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JOHNS-MANVILLE RESEARCH AND ENGINEERING CENTER

Report No. 456-2506

Date December 19, 1966

Title: STUDY OF WEAR DUST FROM BRAKE LINING
Project 2550

SUMMARY

Brake lining wear dust was collected on a membrane filter mounted in a box which surrounded a brake run on an inertia dynamometer. In addition to this airborne fraction, the dust that settled to the floor of the box and that which remained within the brake was also collected. A total of 6-1/2 grams of dust was collected from 2150 stops during a total time of about 110 hours. The airborne portion was 2.7 grams. Most of the stops were made from 35 miles per hour at 10 ft/sec^2 deceleration, interspersed with stops from 50 mph (about 10 per cent).

The airborne dust was examined by light microscope, electron microscope, X-rays and other means. Asbestos fiber could be detected only by the electron microscope which gave a maximum of 1.4 per cent fiber by weight in the wear dust, although the lining contains 70 per cent chrysotile fiber.

This result is accounted for by the high surface temperature and severe abrasion during even the mild braking of these tests when the average temperature did not exceed 200°F. Calculations show that the surface temperature at the true area of contact (1 per cent of the apparent area) can reach 2000°C or more. It is concluded that most of the fiber is converted to an amorphous mineral by intense heat and fine grinding.

It is recommended that samples of the particulate matter in the atmosphere be collected at suitable distances from highways and the sample examined in the electron microscope for asbestos.

Contents: Summary, Introduction, Experimental Method, Results, Appendix I (calculations), Appendix II (Tables 1 and 2), Appendix III (Figures 1-4), and Appendix IV (References).

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Notebook 723, p 141.

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INTRODUCTION

Laboratory measurements were made to determine what type of particulate matter and gases are given off when a brake lining is worn during operation. The wear of the drum, usually cast iron, is necessarily included. Of special interest is the airborne dust expelled into the atmosphere from the moving brake. Previously, some observations had been made at Johns-Manville Research and Engineering Center on dust removed by hand from a laboratory brake,[1] but this is the first time, to our knowledge, that any observations have been made on the airborne fraction.

A search of the literature revealed no measurements on brake lining wear dust, although the rate of wear is sometimes given.[2,3] Recently, numerous articles[4,5] have appeared calling attention to the widespread use of asbestos in materials such as brake linings, floor tile, roofing, asbestos-cement products, etc. It is usually assumed that as these materials wear, much of the asbestos fiber is dispersed into the atmosphere, thereby contributing to air pollution and creating a health hazard. This is understandable, since the asbestos content of these materials is often high, 70 per cent in the brake linings used in these tests, and asbestos is commonly considered to be indestructible.[4] However, we know of no measurements made to test this assumption or to observe the amount of asbestos in urban atmospheres.

The present tests show that during the wear of brake linings very little asbestos fiber is dispersed into the atmosphere. Examination of the airborne dust by light microscope, electron microscope, and X-ray diffraction showed very little of the original chrysotile fiber. Nearly all the fiber appears to have been converted to an amorphous mineral by the severe abrasion and intense heat generated during brake operation. A point-count made on eight electron micrographs gave an upper limit of 1.4 per cent fiber in the airborne dust.

This is not surprising when one calculates the amount of energy dissipated while operating a passenger car brake. It is shown in the appendix that the heat generated raises the temperature of the surface of contact between brake lining and drum to about 2400°C. This high temperature occurs on the surface of the lining at the regions of actual contact with the drum, much less than the apparent area of contact.[6] These regions of contact are worn away during rubbing, so that the actual contact continually shifts to new regions. As a result, the wear particles of asbestos, resin, etc., are heated to a very high temperature for a very short time. Bowden and Tabor[6] observed many incandescent hot spots during the rubbing of metals on glass.

EXPERIMENTAL METHOD

A wooden box, approximately a 1-1/2-ft cube with a Lucite top, was constructed to fit around a 1961 Ford brake mounted on the C inertia machine in the Friction Materials Research Section pilot plant. Figure 1 is a photograph of the box mounted on the brake. The left rear side has a conical air inlet which carries a 1-ft-square Flanders fiber glass filter on the entrance, and tapers to a 4-in.-square opening at the outlet into the box. The right front side of the box carries two 8 x 10-in. filter holders for Gelman membrane filters. These holders are connected through flexible hoses to a 7-1/2-hp industrial vacuum cleaner (not shown). When the vacuum cleaner was run, about 150 cfm of dust-free air was drawn through the Flanders filter, over the brake and out through the membrane filters to collect the airborne wear dust.

The pressure drop across the membrane filters was about 15-cm Hg, measured with the mercury manometer shown standing on the box at the right, connected to a petcock on the exit side of the filters. The pressure drop across the Flanders filter was about 3/4-in. H_2O, measured with the water manometer shown on the left, connected to a tube through the side of the box.

Since the interior of the box was under a negative pressure of 3/4-in. H_2O, it was necessary to seal the joints and screw holes against entrance of dusty ambient air. This was done on the outside with DUXSEAL and on the inside with contact adhesive. The interior of the box and the parts of the brake and mounting within the box were painted white to show up any wear particles that settled out. The stationary hubs at each end of the brake drive-shaft were sealed to the ends of the box with 1/16-in. rubber sheet and rubber cement.

Figure 2 shows the auxiliary equipment used to measure the relative rate of evolution of wear dust during and after braking. At the left rear is seen a Sinclair-Phoenix aerosol photometer connected to the side of the box through a petcock. In the left foreground is a logarithmic amplifier connected to a Varian recorder on the right. Dusty air was drawn continuously from within the box and through the photometer at a rate of about 1 cfm by means of a 1/6-hp Gast pump. Since this rate of air removal is about 0.7 per cent of the total air flow, its reduction of the amount of dust collected on the membrane filters is negligible.

Figure 3 shows the type of record obtained during stops from 35 and 50 miles per hour at 10 to 12 ft/sec^2 deceleration at intervals of 2-1/2 minutes. Two of the stops were from 50 mph as indicated and the others from 35 mph. Usually a more or less regular pattern occurred in which the dust concentration fell to near zero between each of several stops and then remained at an intermediate level for a couple of stops.

The marks numbered 2, 3, and 4 are calibration points for the logarithmic amplifier. They are obtained by interposing neutral optical filters of known light transmission into the photometer light beam.

Figure 4 is the resultant calibration curve which shows the approximate logarithmic relationship between chart reading and dust concentration, the latter proportional to scattered light intensity. For example, a chart reading of 50 corresponds to a dust concentration about 100 times that for a reading of 5.

Dust was collected during 2150 stops, most of it on two membrane filters. The average temperature of the brake lining was kept at 175-200°F and was measured with a thermocouple set in a hole in the lining about 1/16 in. below the surface. The temperature was kept low, in order to simulate average braking, by increasing the time between stops to 3 to 4 minutes when overheating commenced. As indicated earlier, this temperature is far below the instantaneous surface temperature (see Appendix I).

RESULTS

Three fractions of wear dust were collected:

1. Airborne dust collected on membrane filters: 2.71 gm;
2. Dust removed from within brake after completion of test: 3.54 gm;
3. Dust collected from within box after completion of test: 0.214 gm.

These fractions all include some cast iron worn from the drum, about 1 gm total. The samples were analyzed for ignition loss, by light and electron microscope, X-ray spectrometer, emission spectrograph, infra-red spectrograph, and Coulter particle size analyzer. In addition, air samples were withdrawn from the box during braking and analyzed by the Gollob Analytical Service. Table 1 shows the results obtained.

Table 2 shows the composition of linings used. It is seen that the finished lining is about 70 per cent chrysotile fiber after the water and other volatiles are driven off.

The total weight of sample collected, 6.46 gm, is much less than the measured weight loss of the brake shoes and drum: primary, 4.0 ±1 gm; secondary, 7.0 ±1; and 2 ±1 gm. However, the accuracy of these weights is questionable because of the heaviness of the shoes and the drum. We feel certain that negligible loss of dust occurred during the tests, so that we cannot account for the discrepancy.

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APPENDIX I

Calculation of surface temperature of lining.

These tests simulate a front wheel brake of a 1961 Ford, designed to decelerate 30.5 per cent of the car mass, or 1270 pounds. At a velocity of 50 mph = 73.5 ft/sec the kinetic energy of this mass is 106,000 ft-lb or 136 Btu. At a deceleration of 10 ft/sec^2 this heat is generated during a stop of 7.35 seconds' duration. During the first second, the average rate of heat generation is 34.6 Btu per second = 8.72×10^3 cal/sec. This heat is generated over a total lining area of 52.5 sq in. (21 x 2-1/2) rubbing against cast iron.

Bowden and Tabor[6] give a method which allows a calculation of the true area of contact. Their experiments on metals showed that the actual area of contact is directly proportional to the load. As the load was increased, the points of contact* flowed plastically until the area of contact was sufficient to support the load. In the case of less ductile materials such as brake linings, the points of contact would be crushed until the load-bearing area was large enough so that the crushing strength was no longer exceeded.

For metals, Bowden and Tabor found that the yield pressure is three times the tensile strength. We make the same assumption for brake linings. Johns-Manville Research report 456-T-44, received from A. J. Taylor, gives a tensile strength of 1590 psi for a lining similar to that used in these tests. The yield pressure is then p_m = 4770 psi = 6.87×10^5 lb/sq ft.

According to the definition of the yield pressure, $p_m = L/a$, where L is the load and a is the real area of contact. The load on the lining may be calculated by equating the torques about the axle of the simulated car.

The torque on the tires is

$$mdR = 1270 \times 10 \times 1.09/32.2$$

Here, m = mass declerated = 30.5 per cent of total mass of car = 1270-lb mass.

d = deceleration = 10 ft/sec^2 = (10/32.2)g

R = rolling radius = 1.09 ft

The torque on the brake lining is

$$\mu Lr = 0.4 \times L \times 0.463$$

Here, μ = coefficient of friction = 0.4

L = load

r = drum radius = 0.463 ft

Equating these two torques gives the load, L = 2320-lb force.

*The roughness of even the smoothest brake lining (10-microinch average) is about 2500 times molecular dimensions.

JOHNS-MANVILLE RESEARCH AND ENGINEERING CENTER — MASTER FILE COPY — Report No. [redacted] — Date December 12, 1956

Title: BRAKE LINING WEAR DUST: NATURE OF THE DUST

Requested by: J. G. Koch (P-358)

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Summary

Wear products from brake linings were produced in a test machine in the Friction Materials Department. Two runs were made and the dust from the wear products was collected from three locations of the test machine. The air borne dust was collected on Gelman paper. Samples of dust, accumulated in the drum and box, were also collected.

The dust from the wear products was examined by various techniques to determine the nature of the products. Since chrysotile fiber is the major constituent of brake linings, it was surprising to find that the fiber was undetected by x-ray or infrared techniques. Spectrographic data shows that the elemental constituents of chrysotile fiber, that is silica and magnesia, are present proper ratio of 1:1. With the electron microscope, however, chrysotile fiber was identified and estimated to be 1.4 per cent in the air borne dust. (See Report 456-Int-607)

Iron and magnetite were identified by x-ray diffraction patterns. A strong band at 3.0 microns of the [redacted] spectrum may be indicative of a phenolic material, probably a degradation product of phenolic resin.

The mechanism by which the chrysotile fiber is almost completely degenerated to an amorphous product or products, during braking operations, is not understood. It is believed that this phase of the inquiry is being investigated.

A development report 456-2506 will be issued by D. Sinclair regarding the nature of the wear products and other aspects of this work.

Materials Submitted

Sample Ident. No.	Laboratory Index No.	Description
1	A94-25-1	Air borne dust chemically separated from Gelman paper (run 1)
2	A94-25-2	Same as sample 1 (run 2
3	A94-25-3	Dust from drum
4	A94-25-4	Dust from box

Methods of Analysis

Fine air borne dust was removed from Gelman paper (run 1) by dissolving the paper in cold MEK and centrifugation. The solvent was removed and the dust solids dried at 50C in vacuum. Samples were submitted to x-ray, spectrographic, microscopic and infrared laboratories for examination. In run 2 considerably more dust was obtained from three locations. Only air borne dust was collected in run 1.

Notebook 3433, pp. 45-46-66

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Results of Analysis (in per cent)

Chemical

Ignition losses at 800F

Sample	% Loss
2	13.5
3	19.3
4	31.0*

* This sample was apparently contaminated with dried paint flakes and other material found in the box.

Amount of Dust Recovered in Run 2

Sample	Grams Recovered
2	2.4
3	3.54
4	0.214

It is estimated that 0.31 grams of airborne dust was recovered from the Gelman paper after the first run.

Infrared

An infrared spectrum (chart U-2000) of run 1 airborn dust was obtained using the KBr pellet technique to prepare the sample. No evidence of chrysotile was observed in the spectrum. A strong band at 3.0 microns may be indicative of a phenolic material, probably a degradation product of phenolic resin.

X-ray

The following identifications were made from x-ray diffraction patterns:

Sample	Identification
1	magnetite and possible trace of iron
3	iron
4(magnetic fraction)	magnetite and iron
4(non-magnetic fraction)	rutile (TiO_2)
	zincite (ZnO)
	calcite ($CaCO_3$)
	quartz (SiO_2)

Chrysotile was not detected in any of the samples.

Spectrographic (800F ash)

The components of the 800F ash of samples 1, 3, and 4 were found to be similar in composition. The approximate composition is as follows:

* Sample contains some copper, titanium and zinc.

[redacted]

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MgO	30-32 per cent
SiO_2	30-32
Fe_2O_3	18-20
CaO	0.5
Al_2O_3	2.0
Barium	small

Microscopic

Chrysotile fiber was detected with the electron microscope. The amount of chrysotile fiber was estimated at 1.4 per cent in the airborne sample of run 1. (See Report 456-Int-607).

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