more difficult to handle. Most are very brittle and have little or no surface adsorptivity. High bulking, "balling" and segregation occur during mixing. Spring back and low tack lead to weak structures. Combinations of additives, surface treatments and new processing techniques are required to overcome these problems and produce the cohesiveness necessary for manufacturing parts.

Performance Characteristics

The characteristics of the fibers can have significant influence on the performance properties of the final composite. Asbestos has a high, stable friction level, good adsorptivity for strength and wear resistance, and does not contribute to noise.

Substitute fibers generally show greater frictional instability, little or no surface adsorptivity, and/or significant contribution to both noise and mating-surface degradation.

NON-ASBESTOS ORGANIC DISC PADS

Failures on Direct Substitution

A commercial Class A organic disc pad formulation, similar to one reported early (9) and known to contain phenolic resin, asbestos fiber, organic friction particles (cashew and rubber dusts), zinc chips, and barytes was selected as a baseline composition. In a series of new formulations, the asbestos fiber was replaced with glass fiber, mica, mineral wool, Franklin fiber, a glass fiber/mica mixture, a glass/Fiberfrax/graphite fiber mixture, and a glass/Wollastonite fiber mixture.

The composites were run on an inertial dynamometer equipped with a Bendix-designed Series III disc brake loaded to 1000 lbs. Stops from 50 mph (80 km/h) at 3.66 mpsps (12 fpsps) deceleration were run at different initial brake temperatures up to 315°C (600°F). All fiber substitutions produced roughness followed by poor friction. Generally, the composites were structurally inadequate, producing tear-out and poor wear resistance, in addition to roughness (Table 5). All formulations were considered failures. This led to the conclusion that simple direct substitution of alternative fiber systems was not practical.

Alternate Approach

A new baseline was selected with increased reinforcement content to better screen the following characteristics:

- processing
- strength
- performance (friction wear, drum compatibility, and noise properties)
- cost

The initial objective was improved structural capability. A number of formulations were made using high fiber concentration. As shown in Table 6, the tensile strength results were very encouraging. The next step, which proved very difficult, was attaining a proper balance of friction and wear to go along with the strength.

Sample Dynamometer Results

A series of combinations of materials with a fixed ratio of glass fiber and the other reinforcements was evaluated on a sample dynamometer (Table 7). The results indicate that all of these reinforcement combinations are poor substitutes for asbestos fibers in that they exhibit poor friction, poor wear resistance, poor friction stability, or poor rotor compatibility. However, some clues were provided and it was possible to combine two of the formulations to produce a new composite M. This material was then reformulated with additional property modifiers in 6 other iterations to produce yet another formulation S, which exhibited a high but stable friction coefficient, equivalent wear resistance, and slightly poorer rotor wear resistance. At this point, the study was transferred to full brake inertial dynamometer testing.

Inertial Dynamometer Results

The inertial dynamometer confirmed that formulation S had a higher friction level, slightly better wear resistance, and slightly poorer rotor compatibility than the baseline (Table 8). Approximately 40 iterations of formulation S led to formulation AA which gave good friction with friction stability and very good wear resistance. Further iterations ($\approx$10) led to formulation AL which gave lower friction, poorer wear, and good rotor compatibility. In addition to inertial dynamometer tests, a series of vehicles tests was also initiated.

Vehicle Test Results

Several formulation iterations were coupled with processing improvements. Formulation DA was developed after approximately 50 iterations following formulation AL. Formulation DN was developed after 13 iterations of a new-concept material which has been patented (10). The vehicle test results (effectiveness, fade, and recovery, in addition to wear data and noise ratings) are given in Table 9 and were run according to a modified SAE J843c schedule. Formulation Bendix D7180 is a Class A organic used as the baseline.

The line pressure data show that the non-asbestos organics have higher preburnish, post-burnish, and final effectiveness than the baseline, based on full-system as well as "fronts-only" checks. This higher friction level and friction stability are also demonstrated in the fade and recovery portions of the test.

Both non-asbestos organics showed poorer burnish wear resistance, and both showed improved wear resistance during the fade and recovery portions of the test. The rotor compatability of both non-asbestos organics was poorer than that of the asbestos-based baseline.

Formulation DA, which is more typical of Class A organics, showed less loss in rotor wear than did the new-concept DN material. Both materials were prone to be noisy.

Current Vehicle Trends

Due to the ever increasing trend to produce fuel-efficient, front-wheel drive vehicles, a larger amount of braking effort has been shifted to the front brakes (as much as an 83/17 distribution ratio on certain 1986 small cars!). This has resulted in promoting the OEM and AFM demand for semi-metallic disc pads which are ideally suited to quickly absorb large amounts of energy and still remain frictionally stable. This trend has practically eliminated any opportunity to apply non-asbestos organic disc pads on front disc brakes.

The advent of rear disc brake systems for limited production vehicles may permit the introduction of a cost effective asbestos-free organic disc pad. As a result, Bendix is continuing development efforts to improve rotor compatability, durability, noise properties and processability for both OEM and AFM sales.

NON-ASBESTOS ORGANIC DRUM BRAKE LININGS

Process Characteristics

Drum-brake linings require different processing characteristics than do disc pads. When made by a wet process technique, friction materials require a binder-wetted plastic mass with good cold flow properties. When made by a dry process technique, they require good hot flow properties, but first must be capable of being preformed under cold pressure conditions to develop strength for handling purposes. Both wet and dry process types require the capability of ultimate arcuate formation. All alternate fibers commercially available in 1980 were deficient in these areas.

As in the case of disc pads, the direct substitution of alternate fibers in existing asbestos formulations has been unsuccessful. Basic processibility had been the first obstacle. The generally stiff, non-adsorptive alternate fibers did not result in a wetted, densified mass. This precluded cold-pressure forming into brake-lining strip configurations typical of wet-process methods. In the case of dry-process methods, the fiber stiffness was a deterrent to good physical integrity of preforms and also permitted excessive lining cracking during bending. In general, the alternate fiber materials did not develop the desired mix character which allowed them to be processed effectively by the then-known techniques. The solutions to these problems called for radically different approaches to material formulation and processing techniques. The new processing techniques required substantial capital investment.

Testing and Development

With the application of suitable material and process changes, non-asbestos type drum linings were experimentally fabricated and tested. Hundreds of formulations of duo-servo primary linings and secondary linings, along with those for non-servo type brake linings, have been made. When processed satisfactorily, these materials have been tested on sample dynamometers and inertial dynamometers before selecting the better ones for vehicle testing. The use of different formulations to overcome the process problems has resulted in substantially different frictional and wear characteristics which have had to be modified to more closely duplicate the desirable characteristics of acceptable asbestos based friction materials.

Table 10 illustrates the magnitude of some of the early problems and some of the later results. Initial tests using very high friction combinations (A and B) run on Vehicle 1 with a front-brake hold-off valve, resulted in a serious duty shift with front brakes projecting greater than normal mileage, and the rear brakes projecting short life because of their higher work load. However, when Combination A was run on Vehicle 2 (which had no front-brake hold-off valve), the secondary lining (the same as in Combinations A and B) projected almost the minimum requirement of 15,000 although the primary gave only 7900 miles. Subsequent tests of improved combinations, particularly with improved primary lining life, projected over 20,000 miles. Tests on Vehicle 3, again without a front hold-off valve, projected reasonably good life on Combinations E, F, G, and H, with quite acceptable life on the more recently developed Combination H. A comparison of wear projections on Combinations F and G shows the importance of primary-secondary teaming. Both combinations had the same primary, but with different secondaries, the life of the primary decreased from 20,900 to 12,200 miles.

The above data illustrates that basic life and performance were achievable, at least on certain vehicles. However, the materials noted above were prepared by more involved, more expensive processes and were noisier than current asbestos types, and the mating surface condition required further improvement. Further, the ability of these materials to withstand extended in-service usage had to be evaluated in a wide range of vehicle applications and environments. Formula changes were made and the resulting compounds were subjected to year-long nation-wide vehicle testing programs.

Summary

In the early 1980's, the development of process equipment capable of mixing man-made fibers (e.g. chopped fiber glass, Kevlar®, steel wool into synthetic rubber and/or phenolic resin bound compounds made it possible for Bendix to introduce new asbestos-free formulations which met the requirements imposed by governmental units, manufacturers and consumers.

Status

This new class of materials was first installed on USA built 1984 light trucks and then on 1986 passenger cars. Typically, the hydraulic system and the friction material are "engineered as a package" to optimize the physical characteristics of these lining compounds. Thus, the introduction of new model vehicles appears to be the "best time" to bring these products to the consumer due to the myriad of expensive tests which must be completed to bring any new vehicle to the marketplace.

Some of the technology noted above has recently been transferred to the manufacture of brake blocks for air operated S-Cam brakes on a medium sized truck and will shortly be introduced on hydraulic truck brakes by the same builder.

ECONOMIC IMPACT

The economic impact of eliminating asbestos from automotive friction materials is significant, and includes three distinct segments:

1. Research and Development/New Capital Investment: Bendix has committed, and will continue to commit, extensive funding to both research and development efforts and to the new equipment and facilities required to support asbestos-free friction materials.

   a) R & D - From 1975 to 1980, the number of dynamometers and test vehicles at our Friction Materials Division was doubled, and engineering headcount had been increased by over 60 percent. The total engineering budget was tripled, and the share of the budget devoted to asbestos-free product development grew from 13 percent in 1976 to over 71 percent for 1981. For the past five years it has averaged about 80 percent of the engineering budget. The corporate automotive technical center has also expended significant efforts in support of the division. Bendix calculates that it spent over $25,000,000 the past ten years in engineering activities on asbestos-free product in the U.S. alone. Millions more are being budgeted each fiscal year to accommodate planned vehicle model changes.

   b) Capital Investment - When the EPA/CPSC workshop was held in 1980, Bendix assumed that federal regulations and/or vehicle builders' requirements would force a rapid transition to asbestos-free drum brake segments and blocks, approaching 100% of the passenger car and light truck market by 1985. This has not happened.

      As a result, we will have invested only about $20,000,000 by the end of 1986 for the new facilities and equipment required to produce asbestos-free products (instead of the $60,000,000 predicted at that meeting). However, additional sums are budgeted for more equipment to be installed as vehicle manufacturers prescribe additional quantities of this new class of compounds for cars and trucks scheduled for introduction in the next five years.

2. Product Cost: The basic cost of the product itself is a complex function involving many factors. The amount and types of materials used, and the basic raw material costs are obvious factors. The fixed and variable costs of manufacturing can differ greatly, based on the type of process and its complexity, production volumes, labor costs, energy cost, and process yield, among other factors. Administrative costs and handling/distribution costs are also significant variables.

   Current original equipment data indicate that asbestos-free drum brake linings are selling at 50% to 75% more than asbestos linings. Disc brake pads may cost 20% to 100% more than current asbestos materials.

   Regarding aftermarket parts, where the asbestos-free linings must be engineered to fit into existing hydraulic systems without affecting safety and brake balance/performance parameters, we now estimate the price of top quality segments will be from 150 to 200% more than current materials at the retail level.

3. Implementation Costs: As noted earlier, vehicle manufacturers have an extensive series of stringent test requirements. Each different vehicle configuration requires the series of tests to ensure that the product conforms to the requirements. Since asbestos-free materials may have some performance or property differences from current materials, vehicle system redesign may be necessary. We do not have sufficient information to accurately estimate costs associated with the test programs. We would expect that each vehicle manufacturer would expend millions of dollars, and possibly tens of millions, in converting their product lines to asbestos-free materials. A key element is the timing of the test programs. Expenses could be minimized by converting to asbestos-free materials as part of the scheduled new vehicle design programs, where significant brake-system testing is already necessary. This procedure is being used for many models.

   Due to the length of time necessary to develop and field test (usually a minimum of four seasons) a brake design for a new vehicle, it now appears that not all of the existing OEM systems can be re-evaluated with asbestos-free linings for OEM and/or OES requirements by 1990 due to often limited manpower and equipment. "Empty versus full load" conditions complicate these substitutions for light truck applications.

TIMING

Friction materials development is a lengthy process. As mentioned previously, the materials themselves and their properties are the results of optimization procedures, and the necessary testing programs are extensive. These programs include not only testing by the friction material supplier to develop and document the materials' capability, but also extensive testing by the customer to ensure suitability and regulatory conformance in the particular application.

Historical data gives us a sense for program timing. Evolutionary changes generally require eighteen to twenty-four months for supplier development validation testing, twelve to eighteen months for customer application testing, and six months manufacturing lead-time - - that is a total of 3 to 4 years. As example of such a change would be an improved organic disc pad utilizing the same basic components (i.e., asbestos, resin, modifiers). Compared to its predecessor, the new formulation might exhibit 15 percent better wear, improved fade resistance, and the same friction noise properties. Today's asbestos organic linings are essentially the product of 40 years of evolutionary changes.

Revolutionary changes, which advance the state of the art, are more difficult to come by. It is unrealistic to put a timetable on invention, but establishing the feasibility of a new concept can take 12 to 18 months. Reducing that concept to a product with some or most of the basic characteristics can take 12 to 24 months. Formulation development to obtain a balanced set of characteristics for commercial application, and validation of those properties requires 24 to 26 months. As before, 12 to 18 months for customer application testing, and six months manufacturing lead-time are needed--that is a total of 5½ to 8½ years. The semimetallic discussed previously is good example.

Semimetallic development began in 1962. The first low volume, special-purpose applications occurred in 1969. General acceptance came in the mid 1970's with the second generation of semimetallic formulations. Today, semimetallic disc pads are utilized on the front brakes of approximately 85 percent of the new vehicles built in the U.S., and projections approach 100 percent utilization in 1990. It has taken continued development and improvement of semimetallic properties to achieve this level of use.

The elimination of asbestos from automotive friction materials must be considered a revolutionary change. There are strong indications that the asbestos-free materials can achieve general acceptance more rapidly than semimetallics did. However, basic development needs demand a minimum time from the start of a program to initial production application. Assuming a 1975 start date, historical data would suggest that initial applications could have been expected in the 1982/83 time frame. We did obtain our first release in April, 1983 on a duo-servo brake for the 1984 model year for the first generation of asbestos-free materials!

Continued engineering effort (evolutionary changes) were and will be required to develop both the second and succeeding generations of materials with improved properties, and multiplicity of types of formulations necessary for different applications. Our first non-servo asbestos-free linings were released in late 1984 for a 1986 model year passenger car.

As indicated earlier, semimetallic disc brake linings containing no asbestos in either the friction material or the backing layer are in use today. It should be pointed out that the semimetallic friction materials have some characteristics which may preclude their utilization in certain vehicle applications. An orderly transition to significantly increased utilization of semimetallic disc pads on new U.S. vehicles is in process, and will probably approach 100 percent utilization no later than 1990.

Development continues on asbestos-free organic disc-brake linings for both OEM and AFM applications, but the timing for production implementation cannot be accurately predicted.

Some asbestos-free blocks are available for heavy truck applications. While it is too early to tell whether these formulations will achieve great commercial success, the first significant production release was in 1984. We anticipate increased utilization as new models are introduced.

Although this presentation has primarily addressed original equipment considerations, the use of asbestos-free materials in the automotive aftermarket will create additional challenges. As new vehicles are produced with asbestos-free friction materials, they should be serviced with asbestos-free products. However, since these new asbestos-free materials may very well not have property and performance characteristics of current asbestos friction materials, it may not be possible to substitute them directly on older vehicles due to design differences in the hydraulic systems, percent weight distribution variations between the front and rear axles and the major restriction of a wide variety of older vehicles equipped only with drum/drum brake systems (as opposed to the newer front disc/rear drum installations) with limited test equipment and funds available to the industry. Hence, significant time and effort will be needed to evaluate the effect of other variations of asbestos-free friction materials in aftermarket applications to ensure safe and efficient braking and adequate lining life prior to the release of these asbestos-free materials for use in the aftermarket.

SUMMARY

Automotive friction materials are complex composites that have developed around the properties of asbestos. There is no simple substitution for asbestos fibers in automotive friction materials. Extensive engineering programs were and continue to be required to develop new asbestos-free formulations, new process techniques, and to conduct testing to ensure the adequacy and safety of the new friction materials.

Semimetallic disc pads, originally developed for heavy duty passenger car applications, meet the criteria of being asbestos-free and are in high volume use today. The trend toward significantly increased usage is well established. The first generation of asbestos-free drum linings for passenger cars and light trucks is in production at Bendix.

Some asbestos-free friction materials are currently available on the market for heavy truck applications, both semimetallic disc pads and asbestos-free blocks.

Engineering programs continue on improved versions of the materials mentioned above, and also on other types of materials which might prove successful. Bendix is committed to developing asbestos-free alternatives, and an orderly transition to such materials is now taking place. Significant engineering effort and time is needed to complete this transition.

As stated in the Bendix Corporation's 1979 annual report, "...Bendix early in the 1980's will offer its automotive customers brakes made with long-wearing high-performance friction materials that are asbestos-free." We met that commitment!

REFERENCES

1. F. W. Aldrich and M. G. Jacko, "Organic Friction Materials," Bendix Technical Journal, Vol. 2 (No. 1), 42-54, (Spring 1969).

2. M. G. Jacko and R. T. Ducharme, "Brake and Clutch Emissions Generated During Vehicle Operation," Society of Automotive Engineers Transactions, 82, 1813 (1973); also SAE Paper 730548.

3. A. E. Anderson, R. L. Gealer, R. C. McCune, and J. W. Sprys, "Asbestos Emissions from Brake Dynamometer Tests," Society of Automotive Engineers Transactions, 82, 1832 (1973); also SAE Paper 730549.

4. J. C. Murchio, W. C. Cooper, and A. DeLeon, "Asbestos Fibers in Ambient Air of California," Final Report, University of California Contract ARB 4-054-1, March 1973 (also EHS Report #73-2).

5. B. W. Klein, "Semimetallic Outer Pads for Disc Brakes," Bendix Technical Journal, Vol. 2 (No. 3), 109-113, (Autumn 1969).

6. S. K. Rhee and J. P. Kwolek, U.S. Patent 3,835,118, issued Sept. 19, 1974.

7. M. G. Jacko and S. K. Rhee, "Brake Linings and Clutch Facings," Kirk-Othmer Encyclopedia of Chemical Technology, Vol. 4, 202-212, (1978).

8. J. P. Kwolek, "Friction Materials for Small Car Solid Rotor Applications," SAE Paper 750874, October 1975.

9. M. G. Jacko, "Physical and Chemical Changes of Organic Disc Pads on Service," Wear 46, 163-175, (1978).

10. B. W. Klein and M. G. Jacko, U. S. Patent 4,175,070 issued November 20, 1979.

TABLE 2

BRAKE FADE TEMPERATURES*(°F)

(SUBCOMPACT FRONT WHEEL DRIVE VEHICLE)

	1ST SAE FADE** (10 STOPS)		2ND SAE FADE** (15 STOPS)	
	DISC FRONT	DRUM REAR	DISC FRONT	DRUM REAR
COMBINATION 1	780	300	870	360
COMBINATION 2	985	235	1030	240
COMBINATION 3	760	200	855	235

* TEMPERATURES MEASURED BEFORE THE LAST STOP. ACTUAL TEMPERATURES FOR DISC BRAKES ARE 80-180°F HIGHER, AS MEASURED BELOW THE RUBBING SURFACE. SURFACE TEMPERATURES ARE IN EXCESS OF 1600°F (870°C).

** SAE J843c

TABLE 1

CHARACTERISTICS OF FRICTION MATERIALS

FRICTION

- o LEVEL (COEFFICIENT)
- o STABILITY - SPEED
  - PRESSURE
  - TEMPERATURE
  - CONDITIONING
  - AGE
  - VARIATIONS IN WEIGHT OF VEHICLE LOAD ("DRIVER ONLY" VERSUS "DRIVER PLUS MAX LOAD")
- o FADE/RECOVERY

WEAR

- o FRICTION MATERIAL
- o DRUM OR DISC

NOISE

ROUGHNESS

MOISTURE SENSITIVITY

MANUFACTURABILITY

- o PROCESSIBILITY
- o UNIFORMITY

TABLE 3

IMPROVEMENTS OFFERED BY SEMIMETALLIC DISC PADS

- IMPROVED ENERGY ABSORPTION
- FADE RESISTANCE
  - TEMPERATURE INSENSITIVITY
  - IN-STOP FADE
  - SPEED SPREAD
- FRICTION STABILITY (FMVSS 105-75)
- HIGHER TEMPERATURE CAPABILITIES (LIFE)
- ROTOR COMPATIBILITY
  - SCORING
  - HEAT CHECKING
- REDUCED NOISE
- SMALLER BRAKE SIZING

TABLE 4
CHARACTERISTICS OF REINFORCING AGENTS

NAME	ASBESTOS (5R04)	FIBERGLAS 497	MINERAL FIBER	SUZORITE MICA	FIBERFRAX (CHOPPED)	WOLLASTONITE	FRANKLIN FIBER	SOLKA-FLOC	KEVLAR 29	STEEL FIBER
MANUFACTURER	JM, etc.	OWENS/ CORNING	U.S. PIPE AND FOUNDRY	MINED BY MICA SALES	CARBORUNDUM	MINED BY INTERPACE, NY	CERTAIN TEED	BROWN CO.	DUPONT	AMERICAN METAL FIBERS
COMPOSITION	$3MgO \cdot SiO_2 \cdot 2H_2O$	E GLASS	SiO_2 42	SiO_2 41	SiO_2 47	$CaSiO_3$	$CaSO_4$	CELLULOSE	AROMATIC	SAE 1010
(WEIGHT %)	SiO_2	SiO_2 54.5	Al_2O_3 8	Al_2O_3 16	Al_2O_3 51	$CaO \cdot SiO_2$				
	Mgo	Al_2O_3 14.5	CaO 35	MgO 21						C 0.1
		CaO 17	MgO 8	K_2O 10					100% ORG.	Mn 0.4
		MgO 8		FeO 8		SiO_2 51				S 0.1
						CaO 47				Fe 99.4
		Other 6	Other 7	Other 4	Other 2	Other 2				
COST (¢/LB)**	1.0	3.8	1.9	0.8	5.9	.9	0.8	1.2	30	2.6
SHARE	FIBER	FIBER	FIBER	PLATE		FIBER	FIBER	FIBROUS	FIBER	FIBER
LENGTH (mm)	250+	3175+	28	3175+	308	-	50+	76	6360+	800-2000
DIAMETER (mm)	0.023*	13	1-10		2	-	2	18		80-100
ASPECT RATIO	10,000+	240+	40-60		150	15	25+	4		10+
SPECIFIC GRAVITY	2.56	2.8	2.7	2.7	2.73	2.9	3.0	1.4	1.45	
TENSILE STRENGTH (PSI)	200-400 KPSI	450-550 KPSI	3-20 KPSI	33-37 KPSI	400 KPSI	-	300 KPSI		400 KPSI	
AVG:	360 KPSI	500 KPSI	70 KPSI							
THERMAL STABILITY:								~400		~1000
UPPER USE TEMP (°F)	1200	1300	1400		2300	1200	1800			
T_g (°F)	-	1350	1400		-	1200 (tr)	2100 (tr)			~2500
T_{fus} (°F)	-	2000	2300	2900	-	1540	2600			
T_d (°F)	1600									
HARDNESS (Moh)	3.0 - 4.0	6.5		2.5 - 3.0		4.5	3.5	1.0	1.0	~5.5
MISC. INFO.		SILANIZED	ALSO MINERAL WOOL			SILANIZED FORM AVAILABLE	SLIGHTLY SOLUBLE WATER 0.1gm	5-7% MOISTURE	KEVLAR 49 EVALUATED EARLIER	

* FIBRIL DIAMETER
** RELATIVE TO ASBESTOS

TABLE 5

DIRECT SUBSTITUTIONS AND THEIR FAILURES

FORMULATION	REINFORCEMENT	STRENGTH	PERFORMANCE
BASELINE	ASBESTOS	o STRONG NO DEFECTS	o STABLE FRICTION GOOD WEAR RESISTANCE
b,c,e	GLASS	o PAD SURFACE TEAROUT	o ERRATIC FRICTION, FADE, HIGH PAD WEAR, AND SCORED ROTOR
d	MICA	o PAD SURFACE AND EDGE TEAROUTS	o GOOD FRICTION, SL FADE, HIGH PAD, AND ROTOR WEAR
f	GLASS/MICA	o WEAK	o POOR FRICTION, FADE, AND INNER PAD WEAROUT
g	GLASS/FIBERFRAX/GRAPHITE	o STRONG	o ROUGHNESS, FADE, ACCEPTABLE PAD WEAR, AND SCORED ROTOR
h	GLASS/WOLLASTONITE	o PAD SURFACE TEAROUT	o IN-STOP FADE, ACCEPTABLE PAD WEAR, AND SCORED ROTOR

TABLE 6

TENSILE STRENGTH DATA

FORMULATION	REINFORCER	TENSILE STRENGTH (PSI) MIN	AVG	MAX
BASELINE	ASBESTOS	3100	4000	4600
A	GLASS FIBER	3400	4800	6350
B	MINERAL FIBER	600	1300	1850
C	WOLLASTONITE	850	1500	2350
D	SUZORITE MICA	850	1400	1750
E	GLASS*	2750	3500	3750
B'	SILANIZED MINERAL FIBER	2900	3150	3250

*REDUCED CONTENT

TABLE 7

SAMPLE DYNAMOMETER TEST RESULTS

FORMULATION	REINFORCER(S)	250F		450F		650F		250R+		ROTOR WEAR
		μ	W*	μ	W	μ	W	RF	RW	
BASELINE	ASBESTOS	0.32	0.002	0.28	0.004	0.30	0.022	1.00	2.62	0.0000
A	GLASS FIBER	0.32	0.005	0.23	0.010	0.16	>0.080	1.31	1.70	0.0003
F	WOL/GF	0.33	0.004	0.34	0.009	0.16	>0.040	1.16	1.68	0.0003
G	MICA/GF	0.49	0.004	0.19	0.010	0.22	>0.060	1.08	2.31	0.0001
H	MF/GF	0.32	0.004	0.17	0.012	0.16	>0.080	1.37	-	0.0001
J	FRAX/GF	0.36	0.009	0.45	0.013	0.50	>0.200	-	-	>0.0005
K	FF/GF	0.36	0.003	0.50	0.005	0.32	0.016	1.75	2.07	0.0001
L	SOFL/GF	0.35	0.002	0.18	0.003	0.18	>0.080	-	-	0.0000
M	PROPRIETARY	0.35	0.002	0.22	0.003	0.18	-	1.20	1.12	0.0001
S	PROPRIETARY	0.45	0.002	0.45	0.006	0.46	0.018	1.04	2.27	0.0001

* ALL WEAR FIGURES ARE IN INCHES

\+ RERUN USED TO PROVIDE RELATIVE FRICTION (RF) AND RELATIVE WEAR (RW) TRENDS AFTER HIGH TEMPERATURE OPERATION

TABLE 8

INERTIAL DYNAMOMETER TEST RESULTS

	BURN		300F		450F		600F		300F		ROTOR
	LP*	W**	LP	W	LP	W	LP	W	LP	W	W
BASELINE	380	0.004	660	0.003	700	0.009	490	0.028	470	0.007	.0000
S	400	0.003	400	0.003	300	0.008	280	0.018	-	-	.0007
W	400	0.003	400	0.003	350	0.007	300	0.015	-	-	.0004
AA	400	0.002	370	0.002	340	0.006	390	0.008	440	0.003	.0003
AD	420	0.003	650	0.003	600	0.012	450	0.037	330	0.006	.0002
AL	440	0.003	510	0.002	560	0.008	430	0.034	270	0.004	.0000

* ALL LINE PRESSURES ARE IN PSI

** ALL WEAR FIGURES ARE IN INCHES

TABLE 9

VEHICLE TEST RESULTS

(1977 FULL SIZE STATION WAGON LOADED TO 5540 LBS)

FRONTS*	CLASS A ORGANIC D7180 30 MPH (48 KMPH)	CLASS A ORGANIC D7180 60 MPH (97 KMPH)	NON-ASBESTOS ORGANICS DA 30 MPH (48 KMPH)	NON-ASBESTOS ORGANICS DA 60 MPH (97 KMPH)	NON-ASBESTOS ORGANICS DN 30 MPH (48 KMPH)	NON-ASBESTOS ORGANICS DN 60 MPH (97 KMPH)
PREBURNISH EFFECTIVENESS**						
FULL SYSTEM	500	500	440	460	440	400
POST-BURNISH EFFECTIVENESS**						
FULL SYSTEM	600	600	520	530	500	420
FRONTS ONLY	1180	970	1020	900	620	620
1ST SAE FADE (10 STOPS)** MAX	-	1100 MAX	-	1000 MAX	-	1000
(RECOVERY - 10)	(410)	-	(380)	-	(320)	-
2ND SAE FADE (15 STOPS)** MAX	-	800 MAX	-	800 MAX	-	880
(RECOVERY - 10)	(410)	-	(360)	-	(340)	-
POST-FADE EFFECTIVENESS**						
FULL SYSTEM	600	500	450	460	420	460
FRONTS ONLY	900	670	960	850	700	920
WEAR (MILS)						
BURNISH (F/R)	6/6		11/9		11/6	
FADES (F/R)	42/3		33/3		22/2	
TOTAL PADS (F/R)	48/9		44/12		33/8	
TOTAL ROTOR	0		1.0		1.5	
NOISE RATINGS						
FRONTS	10		8		6-8	
REARS	10		10		10	

* ALL TESTS USED SAME REARS (BX4641A/H3133)
** LINE PRESSURES NEEDED FOR 15 FPSPS DECELERATION PER SAE J843C

TABLE 10

LIFE TESTING ON VEHICLES

Rear Lining Combination*	Front Disc Pad Life (Miles)	Rear Drum Brake DSSA Type Primary Life (Miles)	Secondary Life (Miles)
Test Vehicle 1			
A	59,600	3,700	8,200
B	44,500	6,600	5,900
Test Vehicle 2			
A	31,400	7,900	14,500
C	33,200	20,700	26,800
D	27,600	28,300	20,400
Test Vehicle 3			
E	31,100	17,600	15,900
F	34,800	20,900	16,900
G	28,100	12,200	18,700
H	21,450	32,800	27,400

* Same type front disc pads for all tests.

			New Non-servo Type Forward	Reverse
Production Vehicle 1986 Model	New non-asbestos	30,000	34,000	63,000