FILE NAME: Brakes (BRK)

DATE: 0000

DOC#: BRK188

DOCUMENT DESCRIPTION: Published Report of Kourik, P.E. - Friction Products - How They Work and Why They Contain Asbestos

FRICTION PRODUCTS—HOW THEY WORK AND WHY THEY CONTAINED ASBESTOS

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1. BACKGROUND AND FOUNDATION FOR EXPERT OPINIONS

1.1 EXPERIENCE WITH WAGNER ELECTRIC BRAKES

My Curriculum Vitae is Exhibit 1 to this report and it identifies most of the experiences that I draw upon for the opinions expressed herein. My experience in the design, testing and production of automotive brake assemblies spans 40 years of active employment. In my capacity as, first, an engineer and then as the chief brake engineer for Wagner Electric, I was familiar with the various types of brake systems in use for cars, trucks and buses during the length of my career. They basically break down to hydraulic systems or air-brake systems or a composite of air and hydraulic. My work included familiarity with the actual brake lining or friction material that those systems used. I designed brakes, made drawings for them, supervised the manufacturing specifications and I witnessed the assembly and disassembly of brakes.

I am a professional engineer (PE) registered in the state of Missouri. This required me to take certain examinations to qualify for the title of PE. In my PE capacity, I had occasion to conduct or supervise actual road tests or test-track examinations of brakes and brake systems with regard to temperatures and performance. The friction products I have tested and specified were used on brake assemblies for passenger cars, light trucks, medium trucks, busses, coaches, heavy trucks, tractors, trailers, semi-trailers and various industrial equipment. My experience included brake assemblies and friction products used on overhead cranes, specialized heavy-duty industrial equipment and various types of construction equipment. I have also done my own personal brake replacement with asbestos-containing brakes.

Another significant part of my employment activity included the evaluation, testing and specifying of friction products used for replacement purposes in the industry generally referred to as the "aftermarket." These replacement friction products included lining sets, sets of block lining, sets of lined brake shoes as well as pad sets for disc brakes.

1.2 INDUSTRY-WIDE EXPERIENCE WITH BRAKES

When I was Wagner's Chief Brake Engineer, my organization was a supplier of new brake assemblies and replacement friction and a purchaser of friction products. This required continuous contact with many manufacturers of friction compounds. This variety of sources and compounds involved a wide range of manufacturing processes to make the product in its several configurations and various means of attachment, such as:

- Flexible strips (riveted or bonded)
- Rigid strips (riveted or bonded)

- Segments (riveted or bonded)
- Blocks (riveted or bolted)
- Disc pads (riveted, bonded or integrally molded)

I have been involved with setting brake industry standards through the Society of Automotive Engineering activities (SAE). SAE is an international organization that is charged with developing automotive standards, recommended practices and other documents that relate to standardizing items of manufacture in both off-road equipment, motor vehicle equipment and aircraft. During my career, I have participated on the committees or activities of the SAE. I listed the items in my Curriculum Vitae according to the top rank and down to lower elevation of service. For one year I was the Chairman of the Motor Vehicle Council of the SAE, which oversaw all of the specifications, standards, recommended practices and the like that related to automotive equipment. These standards dealt with dimensional and performance standards in the testing of brake linings or brake components. We wrote standards for test procedures that were incorporated into the federal motor vehicle safety standards.

I have published articles relating to the brake manufacturing industry. In 1951, I published a paper related to the design of the industrial brake system, overhead crane brake system, followed by some work on measuring the stopping distance to meet safety standards for rubber mill operation. In October 1964, I published an SAE paper that dealt with theoretical comparison of the two major air-brake types, cam brakes and wedge brakes, that are still used on vehicles today.

I have also had occasion to testify before governmental agencies regarding brakes and highway safety in connection with brakes. For example, I participated in house committee hearings related to brake regulations. I participated in Senate hearings related to antilock or skid-control regulations for commercial vehicles and I have participated in dozens of public meetings related to the regulation of brake systems, brake components and vehicle performance since the Department of Transportation was organized in 1965.

2. EXPERT OPINIONS

2.1 HOW DO BRAKES WORK

The purpose of the brake system is to stop and control the vehicle. The brake performs that function by taking the kinetic energy of the vehicle that is moving along at

its speed and converting that energy into heat at the friction interface with the drum or disc. Brakes can be viewed, quite simply, as energy transformers. During a brake application, the friction material makes contact with the rotating drum or disc (rotor), creating a friction force resisting the relative motion between the two bodies. Using the lining, the brake then forces the heat into the drum where it can be dissipated in the air. As an energy conversion device, the brake miraculously uses 20 pounds of driver pedal force to stop a 3,500-pound vehicle at a comfortable change in speed in city traffic.

2.2 HOW AUTOMOBILE BRAKES BEGAN AND EVOLVED

As the first motor vehicles increased in speed and weight, it became apparent that two-wheel external band brakes on the rear axle did not have the ability to dissipate the heat being generated. The next step was to add external band brakes to the steered wheel on the front axle. A third step was to convert from external mechanical band brakes to internal mechanically applied shoe brakes enclosed within a brake drum.

Early in the 1920's internally actuated hydraulic drum brake became the newest entry into this ongoing product evolution.

Since that time, hydraulic actuated brakes have continued to evolve in sophistication and safety. Long-term brake and brake system development, however, has never been revolutionary. It has evolved. Brake development has also been a privately funded activity. The evolutionary process is a careful, tedious and unrelenting challenge to provide reliable step-by-step refinement from any level of safe performance and durability to another safe level of performance and durability.

It is not practical to define the stages of this engineering evolution in specific blocks of time. The majority of these improvements took place in overlapping steps because of the many industry entities involved. The host of vehicle manufacturers each relied on a multiple base of suppliers and their sources of materials and expertise.

2.3 BRAKES HAVE CERTAIN DESIGN STANDARDS AND REQUIREMENTS

The friction material inside of a brake must operate in a rather hostile environment. Lining temperatures in excess of 400°C (750°F) are not unusual, and temperatures at the contact interface can exceed 850°C (1560°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.

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. 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.

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 (the most popular U.S. design at one time) required 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 many sub-compact vehicles) requires a friction material, which incorporates the best characteristics of the primary and the secondary into 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 drum brakes, and the front disc brakes run hotter than the rear drum brakes on the same vehicle. The friction material for disc brakes must be specifically designed for these higher temperatures, and must possess a higher 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 applications. Numerous parameters such as vehicle weight, front-to-rear brake balance, actuating system design, and duty cycle affect the capability of a particular friction 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 (DOT) (vehicle performance), the Occupational Safety and Health Administration (OSHA) (manufacturing work practices), and the Environmental Protection Agency (EPA) (manufacturing practices and raw materials).

2.4 WHY THE BRAKE INDUSTRY USED ASBESTOS

In the 1890's the first brake friction was woven material composed of cotton and horsehair. It had to be impregnated with bitumin to provide uniform and stable friction during brake applications. By the turn of the century, the increasing speeds of the "new" mode of transportation and the increasing weight was creating brake friction temperatures of 300 degrees Fahrenheit. This temperature charred the cotton and destroyed it.

Chrysotile asbestos fibers were already being converted into thread and became the obvious material of choice for a woven application that needed heat resistance above 300 degrees. It continued to be produced in various widths and varying thickness until the dry mix and wet mix compounds were developed for heat-pressure curing to provide a more uniform friction produce.

Until the early 1980's, only asbestos met the rigorous design specifications for the automotive brake industry. As previously stated, automotive friction materials must operate reliably in an extremely hostile environment. Friction materials must maintain balanced characteristics throughout 20,000 to 40,000 miles of vehicle operation and must remain stable over a wide range of operating speeds, brake application pressures and temperatures, regardless of the conditioning or age of the material.

Processed chrysotile asbestos fiber was chosen for use in automotive friction materials because its unique combination of characteristics meets these needs. The material possesses a high coefficient of friction, provides a high, stable friction level under a wide range of vehicle and environmental conditions. It has excellent thermal stability, has good surface absorptivity for both resin binder systems and friction modifiers, possesses flexibility and durability, has high strength and reinforcing characteristics, and has very low noise generating characteristics. The high level of resistance to thermal conductivity forced the heat into the drum where it could be dissipated. It was essential to prevent the heat of braking from destroying rubber seals in the wheel cylinder and to prevent boiling of the brake fluid.

My professional work in the evaluation of brake friction, included measurement of lining temperatures by thermocouples installed in the brake lining on vehicles and on dynamometer installations. Additional experience in the effects of temperature on brake friction was obtained from data developed during the testing of friction products on a Chase machine. Such tests were conducted in accordance with the SAE Brake Lining Quality Control Test Procedure—SAE J661. Collectively, these tests made it apparent that the dust generated during use of asbestos-containing brakes for control of the vehicle is not one single type of wear product. Examination of the wear products shows it to be a combination of many constituents, including the metal worn off of the drum/lining interface and the resins that are cooked out of the lining under the high heat of braking.

2.5 WHY THE INDUSTRY HAD NO NEED TO SEARCH FOR ALTERNATIVES TO CHRYSOTILE ASBESTOS FRICTION FOR SEVERRAL YEARS AFTER WORLD WAR II

After World War II, the industry began applying the technology that had been created during the war. Higher speed endurance and performance on improved roads, e.g., turnpikes or toll roads, and the Interstate Highway System began to increase the heat dissipation demand on the brake systems.

The industry responded by successfully developing improved resins for this higher operating temperature demand. The resin improvements kept pace with the performance demands and the increased vehicle weights that were occurring. This ability to meet the established brake performance requirements enabled the brake engineers to retain the good insulating feature of chrysotile asbestos for drum brakes.

However, there were some special-duty applications for passenger cars that challenged the friction industry to attempt the use of other manufacturing techniques and other material recipes. I am aware of the shortcomings of the ceramic friction offerings. I am also aware of the several problems that sintered metallic friction submissions demonstrated when subjected to the broad spectrum of test procedures needed to assure safe performance to the general public. The brake test facilities at Wagner Electric included inertia dynamometers and a fleet of test vehicles. I have personally operated vehicles equipped with sintered metallic friction on drum brakes. I have personally encountered some of the dangerous problems reported by others.

I have reviewed the complete 1959 Society of Automotive Engineers (SAE) paper entitled "What's New in Brake Lining." My evaluation included data provided in the 13 illustrations that the author considered important to his topic. The 1959 sintered metallic friction, despite surviving one severe demonstration on the Pike's Peak Highway, **failed to meet all of the following basic criteria for safe vehicle operation that are a part of the text of the paper:**

1. Low wear rate.
2. Minimum friction variation.
3. Resistance to high temperature and fading.
4. Compatibility of lining surface with drum surface.
5. **Standard brakes** or **power brakes** must engage smoothly with low pedal effort and operate effectively.
6. Lining and drum engagement sounds must stay below audible level.
7. Low acquisition cost for friction material.
8. Low warranty cost and low replacement cost.

There is a 1975 SAE paper entitled "Development of Police Car Brake Standards" that details the frustrating problems associated with the ongoing attempts to develop a satisfactory sintered metallic friction product to replace chrysotile asbestos friction. The report identifies many faults that were never corrected – hence the sintered metallic friction programs drifted into obsolescence.

2.6 WHY THE INDUSTRY INITIALLY SEARCHED FOR ALTERNATIVES TO ASBESTOS

Use of chrysotile fibers in brake friction was phased out because of new brake performance requirements that made asbestos obsolete. New friction materials were developed using man-made-mineral-fibers (MMMF) to meet the engineering demands that resulted from two Federal actions: (1) Federal Motor Vehicle Safety Standards promulgated by the DOT's National Highway Traffic Safety Administration (NHTSA); and (2) EPA regulations to implement and enforce the Corporate Average Fuel Economy (CAFE) requirements for new motor vehicles.

2.6.1 NHTSA Safety Standards

In January of 1965, the Federal General Services Administration (GSA) required dual (split) operation on all vehicles they purchased. The industry extended that design feature on all passenger cars by model year 1967. Between 1965 and 1976, Federal Motor Vehicle Safety Standard 571.105 (FMVSS 571.105) evolved into a very complex required performance document. Some of the revisions introduced included, but were not limited to:

- Stopping distance requirements for the full brake system
- Stopping distance requirements for both of the partial systems in the event of a single hydraulic failure
- Grade holding capability on a specific grade in both directions, uphill and downhill

All vehicles had to be certified to comply with FMVSS 571.105. To meet all of those requirements, the vehicle manufacturers had to radically change the braking distribution to 90% front axle and 10% rear axle. A new friction material had to be developed or found because asbestos did not have the ability to dissipate 90% of the heat of braking without self-destructing.

2.6.2 CAFE Standards

The introduction of friction materials that did not include chrysotile asbestos started after the CAFE regulations were issued, circa 1975. Weight reduction was one key change needed to comply with the CAFÉ requirements. Some brake components were reduced in durability. Increased friction operating temperatures resulted. The introduction of a new family of fibers followed. They were referred to as the MMMF and could function at temperatures that destroyed chrysotile fibers. Some of the fibrous materials were metallic in composition.

2.7 INVESTIGATION INTO ASBESTOS SUBSTITUTES IN FRICTION PRODUCTS

In 1987, due to reported health problems associated with the use of asbestos, the EPA's Office of Toxic Substances proposed a regulation to ban the use of asbestos over a 10-year phase-down period. Since asbestos was a critical constituent in some vehicle friction products, the EPA was 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, the EPA contracted with an entity to make an evaluation. The EPA chose the American Society of Mechanical Engineers (ASME). A panel of individuals knowledgeable in various aspects of vehicle brakes was selected. The panel addressed technological issues associated with the removal of asbestos from friction materials, specifically:

(1) Identification of substitute brakes and systems,

(2) Compatibility of the ban with 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.

The bottom line conclusion from this analysis was that attempting to immediately substitute non-asbestos products created greater consumer safety risks than the continued use of asbestos. There were several bases for that conclusion. 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-out (rear lockup). 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.

The majority of the automobiles sold in the United States at the time were fitted with front disc brakes and rear drum brakes. Because of differences between qualification standards, cost, driver preference, and driving conditions in the United States and Europe, American and Japanese automakers were utilizing rear drum brakes. Suitable non-asbestos materials were not available for all of these applications, and industry-wide substitution of non-asbestos materials in all existing brake designs would require considerable development.

The substitution of unqualified non-asbestos friction materials in the after market, however, posed the largest potential safety issue. 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 had an adverse effect on vehicle brake balance and controllability. 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 have resulted in a loss of vehicle controllability during braking. Moreover, in 1985, there were no required performance tests for aftermarket brake friction materials and most of the aftermarket, non-asbestos material suppliers lacked the facilities to evaluate their materials under dynamometer and vehicle braking test conditions. It was determined that mandating aftermarket non-asbestos friction materials for vehicles that were originally equipped with asbestos-based linings could lead to a potentially serious consumer safety risk.

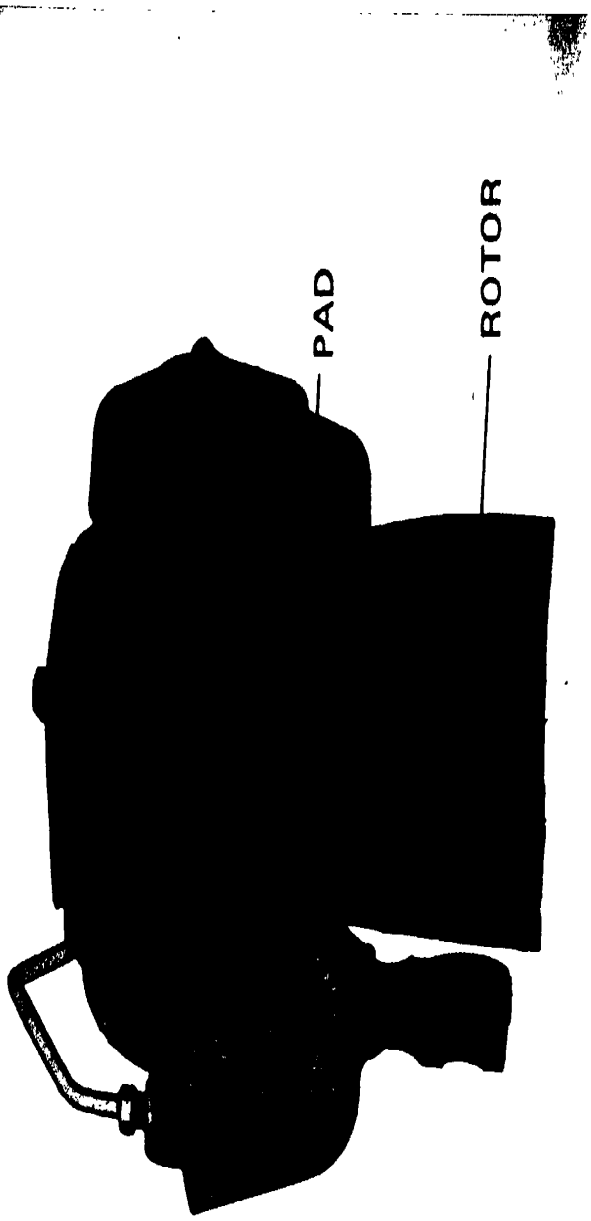
In sum, while there were alternatives to asbestos fibers being examined, the composites were structurally inadequate, producing tear-out and poor wear resistance, in addition to roughness. All formulations were considered failures. This led to the conclusion that simple direct substitution of alternative fiber systems was not practical. In fact, the non-asbestos substitute drum brake materials originally contemplated lacked the insulating capability of asbestos and could not be safely used for replacement friction.

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Detailed Service to Industry Groups:

Chairman: Motor Vehicle Council of the SAE – 1978
Wheel Slip Brake Control Systems Subcommittee of the SAE Brake Committee - 1973
Publication Advisory Committee of the SAE – 1972
Brake Rating Subcommittee of the SAE Brake Committee – 1964

Vice Chairman: Motor Vehicle Council of the SAE – 1977
SAE Brake Committee – 1974

Member: Parking Brake Subcommittee of the SAE Brake Committee
Nomenclature Subcommittee of the SAE Brake Committee
Dynamometer Subcommittee of the SAE Brake Committee
Road Test Procedure Subcommittee of the SAE Brake Committee and Vice Chairman of its Passenger Car Task Force

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Member: Braking Equipment Subcommittee, Western Highway Institute
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Student Engineer, June 1948
Laboratory Project Engineer, October 1948
Junior Mechanical Engineer, November 1949
Project Engineer, Industrial Products, October 1950
Supervisor, Industrial Products Section, April 1956
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Chief Engineer, Brake Products, April 1966
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