A. E. Anderson

PLAINTIFF'S EXHIBIT

FD-717

R-120 R

FRICTION MATERIALS AND SYSTEMS

1. New Materials

Laboratory testing of both wet and dry-mix disc brake formulations indicated that dry-mix formulations would be the most suitable for vehicle usage. Based on this result, dry-mix formulations were selected for dynamometer testing. A formulation containing 3% lithium fluoride showed excellent performance for high energy stops on the dynamometer test; however, recently processed disc brake pads of the same formulation showed high wear of the cast iron rotors and about twice the lining wear of the earlier samples.

It was subsequently discovered that the more recent lining samples were made from a newer supply of Johns-Manville 5K30 grade asbestos. This asbestos was found to contain about 6% magnetite in large pencils, enough in quantity and form to account for the observed high case iron wear rates. Contact with the asbestos supplier revealed that most brake lining vendors are now using the more highly processed 5K04 grade asbestos in their disc brake formulations because 5K30 asbestos which is low in magnetite content is no longer available. The added processing to produce the 5K04 grade breaks apart the asbestos crudes and permits removal of the large magnetite pencils.

Additional samples of our experimental linings were made using new 5K04 grade asbestos. This substitution eliminated the cast iron wear problem but dynamometer tests showed unsatisfactory fade recovery characteristics and lining wear rates above those expected from the earlier tests of this formulation with the old 5K30 grade asbestos. It is believed that the less crudy (fine fiber) 5K04 grade asbestos does not provide enough lining permeability to permit rapid recovery from fade testing and it does not provide enough coulomb damping to

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suppress brake squeal. Tests are in progress to determine the precise influence of the asbestos grade on the lining performance. Recent laboratory testing indicates that a blending of two different grades of asbestos and a slight modification of previous formulations may overcome the limitations of using only 5K04 asbestos.

Besides looking into new asbestos-resin materials which may satisfy more stringent braking requirements, we have been looking into the use of glass fiber-resin and filled metallic materials. An additional impetus for looking at the non-asbestos systems resulted from the recent governmental concern about airborne asbestos in brake wear debris.

The simple substitution of glass fibers for asbestos in disc brake formulations resulted in high wear and unsatisfactory friction; however, one new resin-glass fiber material survived the 65 and 90 mph dynamometer fade tests without structural failure. Additional formulations are being tested in this cooperative program with Owens-Corning Fiberglas.

Studies of sintered ferrous brake lining formulations, indicate that the shear strength of the material should be increased. Attempts to increase the shear strength by heat treatment and coining have met only with limited success. A joint study has been undertaken with personnel in the Process Research Department to increase the strength of these materials without altering their functional properties. An alternative program is under way in which the base powders are bonded with an organic resin.

Our new materials program is currently directed toward the more stringent brake requirements proposed by the government for 1974 vehicles.

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2. Air Pollution from Brake Lining Asbestos

The samples of airborne wear debris from the dynamometer tests of a Pinto disc brake continues being examined for asbestos by Technical Services Department using a new sample preparation technique. The procedure used to prepare the membrane filters for electron microscope examination is one developed in the laboratory of Dr. I. J. Selikoff, et al, at the Mt. Sinai School of Medicine in New York. In this procedure, the filter sample is oxidized in a low temperature, activated oxygen asher, dispersed in a dilute polymer solution on a glass slide by mechanical mashing, mounted in a film of the polymer on copper EM grids, and carbon shadowed. By examining the samples at more than 37,000 magnification, the number and size of the asbestos fibers are determined; this information is used to determine total mass of asbestos present. The method has the advantage of eliminating the obscuring effect of other wear debris present. It has the disadvantage that the original asbestos fiber bundle size distribution is destroyed and only total mass of asbestos may be determined, since fiber bundles are broken down into individual fibrils during sample preparation.

The examination of the samples is not yet completed and appropriate quantitative reference samples have not yet been prepared and counted - thus, obtaining an estimate of actual asbestos content requires, at this time, a reliance on Mt. Sinai laboratory experience to estimate asbestos losses from the samples during sample preparation. However, a preliminary estimate based on the incomplete data available to date indicates that asbestos fiber probably comprises less than 0.02% of the airborne wear dust, or less than 0.01% of the lining worn away.

3. Support to Divisions

A. Material Evaluation

Dynamometer tests were performed at the request of Brake Engineering Department to characterize 15 candidate disc brake lining materials and 4 different

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disc brake rotors. New dynamometer test procedures were developed to efficiently perform these tests. The candidate linings were burnished, then applied 100 times at each of a sequence of rotor temperatures. The friction, wear, squeal, roughness and groan properties of the linings were recorded for each test condition and the overall cast iron wear of the rotor was measured. Rotors with two different rubbing surface wall thicknesses and three different fin configurations were tested to determine cooling rate and effect upon lining wear rate for a prescribed stopping sequence.

At the request of the Advanced Chassis Department, the friction and wear behavior of a new prototype disc brake pad formulation (Bendix D-7131X) has been examined on the FAST machine. The material is essentially an iron wire-graphite composite held together with about 10% of a resin binder. The material exhibits fairly good friction and wear behavior; however, there is a slight increase in the coefficient of friction with temperature which could result in brake temperature imbalance. The material showed a tendency toward brake squeal at rotor temperatures above 500°F. The friction level is low at ambient temperatures with high humidity, so the parking brakes may develop inadequate holding capability and high pedal efforts on the first few brake applications may be experienced.

B. Disc Brake Roughness

Car Engineering requested assistance in solving a disc brake roughness condition exhibited by the initial production of 1972 Thunderbirds. Of the two lining suppliers, Delco 5490 provided definitely greater roughness although some roughness was found with the Bendix 7133 linings. Rotors and linings from Wixom tests were evaluated on our brake dynamometer. Delco linings produced about 60% greater torque fluctuations than Bendix linings. This roughness became significant above 500°F rotor temperature and with repeated use produced some rotor coating.

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Preliminary tests indicated the coating to be zinc oxide. Earlier laboratory bench and dynamometer tests have shown zinc to produce torque fluctuations above 510°F when zinc smears onto the cast iron, then oxidizes to provide a relatively durable and high friction local coating. The Bendix lining appears to have about half the zinc content of the Delco lining and also contains enough abrasive to remove any zinc oxide coatings. Thus it would be expected that the Delco lining should be more prone toward producing brake roughness. The problems sudden appearance after much prior vehicle testing probably was due to the accelerated form of the latest vehicle testing, the brakes being used repeatedly producing high temperatures before the linings seated fully. Our tests showed this exaggerates the roughness. Also the new corporate L-1 disc brake caliper assembly is much more rigid so more stops are required to achieve full seating and uniform lining pressure. Car Engineering was informed of our findings and has specified that the Bendix material be used until more vehicle evaluations are completed with seated linings.

Further reductions of brake roughness were required on the 1972 Thunderbird. Dynamometer tests of early production Kelsey-Hayes rotors showed permanent runout changes after a few brake applications. This was found to have been caused by high surface residual stresses (about 10,000 psi) from the final grinding operation. However, the runout itself did not cause the torque variations. The brake roughness resulting from the rotor appears to result from both the rotor thickness variation and its surface finish. It was found that a lathe turned rotor provides lower brake roughness and lower initial brake effectiveness, however, the latter corrects itself with use. Production rotors now are using a lathe turned finishing operation with low thickness variation limits (.0002" maximum rather than the previous .0005").

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C. Low Mileage Brake Pull Warranties

At the request of Brake Engineering Department, several brake linings and drums were examined to determine the cause of severe brake pulls which have been occurring at low mileage with some 1971 Comets and Mavericks. It was determined that an unaccountable amount of silicon dioxide (presumably sand) was present in the abnormal appearing (grey-black) wear dust on the right front linings of two of the vehicles - actual particles of sand were isolated from the drum of one of the cars. High iron content was found in the wear dust on the right front linings of three such vehicles. It is concluded that sand somehow found its way into the right front drum of these vehicles. The abrasive action of the sand caused a rapid wearing away of the drum iron, resulting in the formation of the observed grey-black dust. Presumably, this dust modified the friction to result in the brake pull.

D. Dry Clutch Facing Materials

Seizure of manual transmission clutches due to adhesion of clutch facings to the clutch plates has been experienced recently on a number of 1972 vehicles. The facing material involved is used on most Ford manual transmission cars. The clutch facing is an asbestos yarn-organic composite manufactured by Thermoid Corporation. The fibrous portion of the yarn is specified to contain about 65% asbestos, 25% rayon, 8.5% cotton, and 1.5% unspecified. At the request of Powertrain Installation Department, an investigation was made of the cause of this problem.

A contaminant was found on the surface of failed clutch facings. With the assistance of Technical Services Department, the contaminant was identified by infrared analysis as Dacron. The source of the Dacron was traced to the yarn used in the clutch facing. Thermogravimetric analysis of the yarn from the Thermoid

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plant indicated that about 5% of the fibrous portion was Dacron. It is suspected that a Dacron-cotton blend was substituted for the cotton normally used in this yarn. A FAST friction test was performed on failed clutch facing material using the test procedure normally used for brake lining quality control. The material suffered a large decrease in coefficient of friction at high temperature and a melt phase appeared at the edges of the test specimen. This was not observed in a similar test of clutch facing material from older batches of the same formulation. Thus it appears that the high interface temperature causes the Dacron to melt and spread across the surface. Upon cooling, the Dacron solidifies and can, under the proper conditions, bond the clutch facing to the clutch plate.

These results have been communicated to Powertrain Installation Department personnel. A sample of facing material from a subsequently prepared certified production batch was subjected to both chemical and FAST testing and was found to be equivalent to the older acceptable production material. In order to achieve better control of clutch facing material, Powertrain Installation Department has decided to set up quality control tests for dry clutch material similar to the brake lining quality assurance tests and decided that the development of suitable chemical tests will be carried out by one of our vendors (Borg-Warner). Borg-Warner is capable of carrying out these tests since we have previously worked with them in establishing and evaluating the PGC test for their brake lining material. At a recent meeting, Borg-Warner personnel presented data which showed that the PGC test can readily detect tramp materials in a clutch facing and can distinguish between cured and uncured clutch facings. Additional testing is being done by Borg-Warner in order to optimize the PGC operating variables for routine testing of dry clutch material.

The development of a new quality assurance test for frictional properties

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of dry clutch materials has been completed in our laboratory. It consists essentially of the standard brake lining test procedure but requires the use of a 1/2 x 1 inch test sample. Tests have shown that the new procedure can readily distinguish between satisfactory facings and facings containing tramp materials. The new procedure requires half the test time of the previously used friction test. Further generation of test data using the new procedure will be carried out by vendors.

E. Overseas Consulting

Assistance on brake lining processing technology, brake squeal suppression, and friction material quality control testing was given to engineers from Ford of England and Brazil.

F. Wet Clutch Friction Materials

Our research into wet friction materials, particularly the impregnated paper types as used in automatic transmission clutches and bands, has led to a model of clutch engagement which appears promising as a basis for quality control testing procedures and for friction material classification and development. This model involves three phases: 1) a squeeze film phase where oil flows over and through the porous friction material with no physical contact and where torque is generated exclusively through viscous shear; 2) a squash film phase where periodic contact of surface asperities produces some adhesive friction and releases oil from within the friction material to maintain viscous shear torque in the remaining thin oil film; 3) an adhesive friction phase where hydrodynamic and elasto-hydrodynamic effects are minimal and adhesive friction and wear predominate.

This model was used to troubleshoot the cause of friction variation with the use of Raybestos R-4893-1 clutch material. However the full evaluation of the model requires testing of friction materials with different values of permeability,

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compliance, and grooving. Also the effect of fiber changes such as cellulose-to-asbestos ratio and resin content/cure state should be studied with respect to effect on performance and chemical tests such as PGC.

Meetings were arranged through the Transmission and Chassis Division with engineerig and research personnel of Raybestos-Manhattan Corporation to establish a cooperative quality assurance specification program for the above critical variables. Raybestos has agreed to fabricate and supply the necessary clutch samples for this study and to perform a portion of the functional, physical and chemical testing.

Personnel: Anderson
Gealer, Weintraub (Chemical Engineering Department)

Letter Reports: M. Weintraub to J. Rich (Advanced Chassis Department), "FAST Testing of Bendix D 7131 X Semi-Metallic Friction Material", September 17, 1971.

R. L. Gealer to A. C. Pope (Brake Department), "Low Mileage Brake Pulls in Mavericks and Comets", September 29, 1971.

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