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PERFORMANCE IMPROVEMENT OF AUTOMOTIVE BRAKE LINING MATERIALS

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ABSTRACT

Brake linings used in automobile brake systems are complex composite formulated from asbestos fibers as reinforcement, organic resin as binder and different fillers and additives used to obtain the required characteristics, which satisfy highly stable braking performance.

The objective of this work is to study the effect of changing the grain size of some constituents of the brake lining materials on its characteristics. To achieve this goal sieving analysis of the chosen constituents (Brass, Graphite, and Magnesium oxide) was made and samples of different grain sizes were prepared and tested using the Friction Assessment and Screening Test machine (FAST) to evaluate the friction and wear characteristics. Tensile, compression and hardness tests were also conducted to evaluate the mechanical properties.

The results showed that increasing brass chip size gives better friction and mechanical behavior while reducing brass chip size gives suitable wear resistance. Finer graphite grain size gives better friction and wear resistance while coarse graphite grain size gives reasonable mechanical behavior. Fine magnesium oxide grain size gives good friction, wear and mechanical behavior.

KEY WORDS

Automotive, Brake Lining, Composite Materials

1. INTRODUCTION

Friction materials used in automotive engineering applications must involve the conversion of mechanical energy in to heat which must be dissipated . this problem complicates the choice of friction lining [1]. General types of friction materials maintain their friction values to fairly high temperature, after which the friction coefficient falls progressively and lining is said to be fading [2]

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It is required to design friction material that gives a uniform and suitable friction coefficient with maximum fade and wear resistance [3&4]. Brake lining materials are complex composites including reinforcing fibers, fillers ,binders and additives [5] . The characteristics of some of the lining constituents were studied and optimized , together with processing conditions [6] In this study the effect on the tribological and mechanical characteristics of some of the lining constituents are studied for further improvement of its properties . For this purpose , different grain sizes of three of the lining constituents were tested . Sieving analysis of the chosen constituents (Brass, Graphite and Magnesium Oxide) was made and samples of different grain sizes were prepared and tested using the FAST machine to evaluate the friction and wear characteristics .Tensile , Compression and hardness testes were also conducted to evaluate the mechanical properties[7].

2. EXPERIMENTAL WORK

In this work, the effect of changing the grain size of three of the lining constituents (Table 1) (Brass, Graphite and Magnesium Oxide) on the tribological and mechanical behavior of the lining material was studied. For this purpose six or seven different grain sizes of each of the mentioned constituents (Tables 2, 3) were tried through sieving analysis (Figure 1). Samples were prepared and tested using FAST machine (Figure 2) which gives a complete history of the friction and wear characteristics during a test period of 90 minutes for each sample. Hardness and compression tests were carried out to evaluate the mechanical properties.

2.1. Samples Preparation:

Samples were prepared for the different grain size of the constituents under investigation. The results were averaged from 3 samples for each grain size. The constituents are weighed using electric balance, mixed for (15-30) min. then the samples are cold molded under pressure of 5 MPa in a special die for 10 seconds, followed by hot molding at temperature 160 °C and pressure 12 MPa for a time period of 270 seconds. Two specimen sizes ½ x ½ x 0.15 (brake lining) or ½ x 1 x 0.15 inch (clutch lining) can be tried.

2.2. Test Rig :

The FAST machine is developed for evaluating of brake and clutch lining materials. It consists mainly of: the test machine, signal conditioner, and x-y recorder,. The machine major elements are: drive motor and friction disk, pivot and load arm, clamping assembly, control valve assembly, oil reservoir, hydraulic components, and pressure transducer. For the mechanical properties evaluation, the Instron electro-hydrolic universal machine model 8032, Figure 3 and the Rockwell hardness testing machine Avery type 6402 were used.

2.3. Test procedure:

At first the disc is cleaned, the test specimens are weighed and the thickness is measured. The sample is mounted in the sample arm. The drive and pump motor are started and the clamping load is applied for 90 min. The clamping force is recorded as a function of the time during the test. By the end of the test the sample is removed, weighed and remeasured to calculate the wear. The constant friction force test mode of operation is used in this study. This maintains both friction force and sliding velocity at constant values.

3. RESULTS AND ANALYSIS

For the analysis of results, the following characteristics values are considered:
f_{max} ... maximum value of the friction coefficient.
f_{min} ... minimum value of the friction coefficient.
$\Delta f = f_{max} - f_{min}$, which indicates the stability of the lining friction, as Δf decreases, the stability increases.
$f_{mean} = \Sigma f_i / n$, mean value of friction coefficient
where:

f_i ... instantaneous coefficient of friction.
n ... number of the discrete points considered.
W ... wear in gm.

3.1. Effect of Brass Chip Size on The Tribological and Mechanical Behavior:

3.1.1. Effect of brass chip size on friction coefficient :
Tables 4,5 together with Figures 4,5 show the effect of change of brass chip size on friction coefficient. It is shown that for smaller brass chip size, the maximum coefficient of friction reached is decreased and the friction stability is increased. For larger brass chip size the maximum coefficient of friction is increased.Fading resulting in rapid wear .Hence stable braking operation is optaind In fact, the smaller brass chip size will reduce the presence of hot spots which causes fading resulting in rapid wear. Hence stable braking operation is obtaind.

3.1.2. Effect of brass chip size on wear:
The specific gravity is calculated from the following equation:

$$\gamma = \frac{x}{x-y}$$

where:

γ ... specific gravity of specimen.
x ... weight of specimen on air (gm).
y .. weight of specimen on water (gm).

The specific wear rate is calculated using the following equation:

$$S.W.R = \frac{\Delta W}{\gamma \times 0.2754}[10^7 cm^3 / N.m]$$

where

$\Delta W = W_i - W_e$
W_i ... initial sample weight (gm).
W_e ... end sample weight after FAST test(gm).

Table 6 and Figure 6 show the specific wear rate of each sample. The minimum specific wear rate was obtained foe the smallest brass chip size, while the maximum specific wear rate was obtained for the largest brass chip size. This can be explained by assuming that the smaller chip size improve the structure homogeneity which resist the chip take-off, hence the wear resistance is improved.

3.1.3. Effect of brass chip size on maximum tensile strength, maximum compressive strength, and hardness:

Tables 7 and Figure 7,8 show the effect of brass chip size on the maximum tensile strength, maximum compressive strength, and hardness. The results indicates that the maximum tensile and compressive strength are reduced by increasing the brass chip size, while the hardness is not affected by the brass chip size change.

3.2. Effect of Graphite Grain Size on The Tribological and Mechanical Behavior:

3.2.1. Effect of graphite grain size on friction coefficient:

Tables 8,9 along with Figures 9,10 illustrate that the maximum mean coefficient of friction as well as stable friction behavior are reached when using finer graphite grains

3.2.2. Effect of graphite grain size on wear

Table 10 and Figure 11 show the specific wear rate of each sample. The minimum specific wear rate is obtained when using fine graphite grain size, while the maximum specific wear rate is reached when using coarse graphite grain size.

3.2.3. Effect of graphite grain size on maximum tensile strength, maximum compressive strength, and hardness :

Table 11 and Figure 12,13 show the effect of graphite grain size on the maximum tensile strength, maximum compressive strength and hardness. The results show that the maximum tensile strength, minimum compressive strength and maximum hardness are obtained when using fine grains.

3.3. Effect of MgO Grain Size on The Tribological and Mechanical Behavior:

3.3.1. Effect of MgO grain size on friction coefficient :
Tables 12,13 and Figures 14,15 show that using finer MgO will give a little increase in the mean friction coefficient with stable friction behavior.
There is no apparent change of friction behavior else where by changing MgO grain size.

3.3.2 Effect of MgO grain size on wear
Table 14 and Figure 16 show that the minimum specific wear rate is obtained for fine MgO grain size, while the maximum specific wear rate is obtained for coarse MgO grain size. It is known that MgO works as an agent in polymerization of the phenol formaldehyde, so finer MgO support the improvement of producing longer polymer chain, leading to better bonding of the lining materials

3.3.3: Effect of MgO grain size on maximum tensile strength, maximum compressive strength, and hardness:
Table 15 and Figures 17,18 show that fine MgO grain size gives higher tensile and compressive strength and hardness. This is again due to the fact that the fine MgO grain size will improve the polymerization of the lining material matrix.

3.4. Microscopic Scanning of Disk Surface After FAST Test.

An important factor in the evaluation of the friction material is that how the friction disk surface is affected [8]. Due to the similarity of the friction disk and friction test sample surfaces, scanning of disk surface was substituted by scanning the test sample surface. It was observed that using large brass chip size will cause large scars in the mating surfaces which lead to greater run-out or excessive wear of the friction disk life. This is illustrated in Figure 19 (Sample A2, Sample A6)

CONCLUSIONS

1. **Small brass chip size showed:**

   a- Decreased maximum friction coefficient, hence increased friction stability.
   b- Minimum specific wear rate.
   c- Increased maximum tensile and compression strengths, while the hardness was not affected by brass chip size change.

2. **Fine graphite grain size showed:**

   a- Maximum mean friction coefficient and stable friction behavior.
   b- Minimum specific wear rate.

c- Maximum tensile strength, minimum compressive strength and maximum hardness.

3. Fine MgO grain size showed:

a- Little increase in the mean friction coefficient with stable friction behavior.
b- Minimum specific wear rate.
c- Higher tensile and compressive strengths, and hardness.

REFERENCES

[1] Newcomb T.P. and Spurr R.T., "Friction Materials for Brakes", Tribology, Vol.4, 1971, pp. 75-81.

[2] Bedewy M.K., "Tribological Characteristics of Composite Brake-Lining Materials", Ph.D., Thesis, University of Salford, England, 1979.

[3] Rhee S. K., "Friction Coefficient of Automotive Friction Materials – Its Sensitivity to Load, Speed, and Temperature." SAE Trns. Paper 740415, 1974, pp. 1575.

[4] Schiefer H. M. and Kubezak G. V., "Controlled Friction Additives for Brake Pads and Clutches", SAE Paper No. 790717, Passenger Car Meeting, June 11-15, 1979.

[5] Tanaka K., Seichi, And Noguchi N., "Fundamental Studies on the Brake Friction of Resin-Based Friction Materials", Wear, 23, 1973, pp. 349-365

[6] El-Hemeily, M.A. "Automotive Brake Lining Analysis"; M.Sc. Thesis; Military Technical College, Cairo, 1999.

[7] Anderson A. E. and Knapp R.A., "Brake Lining Mechanical Properties, Laboratory Specimen Studies", SAE Paper No. 790715, Passenger Car Meeting, Hayatt Regency, Dearborn USA, June 11-15, 1979.

[8] Chapman B. J. and Rizkallah A. A. M. – Ellis, "Effect of the Surface Finish of Brake Rotors on the Performance of Brakes", Wear, 57, 1979, pp. 345-356.

Table 1: Friction Materials constituents

No.	Friction Material constituents	Function	% (About)
1	Asbestos fibers	Basic friction material	35%
2	Phenol formaldehyde	Matrix	20%
3	Barium sulphate	Filler	20%
4	Rubber Powder	Improve impact resistance	5%
5	Brass chips	Improve the thermal distribution	5%
6	Graphite	Control the hardness	4%
7	Magnesium oxide	As an agent in polymerization	4%
8	Carbon black	As a lubricant during manufacturing	1%
9	Zinc stearate	Control the water content	1%
10	Others	Friction and wear modifiers	5%

Table 2: Sieving Results of Brass Chips

Group	Size	Brass Call Name
1	<300 μm	A1
2	300-355 μm	A2
3	355-425 μm	A3
4	425-500 μm	A4
5	500-600 μm	A5
6	600-700μm	A6
7	>700μm	A7

Noting that: The dimensions listed above are the minimum chip dimensions that can pass throw the sieving trays. Samples of each group were manufactured in El-Yayat Factory.

Table 3: Sieving Results of Graphite and Magnesium Oxide Grains.

Group	Grain Size	Graphite Call Name	MgO Call Name
1	<11 μm	B1	C1
2	11-15 μm	B2	C2
3	15-25 μm	B3	C3
4	25-33 μm	B4	C4
5	33-44 μm	B5	C5
6	>44 μm	B6	C6

Table 4: FAST Results for Brass Group

Reference		Coefficient of Friction							
		Brass Chip Dimensions are in micrometer							
Temp. (°C)	Time (min)	(<300)	(300-355)	(355-425)	(425-500)	(500-600)	(600-700)	(>700)	Basic
52	5	0.31	0.38	0.41	0.33	0.28	0.33	0.25	0.37
104	10	0.33	0.4	0.45	0.5	0.5	0.48	0.38	0.41
132	15	0.37	0.45	0.5	0.51	0.56	0.53	0.46	0.47
160	20	0.39	0.48	0.53	0.53	0.58	0.54	0.53	0.54
179.5	25	0.43	0.5	0.55	0.56	0.6	0.55	0.54	0.6
199	30	0.44	0.58	0.55	0.57	0.58	0.58	0.54	0.63
214	35	0.43	0.59	0.6	0.58	0.62	0.57	0.63	0.59
229	40	0.41	0.533	0.6	0.55	0.57	0.62	0.65	0.64
242.5	45	0.43	0.55	0.6	0.57	0.54	0.65	0.65	0.6
252	50	0.39	0.53	0.56	0.54	0.53	0.62	0.64	0.57
259	55	0.38	0.5	0.54	0.58	0.5	0.55	0.65	0.52
266	60	0.37	0.48	0.52	0.55	0.49	0.54	0.57	0.55
271.5	65	0.36	0.43	0.45	0.53	0.48	0.53	0.55	0.52
277	70	0.35	0.4	0.45	0.48	0.47	0.48	0.55	0.5
281	75	0.33	0.39	0.4	0.49	0.42	0.49	0.54	0.5
285	80	0.34	0.37	0.39	0.44	0.4	0.47	0.53	0.47
287.5	85	0.36	0.35	0.41	0.4	0.43	0.48	0.53	0.43
290	90	0.37	0.36	0.38	0.43	0.402	0.42	0.45	0.47

- Basic refers to the actually used materials
- Dimensions are in μm

Table 5: Assessment of Stability of The Coefficient of Friction for Brass Group

Group	(<300)	(300-355)	(355-425)	(425-500)	(500-600)	(600-700)	(>700)	Basic*
f_{max}	0.44	0.59	0.6	0.58	0.62	0.65	0.65	0.64
f_{min}	0.31	0.35	0.38	0.33	0.28	0.33	0.25	0.37
f_{mean}	0.3772	0.4596	0.4938	0.5077	0.4973	0.5238	0.5355	0.5211
Δf	0.13	0.24	0.22	0.25	0.34	0.32	0.40	0.27
$\Delta f / f_{meam}$ [%]	34.5	52.2	44.5	49.2	68.4	61.1	74.7	51.8

- Basic refers to the actually used materials

Table 6: Specific Wear Rate of Brass Group

Sample	S.W.R. [10^{-7} cm^3 /N.m]
(<300)	0.34237
(300-355)	0.34895
(355-425)	0.36706
(425-500)	0.41479
(500-600)	0.42138
(600-700)	0.44442
(>700)	0.44936
Basic	0.39669

Table 7: Maximum Compressive Strength and Hardness Brass Group

Group Item	Maximum compressive Strength [MPa]	HR_P
(<300)	121.5	122
(300-355)	122	122
(355-425)	115	121
(425-500)	109.38	122
(500-600)	99	121.5
(600-700)	91	122
(>700)	85.6	122
Basic	107	122

Table 8: FAST Results for Graphite Group

Reference		Coefficient of Friction						
		Graphite grain size are in micrometers						
Temp. (°C)	Time (min)	(<11)	(11-15)	(15-25)	(25-33)	(33-44)	(>44)	Basic
52	5	0.38	0.43	0.49	0.48	0.26	0.28	0.37
104	10	0.44	0.45	0.54	0.53	0.41	0.51	0.41
132	15	0.54	0.49	0.56	0.56	0.41	0.55	0.47
160	20	0.58	0.53	0.6	0.56	0.48	0.61	0.54
179.5	25	0.59	0.58	0.61	0.58	0.53	0.63	0.6
199	30	0.6	0.6	0.59	0.64	0.54	0.64	0.63
214	35	0.64	0.63	0.6	0.63	0.59	0.64	0.59
229	40	0.63	0.62	0.55	0.56	0.55	0.57	0.64
242.5	45	0.62	0.58	0.53	0.58	0.57	0.54	0.6
252	50	0.603	0.55	0.51	0.57	0.54	0.53	0.57
259	55	0.59	0.54	0.49	0.56	0.52	0.52	0.52
266	60	0.57	0.53	0.48	0.54	0.5	0.5	0.55
271.5	65	0.56	0.52	0.48	0.53	0.49	0.546	0.52
277	70	0.54	0.51	0.48	0.51	0.46	0.527	0.5
281	75	0.53	0.5	0.48	0.49	0.44	0.56	0.5
285	80	0.51	0.45	0.48	0.48	0.44	0.535	0.47
287.5	85	0.48	0.44	0.48	0.47	0.43	0.56	0.43
290	90	0.45	0.43	0.48	0.46	0.42	0.4	0.47

- Basic refers to the actually used materials

Table 9: Assessment of Stability of the Coefficient of Friction for Graphite Group

Group	(11>)	(15-11)	(25-15)	(33-25)	(44-33)	(44<)	Basic
f_{max}	0.64	0.63	0.61	0.64	0.59	0.64	0.64
f_{min}	0.38	0.43	0.48	0.46	0.26	0.28	0.37
f_{mean}	0.54739	0.52111	0.52389	0.54056	0.47667	0.536	0.521111
Δf	0.26	0.20	0.13	0.18	0.33	0.36	0.27
Δf / f_{mean} [%]	47.5	38.4	28.8	33.3	69.2	67.2	51.8

- Basic refers to the actually used materials

Table 10: S.W.R. and Specific Gravity for Graphite Group

Sample	S.W.R. $[10^{-7} cm^3/N.m]$	specific gravity $[grams/cm^3]$
(<11)	0.404917	2.204
(11-15)	0.388457	2.207
(15-25)	0.413147	2.205
(25-33)	0.426315	2.208
(33-44)	0.446067	2.206
(>44)	0.452651	2.206
Basic	0.39669	2.204

Table 11: Max. Compressive Strength and Hardness for Group B

Group Item	Maximum compressive Strength [MPa]	Hardness HR_P
(<11)	90.8	124
(11-15)	92.3	123
(15-25)	96	122.5
(25-33)	99.4	122
(33-44)	109	122
(>44)	115	121
Basic	107	122

Table 12: FAST Results for MgO Group

Reference		Coefficient of Friction						
		MgO grain size are in micrometers						
Temp. (°C)	Time (min)	(<11)	(11-15)	(15-25)	(25-33)	(33-44)	(>44)	Basic
52	5	0.34	0.37	0.44	0.45	0.55	0.55	0.55
104	10	0.38	0.52	0.53	0.45	0.53	0.57	0.57
132	15	0.42	0.54	0.52	0.48	0.56	0.6	0.64
160	20	0.45	0.57	0.6	0.51	0.61	0.6	0.57
179.5	25	0.53	0.6	0.55	0.61	0.63	0.65	0.64
199	30	0.59	0.6	0.64	0.63	0.64	0.64	0.64
214	35	0.64	0.64	0.63	0.63	0.63	0.57	0.63
229	40	0.64	0.64	0.62	0.6	0.57	0.53	0.58
242.5	45	0.63	0.63	0.6	0.59	0.55	0.52	0.54
252	50	0.625	0.6	0.58	0.58	0.53	0.51	0.53
259	55	0.62	0.56	0.56	0.57	0.52	0.5	0.53
266	60	0.61	0.53	0.55	0.54	0.5	0.5	0.52
271.5	65	0.6	0.52	0.53	0.5	0.48	0.49	0.51
277	70	0.58	0.51	0.5	0.48	0.47	0.48	0.48
281	75	0.56	0.48	0.48	0.48	0.46	0.47	0.47
285	80	0.55	0.47	0.47	0.47	0.43	0.46	0.46
287.5	85	0.54	0.47	0.47	0.46	0.43	0.45	0.45
290	90	0.52	0.45	0.46	0.43	0.42	0.43	0.45

- Basic refers to the actually used materials.

Table 13: Assessment of Stability of the Coefficient of Friction For The MgO Group:

Group	(<11)	(11-15)	(15-25)	(25-33)	(33-44)	(>44)	Basic
f_{max}	0.64	0.64	0.64	0.63	0.64	0.65	0.64
f_{min}	0.34	0.37	0.44	0.43	0.42	0.43	0.37
f_{mean}	0.546	0.539	0.541	0.526	0.528	0.529	0.521
Δf	0.30	0.27	0.20	0.2	0.22	0.22	0.27
$\Delta f / f_{mean}$ [%]	47.6	37.1	24	34.2	62.5	68.1	51.8

- Basic refers to the actually used materials

Table 14: S.W.R. and Specific Gravity for MgO Group

Sample	S.W.R. [10^{-7} $cm^3/N.m$]	specific gravity [gm/cm^3]
(<11)	0.353837	2.368
(11-15)	0.390486	2.351
(15-25)	0.455965	2.309
(25-33)	0.490111	2.163
(33-44)	0.514751	2.109
(>44)	0.534654	2.085
Basic	0.39669	2.204

Table 15: Max Compressive Strength and Hardness for MgO group

Group Item	Maximum compressive Strength [Mpa]	Hardness HR_P
(<11)	115	123
(11-15)	112.4	123
(15-25)	110	122
(25-33)	105	121.5
(33-44)	104.7	121
(>44)	98.4	120
Basic	107	122

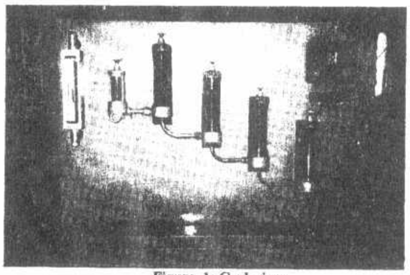

Figure 1: Cyclosizer

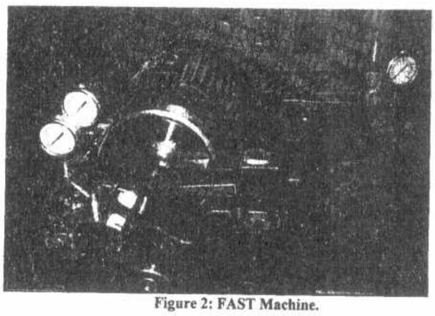

Figure 2: FAST Machine.

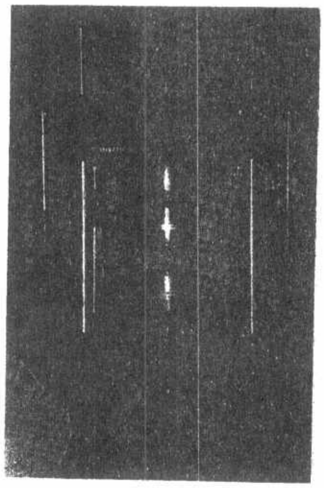

Figure 3: Instron Machine.

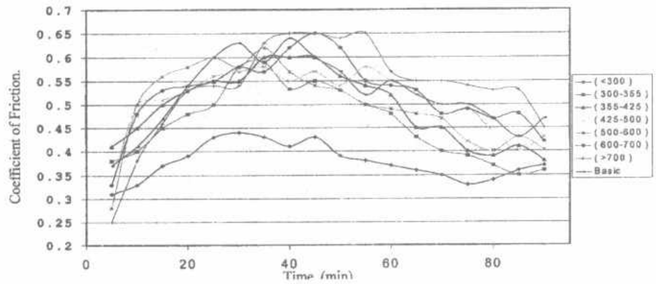

Figure 4: Coefficient of Friction Against Time (min.) for Brass Groups

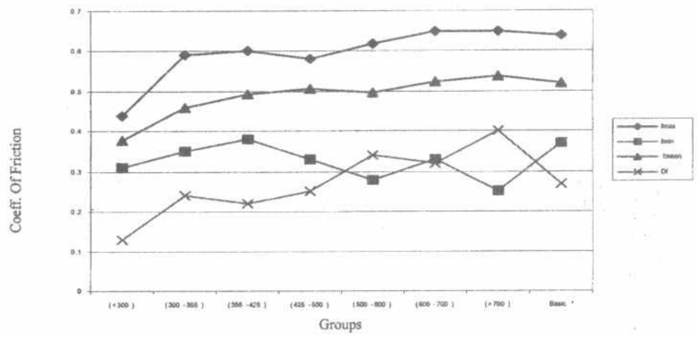

Figure 5: Assessment Of Stability Of The Coefficient Of Friction For The Brass Group

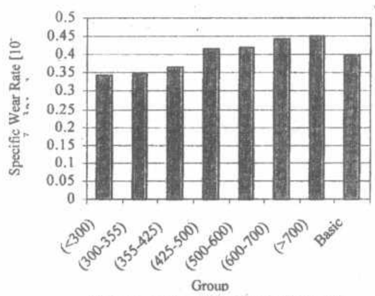

Figure 6: Specific Wear Rate of Brass Group

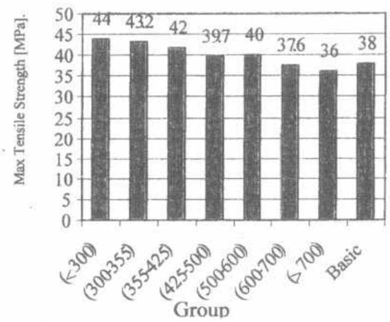

Figure 7: The Maximum Tensile Strength for Brass Group

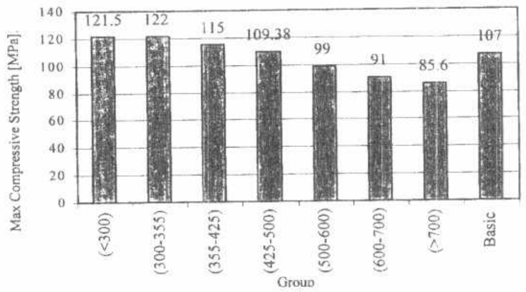

Figure 8: Maximum Compressive Strength for Brass Group

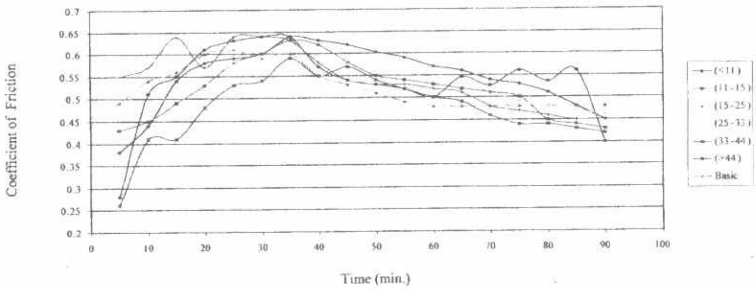

Figure 9 : Coefficient of Friction Variation With Time for Graphite Group

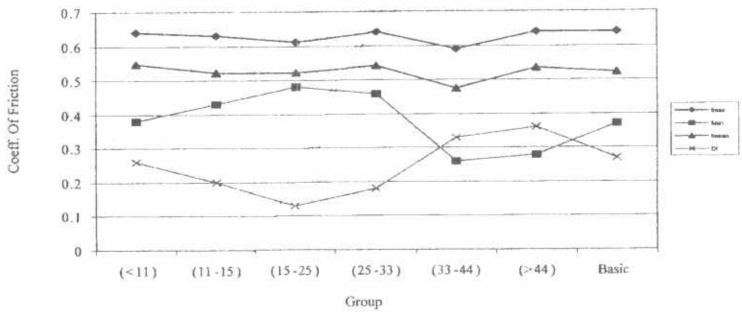

Figure 10: Assessment of Stability of Coefficient of Friction for Brass Graphite Group

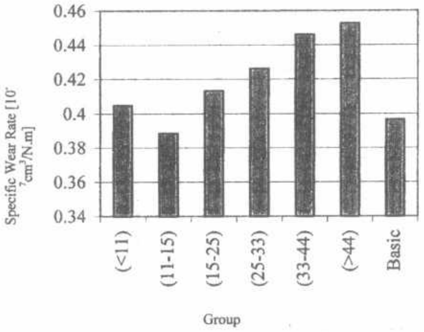

Figure 11: Specific Wear Rate For The Graphite Group

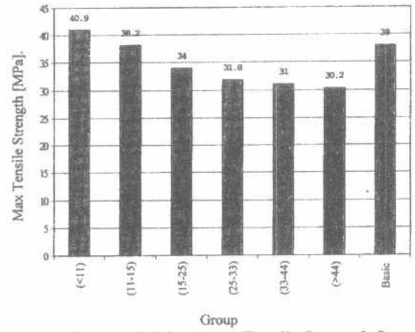

Figure 12: Maximum Tensile Strength for Graphite Group

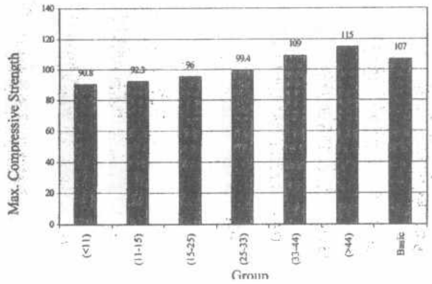

Figure 13: Maximum Compressive Strength for Graphite Group

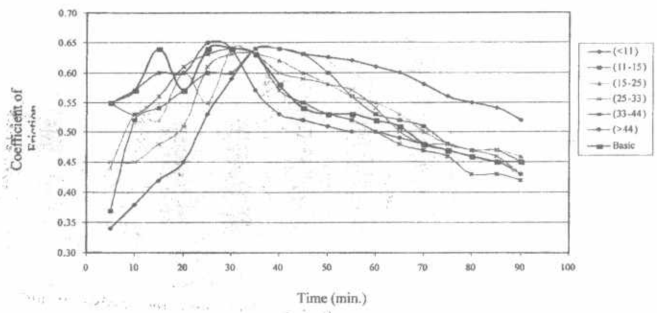

Figure 14: Coefficient of Friction Against Time for MgO Group

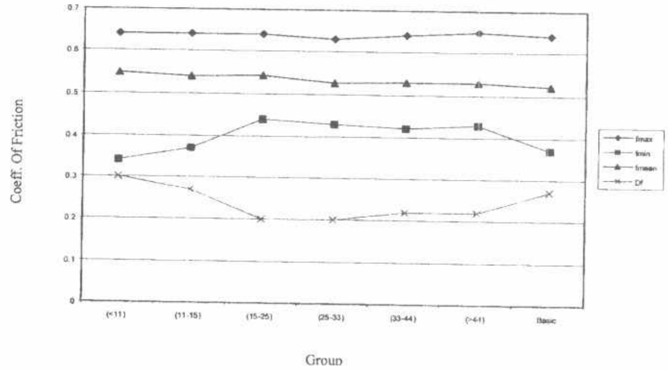

Figure 15: Assessment of Stability of the Coefficient of Friction for MgO Group

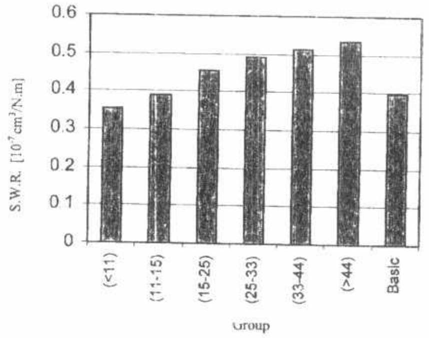

Figure 16 : Specific Wear Rate for the Graphite Group

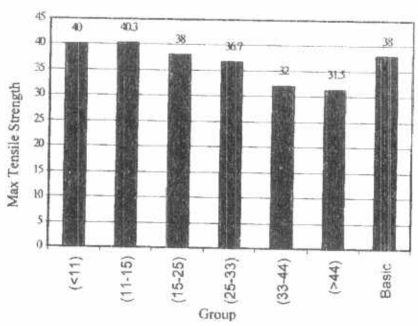

Figure 17: Maximum Tensile Strength For MgO Group

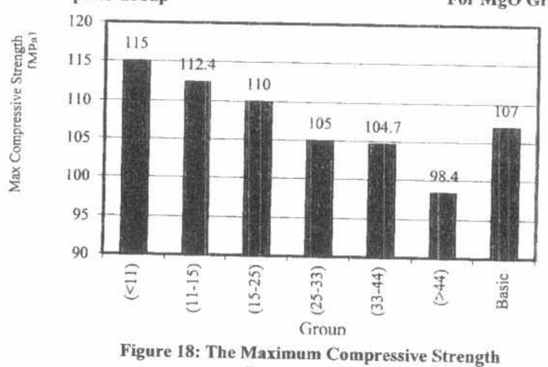

Figure 18: The Maximum Compressive Strength For MgO Group

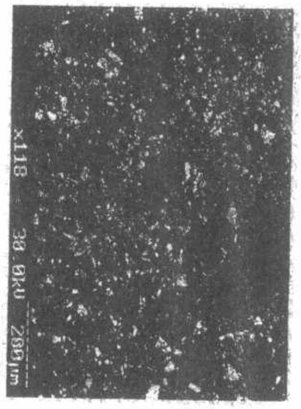

Figure 19: Sample A2

Figure 20 :Sample A6