To: Mr. J. C. Garward

From: W. K. Skuba

cc: J. L. Rich

Subject: FAST evaluation of eleven Australian Ford brake linings

The friction and wear characteristics of eleven Australian Ford brake linings supplied by Mr. F. P. Hill of your department were investigated using Ford's FAST procedures.

We would like to include correlation (or lack of correlation) with vehicle test experience in the report to be issued on this investigation. Specifically, we would like vehicle test information (quantitative, where possible) on the wear rates and friction characteristics of each material for conditions of braking severity ranging from light to very heavy.

Enclosed is a copy of the report with the exception of a discussion of vehicle correlation for which we would appreciate your suggestions. We are enclosing also a copy of report ARM 66-7, April 1, 1966,"Instruction Manual for the FAST Machine", which gives in detail the procedure used in our studies.

Also enclosed is a tentative distribution list for the report.

We would appreciate your suggestions for any changes.

W. K. Skuba

8002 1949

TITLE: FAST Procedure Friction and Wear Studies of Australian Ford Brake Linings

Author: J. L. Rich

Department: Chemical Processes and Devices

SUMMARY

Ford FAST (Friction Assessment and Screening Test) procedures were used to evaluate friction and wear characteristics of eleven Australian Ford brake lining materials (five drum brake lining materials and six disc brake pad materials) under different conditions of temperature, lining unit pressure and input power density. The effect of water vapor or humidity on the friction level of each material was also investigated.

(Mr. Garward - we would appreciate your suggestions for a summary on the comparison with vehicle experience)

8002 1950

INTRODUCTION

Friction and wear studies of five Australian Ford drum brake lining materials and six disc brake pad materials were undertaken to:

1. assess the usefulness of FAST as a friction material screening tool,
2. enlarge our knowledge of friction materials to include some of those manufactured and used outside of the United States.

Two samples of each material were subjected to FAST Light and Heavy Duty procedures (see Appendix). Three of the disc brake materials were also subjected to the FAST Extra Heavy Duty Procedure (see Appendix). Water vapor sensitivity tests were performed on all samples during the Heavy Duty Procedure (see appendix).

All Australian vehicles presently use a nine-inch rear drum brake with a disc or drum front brake. The following interpretation of FAST results takes vehicle use into consideration.

Discussion of Results

A summary of FAST results, and an evaluation of those results according to vehicle use follows: (Mr. Garward: we would appreciate any comments you may be able to add concerning correlation with vehicle performance).

Hardie-Ferodo E113 drum brake friction material is the current production primary and secondary lining for rear brakes when front disc brakes (with Ferodo DS-31) are used on the Falcon. FAST laboratory results indicate very good wear life for both light and heavy duty conditions (Table 1) with a friction level that is virtually independent of unit pressure but which rolls off slightly with increase in temperature above 475°F (Figures land 2). This appears to be the best drum lining of those tested for use with Ferodo DS 31 on the front disc brake. However, the near absence of friction rolloff of DS 31 would lead to a variation of braking effort (toward the front) as braking severity increases.

Hardie-Ferodo E110 drum brake friction material is the current production primary and secondary lining for the four wheel drum brake Falcon. FAST laboratory tests indicated good friction (Figures 1 and 2) and wear characteristics under light duty conditions but high wear (Table 1) and a pronounced friction rolloff above 310°F on the heavy duty tests (Figure 1). The friction was erratic above 450°F. This material should be satisfactory for light duty conditions but result in high pedal efforts, high wear, and perhaps some "pulls" under heavy braking conditions.

Hardie-Ferodo E001 drum brake friction material was formerly used for both primary and secondary linings on heavy duty Police and Taxi vehicles. It is not currently in use. FAST laboratory tests indicated good wear life (Table 1) under light and heavy duty conditions, but a pronounced friction rolloff above 200°F (Figure 3). This would be expected to result in high pedal efforts under heavy duty conditions.

Hardie-Ferodo E120 drum brake friction material is a proposed primary lining for the 1967 Falcon, to be used with E 308 as the secondary lining. FAST laboratory results indicate a moderate wear rate for light conditions, but a high wear rate for heavy duty conditions (Table 1). With E 308 this should result in balanced wear for light duty conditions, but unbalanced (high primary lining) wear under heavy

8002. 1952

duty conditions. The friction level rolls off slowly with increasing temperature and decreases with increasing unit pressure (Figures 3 and 4).

Hardie-Ferodo E-308 drum brake friction material is a proposed secondary lining for the 1967 Falcon, to be used with D-120 as the primary. FAST laboratory results indicate low wear rates for light and heavy braking conditions (Table 1). The friction of this lining is sensitive to water vapor, dropping about 30% in the water vapor test.

Furthermore, the friction of this lining drops about 30% between 400°F and 500°F, presumably from water vapor evolved from a mineral filler material (Figure 3). In service this material could be expected to result in "pulls" and/or poor front-to-rear braking balance under heavy duty conditions.

Ferodo DS 31 disc brake friction material is currently used on Falcon disc brakes. FAST laboratory results indicate low wear rates for light and heavy duty conditions (Table 1) with a near-constant friction coefficient that rolls off only slightly at elevated temperatures (Figures 5 and 6). It has a moderate (for disc materials) 27% drop of friction with water vapor. This material should result in substantially increased lining and rotor wear (and some rotor scoring) when used in dusty conditions. This was revealed by the cracking of the cashew friction particles (Figure 10) with heat.

Mintex M-33 disc brake friction material is an alternate material for DS 31. FAST laboratory results indicate a wear rate similar to DS 31 for light duty conditions, but about 40% higher wear rate for heavy duty conditions (Table 1). The friction level of M-33 is somewhat lower than DS 31, and also is nearly constant, even to elevated temperatures (Figures 5 and 6).

Don 212 disc brake friction material is the production material on the Cortin: FAST laboratory results indicate that DON 212 has a very flat friction level (Figures 5 and 6) which is higher than either DS 31 or M-33, but the wear rate for light duty conditions is about two-and one-half times that of the above disc materials. The heavy duty wear rate is about equal to that of M-33, or about 40% above that of DS-31 (Table 1). The higher wear rate of DON 212 for light duty conditions should be its principal drawback.

Ferodo DS5S disc brake friction material is being considered for 1967 Falcon front disc brakes. FAST laboratory results indicate a low wear rate for light duty conditions and an exceptionally low wear rate for heavy duty conditions (Table 1). However, the friction level of this material is subject to substantial variations (Figures 7, 8, and 9). The effectiveness (friction) of this material should be relatively low when cold, increasing with temperature to nearly double the initial level, then falling off at the higher temperatures. This material should exhibit a rapid drop in friction above 500°F under very heavy braking conditions (Figure 9). The relatively low fade temperature and large friction level variations should make this a less desirable disc brake material despite its outstanding wear characteristics.

Mintex M-69 is a prototype disc brake friction material. FAST laboratory results indicate a high wear rate under both light and heavy duty conditions. The friction level drops over one-third with water vapor and has a "humped" variation of friction much like Ferodo DS5S. The performance of this material in a car could be expected to be marginal at best.

Mintex M-78 is a prototype disc brake friction material. FAST laboratory results indicate slightly higher wear rates for M-78 than M-69, the same kind of friction variation, but much less water sensitivity. Like M-69, the performance of this material in a car could be expected to be marginal, at best.

8002 1954

CONCLUSIONS

(Mr. Garward: we are deferring any conclusions until we have the benefit of your comments)

Procedure	Duration min.	Friction Force	Shear Stress psi	Final Disc Bulk Temperature °F
Light Duty	60	8.7	35	210°
Heavy Duty	90	17.4	69	560°
Extra Heavy Duty	60	26.1	104	690°

APPENDIX

FAST PROCEDURES

A complete description of the FAST machine, sample and disc preparation and basic testing procedures may be found in the Instruction Manual for the FAST machine (ARM 66--7, April 1, 1966). The comparative severity of the three FAST procedures employed in this study is summarized in the following table:

Procedure	Duration	Friction Force/ Shear Stress		Final Disc Bulk Temperature
Light Duty	60 min	8.7 lbs	35 psi	210°F
Heavy Duty	90 min	17.4 lbs	69 psi	560°F
Very Heavy Duty	60 min	26.1 lbs	104 psi	690°F

In all three procedures the sliding velocity is constant at 23 fps.

WATER VAPOR SENSITIVITY TEST

The effect of water vapor on friction properties is a qualitative indication of the type of resin binder used in the friction material. For example, a straight phenolic resin binder material loses friction with application of water vapor while the friction level of an oil-modified phenolic or a rubber binder material increases. The friction level of a cashew material is unaffected by water vapor. For the sake of standardization, the test is run at the 350°F point of the FAST heavy duty procedure since at this disc bulk temperature the coefficient of friction of most lining materials is fairly constant. A low velocity (2-3 fps from 1/4" dia. orifice) stream of water vapor is played on the friction track just above the sample for a period of one minute. The amount applied must be sufficient to insure maximum effect but not large enough for condensation to form on the loading arm. The percent change of friction and the direction of that change, if any, are then recorded.

EVALUATION OF LINING UNIT PRESSURE SENSITIVITY

Evaluation of the sensitivity of the coefficient of friction to lining unit pressure is based upon comparison of the friction levels exhibited by a material during the light and heavy duty procedures for the same temperature range.

TEST RESULTS

Drum Brake Lining Materials

Hardie-Ferodo E113. The wear rates of this material for both duty cycles are among the lowest of the drum brake lining materials tested (Ref. Table 1). The friction level varies little with temperature (Ref. Fig. 1), rolling off slightly above 475°F under heavy duty conditions. Comparison of light and heavy duty test curves for the same temperature range shows the friction level of E113 to be essentially independent of unit pressure for the temperature range available (below 210°F). The friction level drops about 20% with application of water vapor. Microscopic examination (7X-30X) reveals large crudes of asbestors, black particles which appear to be an oil modified phenolic, and small particles of a white crystalline mineral. The general appearance of the material suggests a dry-mix process. On the basis of the test procedures employed, E113 is a very good drum brake lining material.

Hardie-Ferodo E110. Under light duty conditions the E110 material exhibits a good friction level (Figure 2) and a low wear rate (Table 1). Under heavy duty conditions, however, its friction level rolls off from $\mu = .51$ at 310°F to $\mu = .27$ at 475°F (Figure 1). In addition, the variation of friction with temperature becomes very erratic at 450°F, indicating possible degradation of one or more of the lining constituents. It also possesses a very high wear rate under heavy duty conditions (Table 1). The friction level of E110 is not sensitive to changes in lining unit pressure (Figures 1 and 2) but drops 8% upon application of water vapor. Microscopic examination reveals large asbestos crudes, brown resin particles (probably phenolic) and appears to be a dry-mix process material. This material should be acceptable for light duty application.

Hardie-Ferodo E001. Although this material demonstrates good wear characteristics under both light and heavy duty conditions, (Table 1), its friction level varies rapidly with temperature. Under heavy duty conditions its friction level drops from $\mu = .54$ at 400°F to $\mu = .18$ at 525°F (Figure 3). This rapid friction rolloff would probably result in excessive pedal efforts under severe duty conditions. The friction level of this material exhibits essentially no pressure sensitivity (Figures 3 and 4) but drops 15% upon application of water vapor. Microscopic examination shows that E001 contains what appears to be phenolic resin, large asbestos crudes, approximately 5% brass, and appears to be a dry-mix process material. The acceptability of this material would depend on the design of the brake in which it is used. In particular, the manner in which the actuation factor of the brake varies with change in lining coefficient of friction would be of critical importance.

Hardie-Ferodo E120. This material possesses acceptable friction characteristics under both light and heavy duty conditions (Figures 3 and 4). It exhibits, however, the highest wear rates for both light and heavy duty test procedures of all the drum materials tested (Table 1). Its friction level is essentially insensitive to lining unit pressure and relatively insensitive to water vapor (10% loss of friction upon application of water vapor). The presence of large asbestos crudes, particles of what appears to be phenolic resin, white crystalline particles and the general appearance of a dry-mix process lining are revealed under the microscope. The high wear rate exhibited by E120 under all duty conditions makes it less desirable for vehicle application than all the other drum brake materials tested.

Disc Brake Pad Materials. The six disc brake pad materials may be divided into two groups of three on the basis of friction behavior with temperature. The first group exhibits very little variation of friction over a wide temperature range (75°F to 560°F) (Figure 5) while the second group exhibits a pronounced friction buildup with temperature, followed by a marked friction rolloff (Figure 7).

Hardie-Ferodo E308. The wear rate of this material nearly matches that of E113 under both light and heavy duty conditions (Table 1). Between 400°F and 425°F, however, it loses 33% of its friction very rapidly, remains at this low level through a 100°F temperature range, and then recovers to its original level (Figure 3). This rapid loss of friction may cause braking imbalance in some instances. Subsequent water vapor tests and microscopic observations lead to the tentative conclusion that the friction loss may be due to a white crystalline mineral contained in the lining which loses water of hydration in this temperature range. Coupled with a high water vapor sensitivity, (28% drop in friction level with water vapor application), this occurrence can easily account for the friction loss. E308 decreases in friction with increase in lining unit pressure (Figures 3 and 4). In addition to the white crystalline mineral, microscopic examination also reveals large asbestos crudes, brown chunks of what appears to be phenolic resin, and the general appearance of a dry mix process material. If the friction loss described above can be corrected, E308 may match the performance characteristics of E113.

Ferodo DS31. The low wear rates for both test procedures make it the best wearing material of group one (Table 1). It loses 27% of its friction upon application of water vapor and increases in friction somewhat with an increase in lining unit pressure (Figures 5 and 6). Microscopic examination reveals chunks of resin (probably phenolic) particles, and appears to be a dry-mix process material. This material was one of three disk materials subjected to an additional very heavy duty test (see appendix) at the request of Australian engineering personnel, to acquire information about their friction behavior under higher energy input conditions. DS31 produced a moderate controlled friction rolloff during this test (Fig. 9).

Microscopic examination of the surface of a sample of this material which had completed the FAST heavy duty procedure showed cracks in the cashew friction particles on this surface. A photomicrograph of the used lining surface is included as Figure 10. Preliminary tests run after contaminating the friction surfaces with road dust show that such dust collects in these cracks and increases the wear rate of the sample through abrasive action.

The cracking of cashew friction particles is known to be due to thermal degradation and it was therefore suggested that a friction particle of higher temperature capability and smaller size be considered to help alleviate the problem.

A sample of a commercially available high temperature 60 mesh friction particle (Cardolite NC111-60) was sent to Ford of Australia for evaluation in a production batch of Ferodo DS-31.

Mintex M33. This material wears at a rate similar to DS31 under light duty conditions, but at a considerably higher rate under heavy duty conditions (Table 1). It loses 20% of its friction with application of water vapor and increases in friction with an increase in lining unit pressure (Figures 5 and 6). Visual inspection of the surface under a microscope reveals the presence of graphite, large brass chips, open fiber asbestos, and the general appearance of a dry-mix process material. The material appears acceptable for light duty conditions, but less desirable than DS31 for heavy duty application because of high wear. The friction of M33 remains at a relatively constant level under light, heavy and severe duty conditions (Figs. 5, 6, and 9).

DON 212. This material of group one, wears 2.5 times faster than the other two materials under light duty conditions (Table 1). It loses 10% of its friction upon application of water vapor and decreases slightly in friction with an increase in lining unit pressure (Figures 5 and 6). Large amounts of coal and a crudy fibre asbestos were visible under the microscope. It appears to be a dry-mix process material.

The second group of three disc brake materials tested, Ferodo DS5S, Mintex M69, and Mintex M78 exhibit more variation in friction level with temperature. Under heavy duty conditions, all three of these materials possess low friction values at near-ambient temperatures, increase to maximum friction values at approximately 400°F, and thereafter gradually decrease in friction with an increase in temperature (Figure 7).

Ferodo DS5S possesses far better wear characteristics for both light and heavy duty conditions than either of the other two materials in this group (Table 1). It loses 24% of its friction with water vapor application and decreases in friction with an increase in lining unit pressure (Figures 7 and 8). Under severe duty conditions, the friction level of DS5S increases from μ = .26 at ambient temperatures to μ = .37 at 500°F then decreases rapidly to μ = .22 at 525°F (Figure 9), thus exhibiting an inability to withstand the high energy input. Visual examination reveals an open fibre asbestos and particles of brass. Large amounts of a coloring agent (probably carbon black) made visual observations difficult.

Mintex M69. wears more than twice as fast as DS5S under light duty conditions and over 3-1/3 times as fast under heavy duty conditions (Table 1). It loses 36% of its friction with water vapor and decreases in friction with an increase in lining unit pressure (Figures 7 and 8). Microscopic examination shows the presence of large brass chips, some coal and large crudes of asbestos. It appears to be a dry-mix material.

Mintex M-78 exhibits the highest wear rates under both light and heavy duty conditions of all six disc brake materials tested (Table 1). The heavy duty procedure friction curve for this material (Figure 7) shows large variations of friction above 500°F, indicative of a rapid deterioration of this lining material above this temperature. It loses 15% of its friction with water vapor and its frictio: level appears to be essentially insensitive to changes in lining unit pressure (Figures 7 and 8). It appears to be a dry-mix material, containing some coal, chunks of resin (probably phenolic), and particles of brass.

TABLE 1

Material	Avg. Specific Gravity	Avg. Specific Wear		Water Vapor sensitivity % decrease of friction
Drum Brake Materials		Lt. Duty	Hvy. Duty	
Hardie-Ferodo E113	1.85	2.06	3.70	20.0%
Hardie-Ferodo E110	1.83	2.75	9.55	8.0%
Hardie-Ferodo E001	1.98	2.43	4.11	15.6%
Hardie-Ferodo E120	2.00	4.23	15.3	10%
Hardie-Ferodo E308	2.00	2.00	3.98	28%
Disc Brake Materials				
Ferodo DS31	2.88	1.29	3.72	26.8
Mintex M33	2.65	1.26	5.12	19.4%
DON 212	1.99	3.51	4.95	98%
Ferodo DS5S	2.19	1.55	2.55	23.7%
Mintex M69	2.69	3.28	8.96	35.6%
Mintex M78	2.12	3.69	9.36	14.6%

TABLE IIA VEHICLE CORRELATION

DRUM MATERIAL

Material	WEAR RATE			FRICTION BEHAVIOR	
	FAST.		VEHICLE	FAST	VEHICLE
	Wear Rate ($In^3/10^3$ HPHR)				
Hardie-Ferodo E113	Light Duty 2.06 (low)	Heavy Duty 3.70 (low)		varies little with temperature, slight roll off above 475°F, drops 20% with water vapor (fig.1)	
Hardie Ferodo E110	Light Duty 2.75 (moderate)	Heavy Duty 9.55 (high)		light duty - good heavy duty - loses 45% between 310°F and 475°F (Fade), very erratic above 450°F, 8% loss with water vapor (fig. 1)	
Hardie Ferodo E001	Light Duty 2.43 (moderate)	Heavy Duty 4.11 (low)		varies rapidly with temperature, loses 67% between 400°F and 525°F (Fade), loses 15% with water vapor (fig. 3)	
Hardie-Ferodo E120	Light Duty 4.23 (high)	Heavy Duty 15.3 (high)		acceptable variation with temp., 10% loss with water vapor (fig. 3)	
Hardie-Ferodo E308	Light Duty 2.00 (low)	Heavy Duty 3.98 (low)		sudden 33% drop in friction level between 400°F and 425°F, recovers to original level above 500°F, 28% loss with water vapor (fig. 3)	

TABLE IIB VEHICLE CORRELATION

DISC MATERIALS

Material	WEAR RATE			FRICTION BEHAVIOR	
	FAST		VEHICLE	FAST	VEHICLE
	Wear Rate ($In^3/10^3$ HPHR)				
Ferodo DS31	Light Duty 1.29 (low)	Heavy Duty 3.72 (low)		little variation with temperature, 27% loss with water vapor (fig. 5)	
Mintex M-33	Light Duty 1.26 (low)	Heavy Duty 5.12 (moderate)		little variation with temperature, 20% loss with water vapor (fig. 5)	
DON 212	Light Duty 3.51 (high)	Heavy Duty 4.95 (moderate)		little variation with temperature, 10% loss with water vapor (fig. 5)	
Ferodo DS5S	Light Duty 1.55 (moderate)	Heavy Duty 2.55 (very low)		increases from μ = .26 at ambient temperature to μ = .50 at 500°F then decreases to μ = .22 at 525°F, drops 24% with water vapor (fig. 7)	
MINTEX M-69	Light Duty 3.28 (high)	Heavy Duty 8.96 (high)		increases from μ = .29 at ambient temperature to μ = .46 at 450°F then decreases to μ = .29 at 550°F, drops 36% with water vapor (fig. 7)	
MINTEX M-78	Light Duty 3.69 (high)	Heavy Duty 9.36 (high)		increases from μ = .35 at ambient temperatures to μ = .60 at 400°F then decreases to μ = .37 at 520°F at which point it becomes very erratic. 15%	

8002 1967 PQ

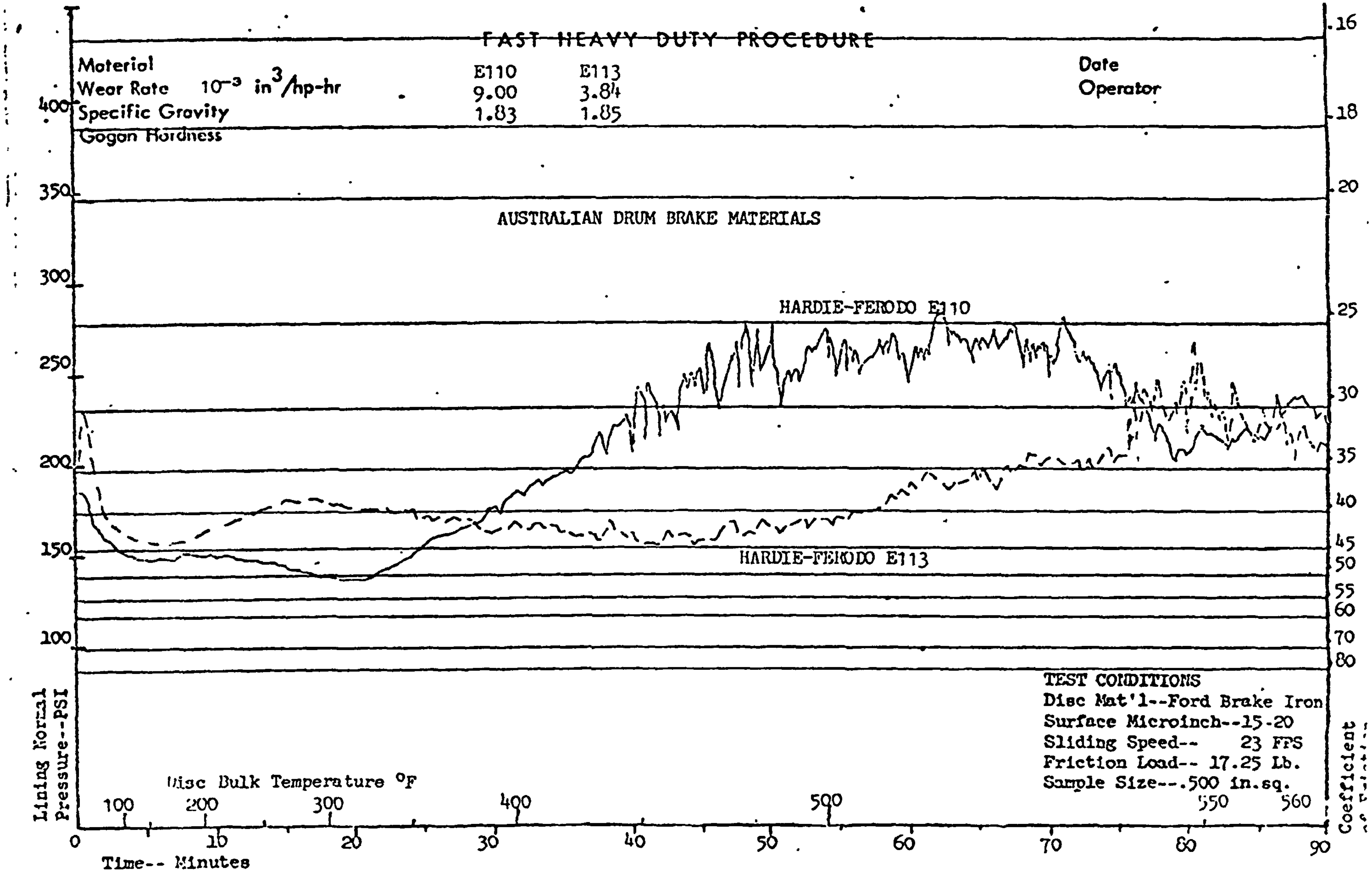
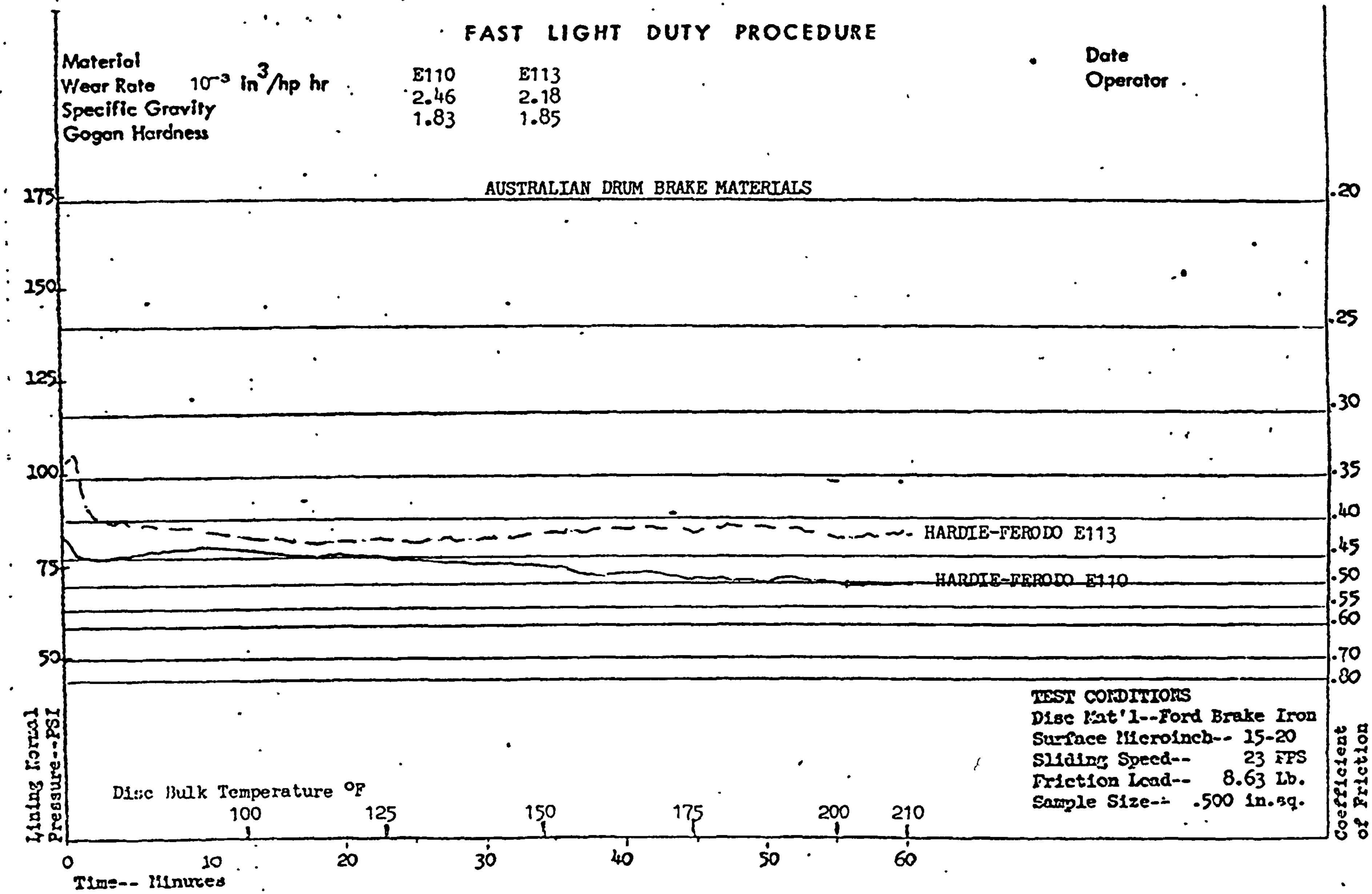


FIGURE 1

8002 1968



FAST LIGHT DUTY PROCEDURE
Material
Wear Rate 10^{-3} in^3/hp hr
Specific Gravity
Gogan Hardness
E110
2.46
1.83
E113
2.18
1.85
Date
Operator
AUSTRALIAN DRUM BRAKE MATERIALS
HARDIE-FERODO E113
HARDIE-FERODO E110
TEST CONDITIONS
Disc Mat'l--Ford Brake Iron
Surface Microinch-- 15-20
Sliding Speed-- 23 FPS
Friction Load-- 8.63 Lb.
Sample Size-- .500 in.sq.
Lining Normal Pressure--PSI
175
150
125
100
75
50
Coefficient of Friction
.20
.25
.30
.35
.40
.45
.50
.55
.60
.70
.80
Disc Bulk Temperature °F
100
125
150
175
200
210
Time-- Minutes
0
10
20
30
40
50
60

8V02 1969

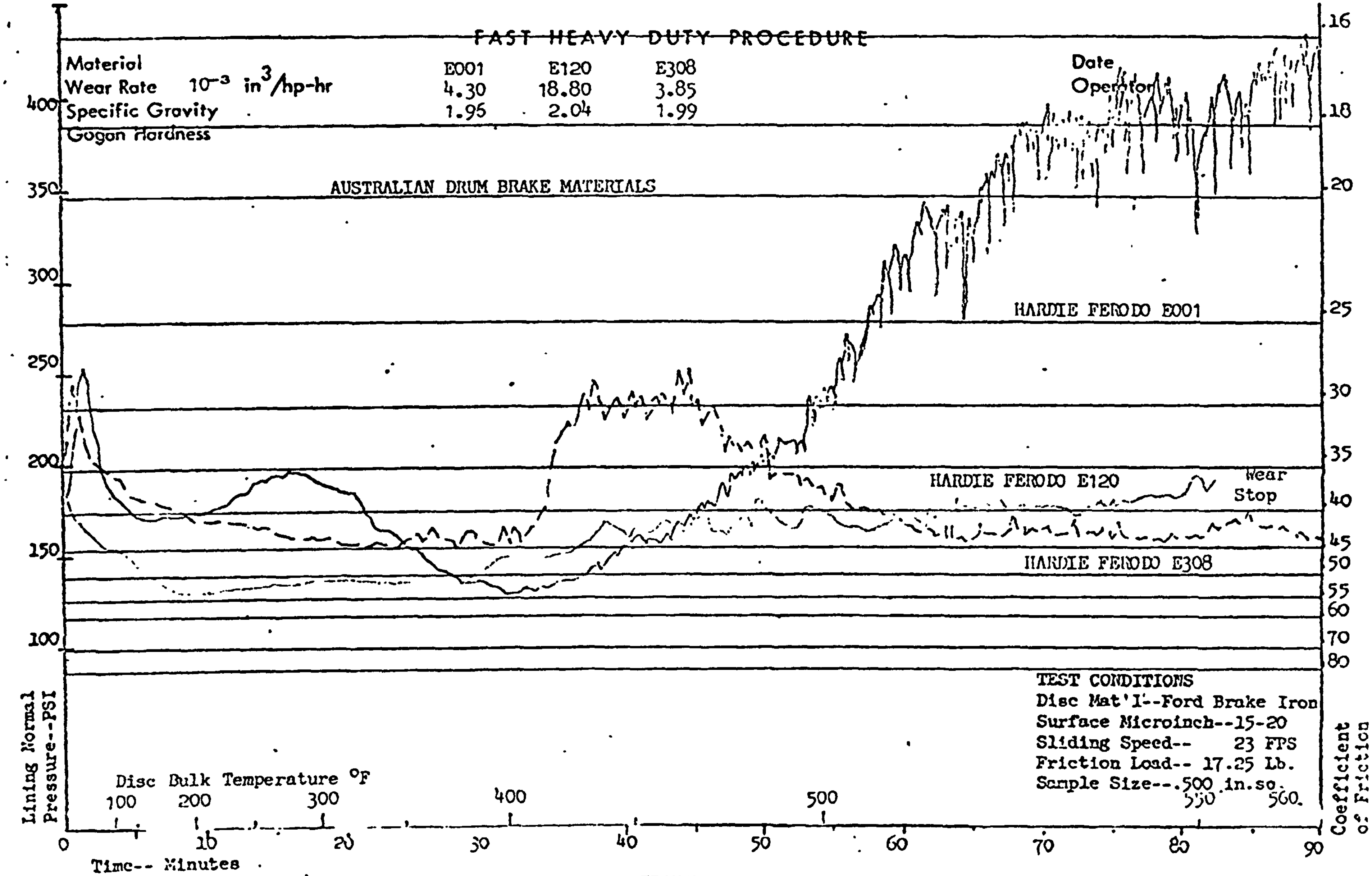


FIGURE 3

8002 1970

FAST LIGHT DUTY PROCEDURE

Material	E001	E120	E308
Wear Rate 10^{-3} in^3/hp hr	2.54	4.20	1.90
Specific Gravity	1.96	2.04	1.99
Gogan Hardness			

Date
Operator

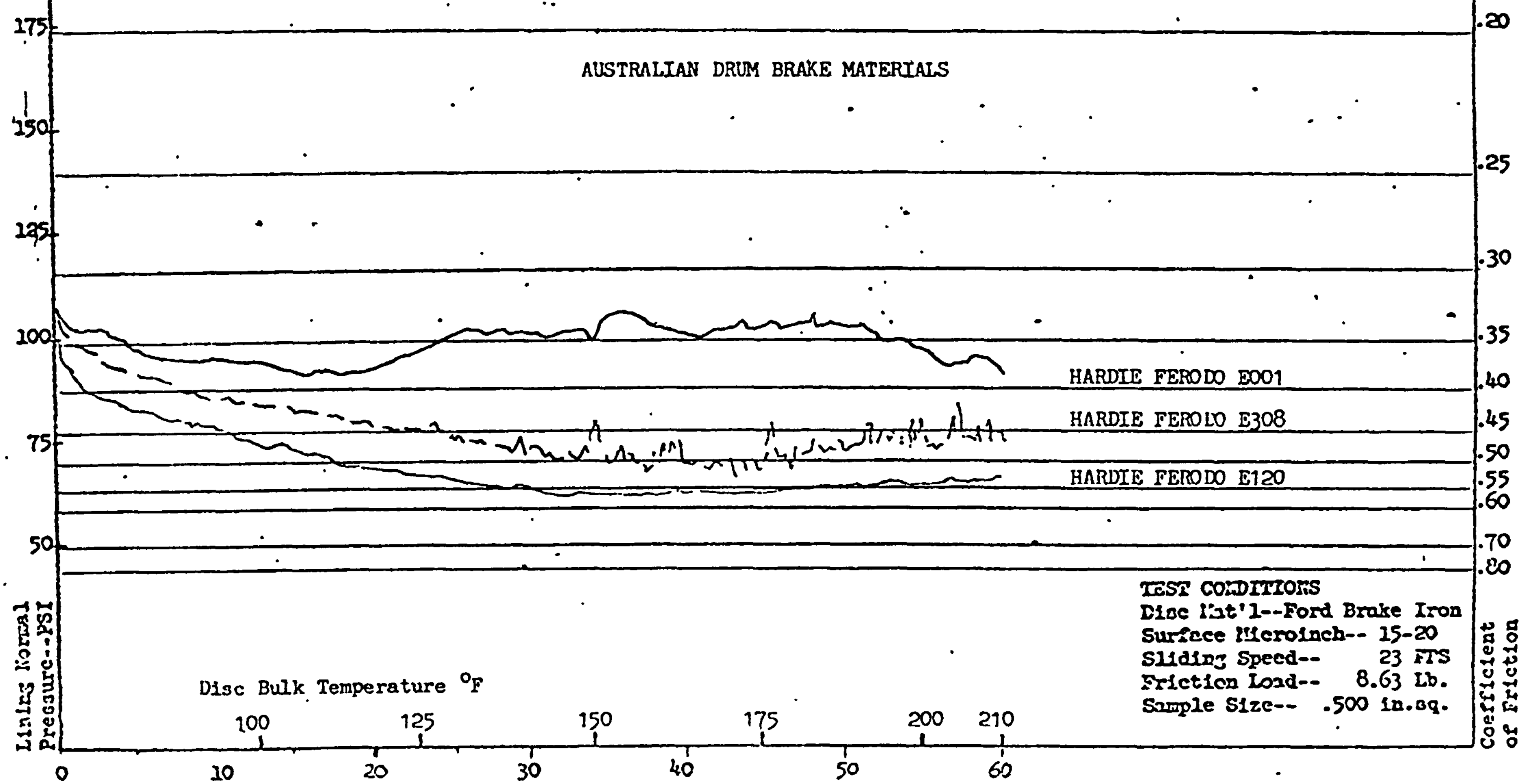


FIGURE 4

8002 1971

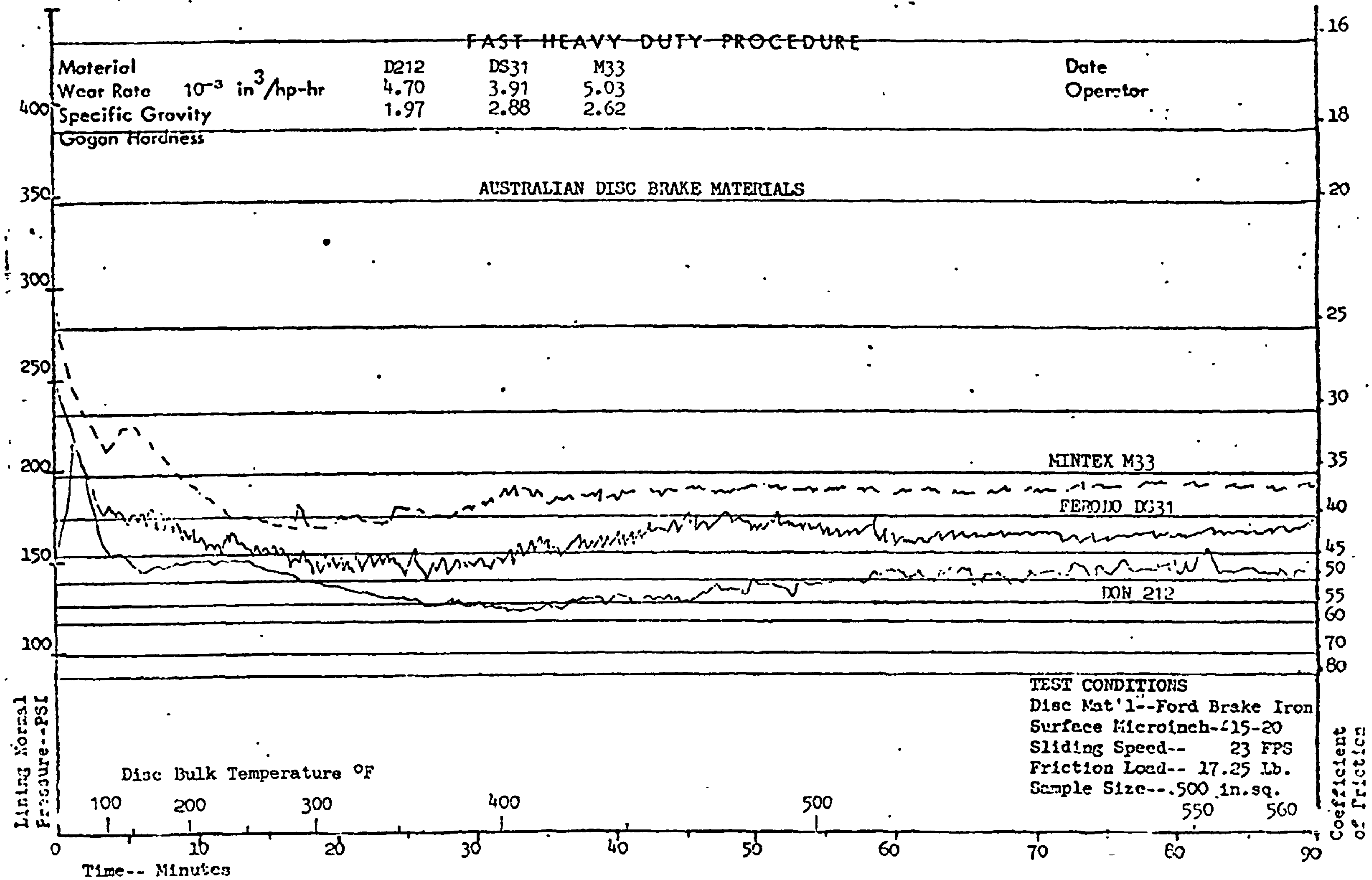


FIGURE 5

8002 1972

FAST LIGHT DUTY PROCEDURE

Date
Operator

Material	D212	DS31	M33
Wear Rate 10^{-3} $in^3/hp \cdot hr$	3.34	1.29	0.98
Specific Gravity	1.97	2.88	2.62
Gogan Hardness			

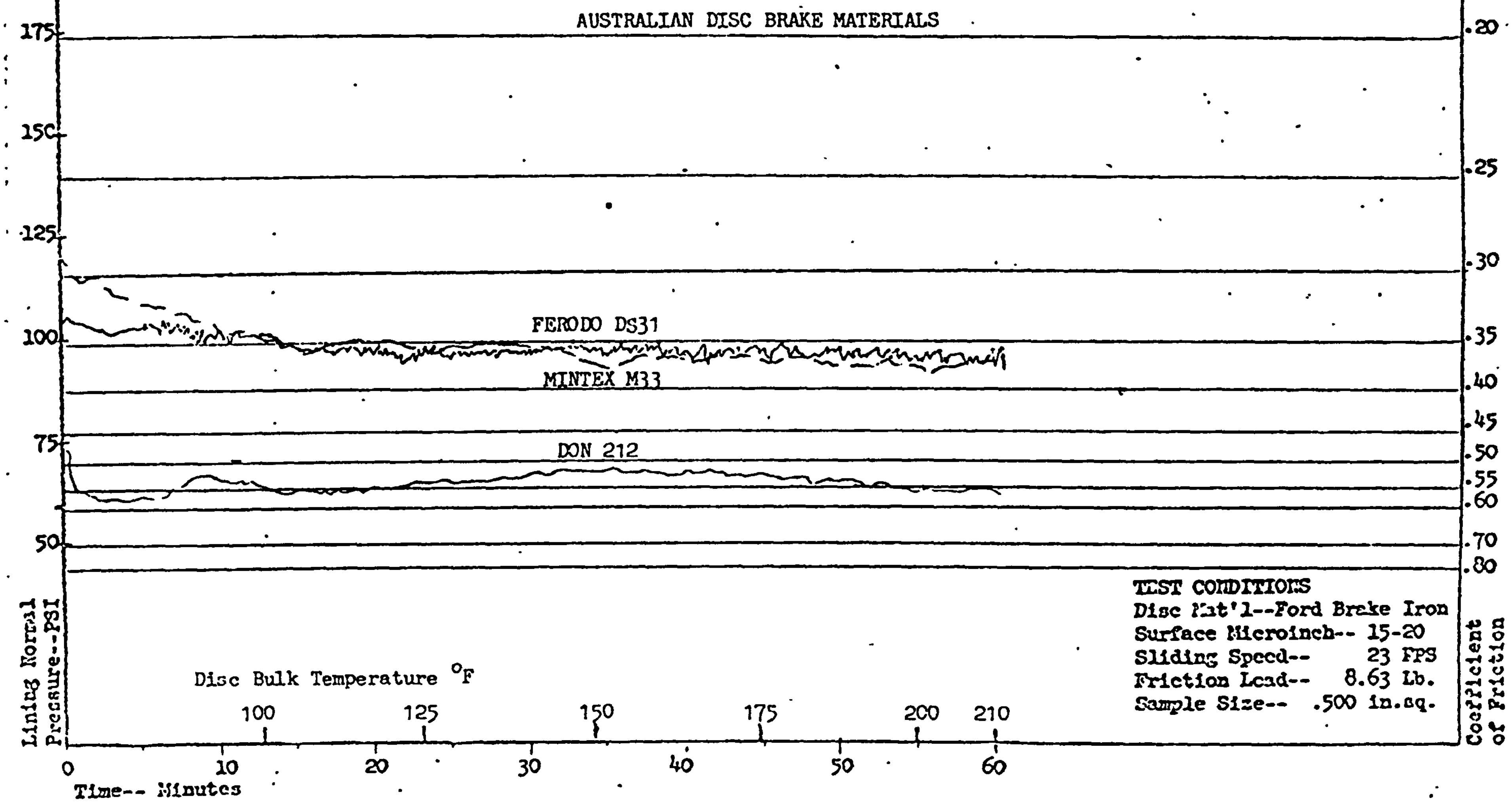


FIGURE 6

8002 1973

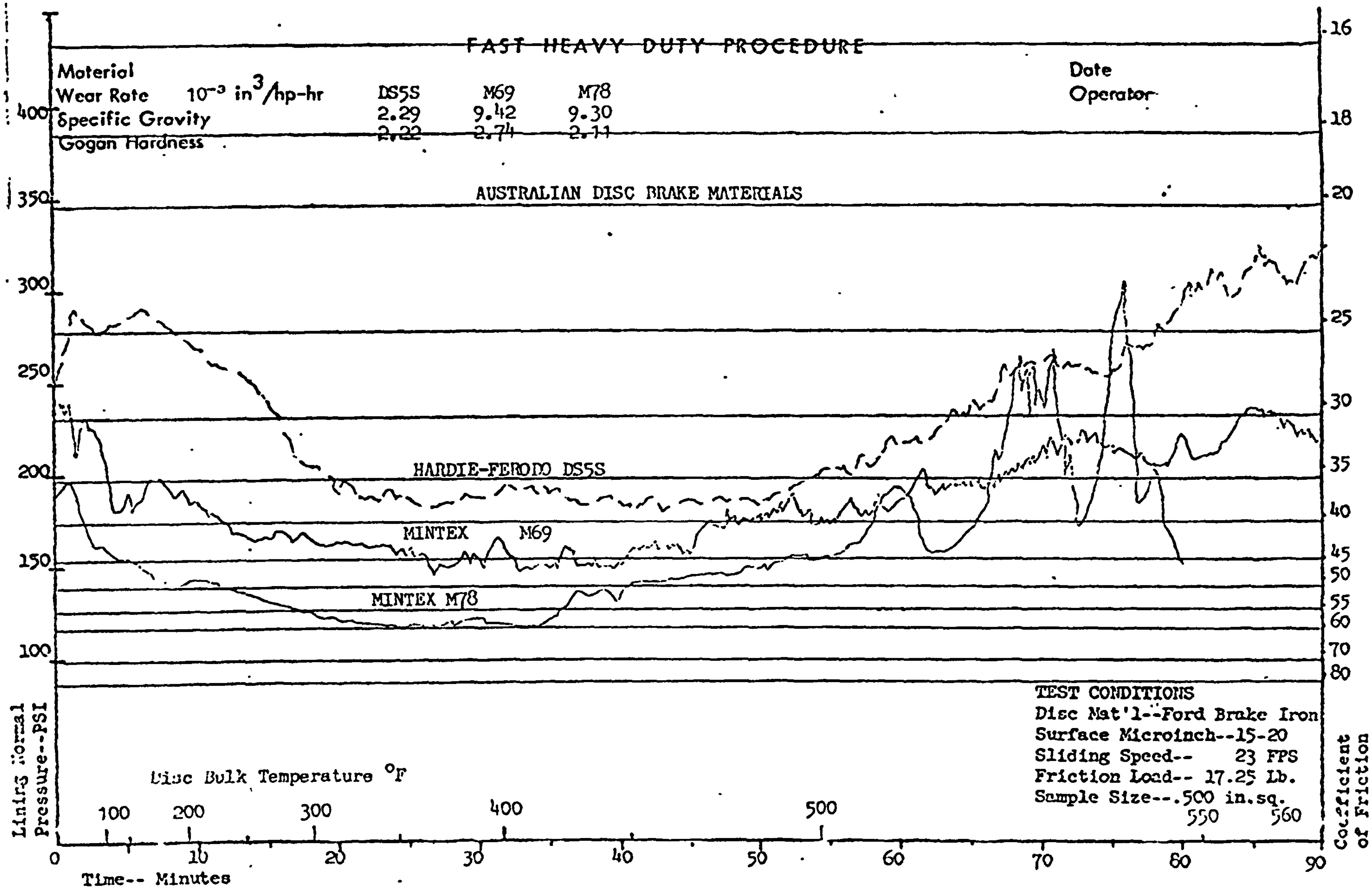


FIGURE 7

8002 1974 **PQ**

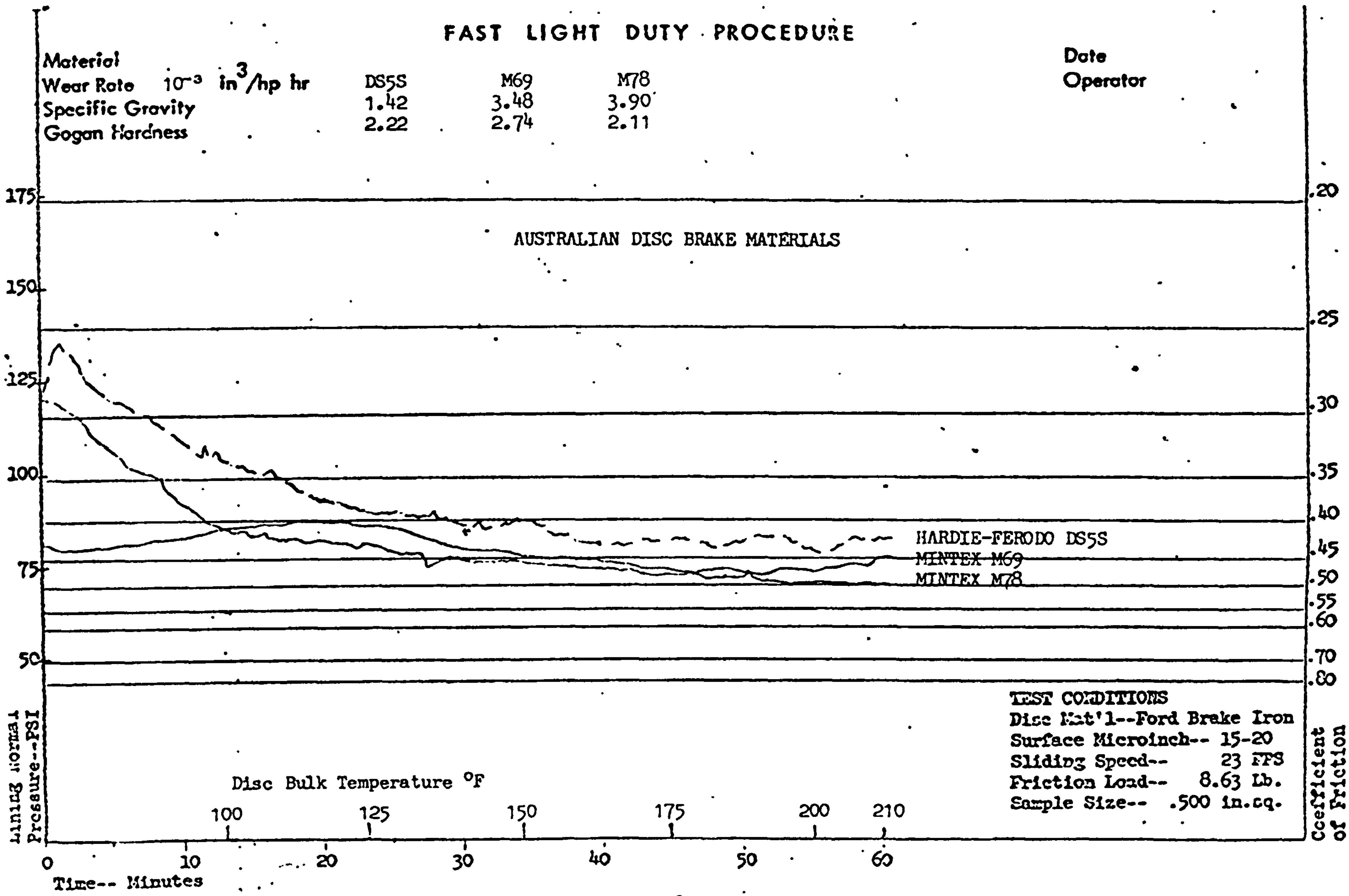


FIGURE 8

8002 1975

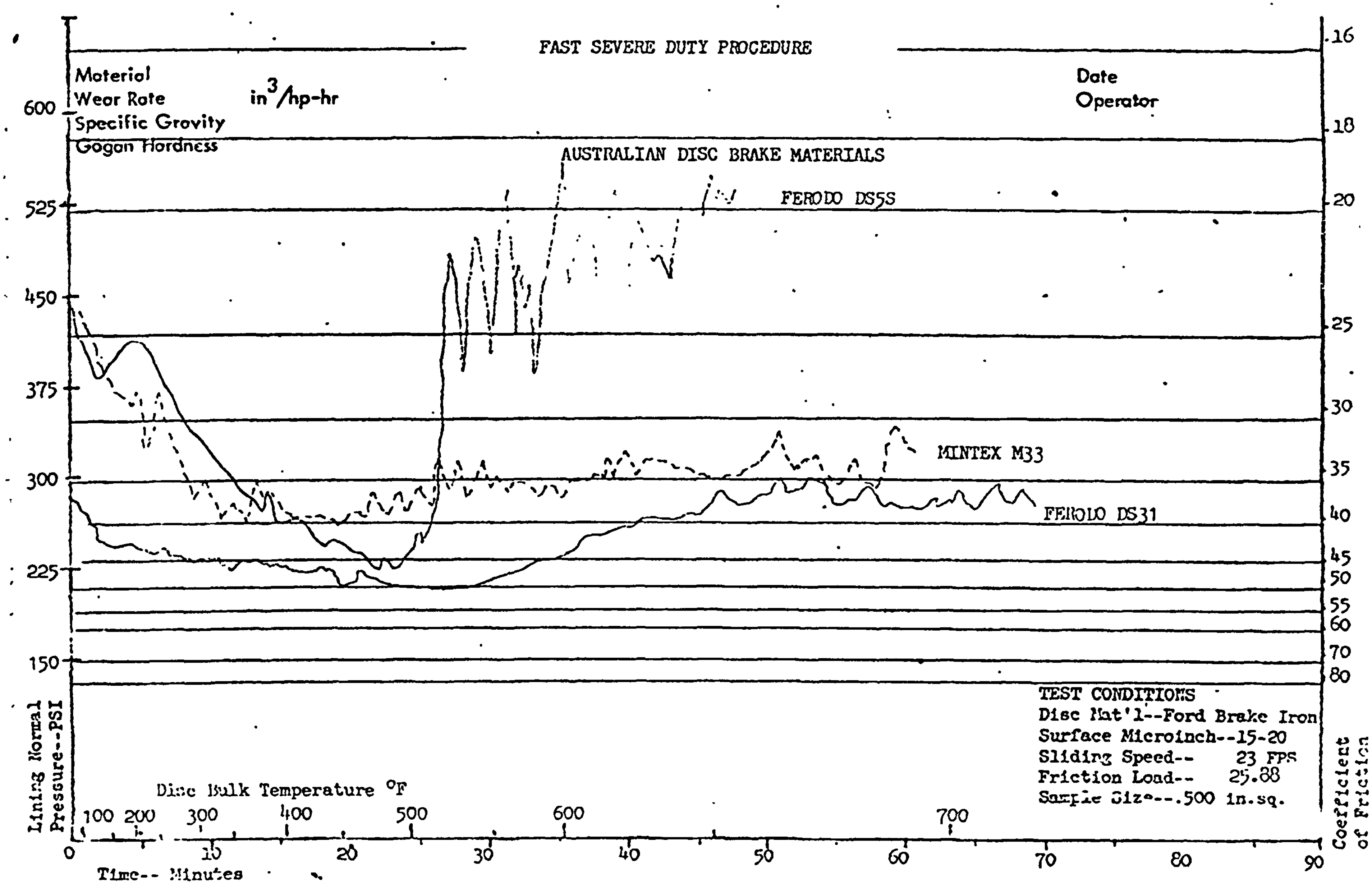
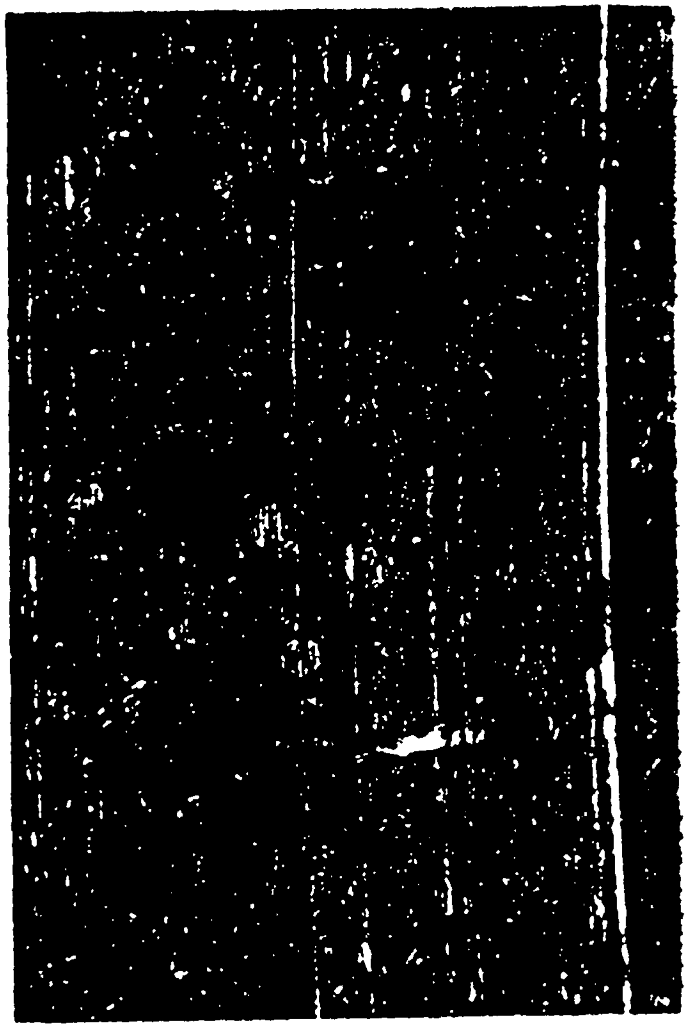


FIGURE 9

Fig. 16   Sample of Ferodo DS31 after heavy duty test.



Note cracks in cashew friction particles. The light ridge was formed on the sample surface when a piece of brass lodged in one of the cracks.

9002 1976

CALL W. D. ROSS 8 - 694 - 8108

~~re the attached~~

File - Brake & Clutch
Friction elements? EDH

8002 1977