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(54) Titre : ALLIAGE DE FONTE CONTENANT DU MOLYBDENE
(54) Title: IRON ALLOY CONTAINING MOLYBDENUM

(57) Abrégé/Abstract:

An iron alloy comprises 1.5-4.5 % carbon, 1.5-4.5 % silicon, at least 1.0 to 6.5 % molybdenum and optionally copper and/or nickel wherein (% Mo + % Ni + % Cu) does not exceed 6.5 %, balance iron and incidental impurities. The alloy is preferably spheroidal graphite cast iron. The alloy is especially useful in manufacturing brake disc rotors.

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(54) Title: IRON ALLOY CONTAINING MOLYBDENUM

(57) Abstract

An iron alloy comprises 1.5–4.5 % carbon, 1.5–4.5 % silicon, at least 1.0 to 6.5 % molybdenum and optionally copper and/or nickel wherein (% Mo + % Ni + % Cu) does not exceed 6.5 %, balance iron and incidental impurities. The alloy is preferably spheroidal graphite cast iron. The alloy is especially useful in manufacturing brake disc rotors.

IRON ALLOY CONTAINING MOLYBDENUM

The present invention relates to iron alloys and processes for their production. Iron alloys in accordance with the invention are particularly suitable for use in disc brakes for vehicles and in other vehicular, especially automatic 5 components.

Disc brakes were introduced into motor cars in the late 1950's. Disc brakes comprise a disc or rotor that is rigidly connected to the vehicle wheel hub. Two or more pads close by caliper action onto the disc or rotor in order to stop rotation of the disc or rotor and hence brake the vehicle. The pads have a friction lining 10 which used to be composed of an asbestos material. The asbestos material served to substantially protect the pads from heat and mineral attack. However, in view of the extreme toxicity of asbestos, brake pads are now generally composed of a friction material which contains 10-20% volume resins, 0-10% volume friction modifiers, 0-10% volume metal powders, 20-40% volume fillers and 10-50% 15 volume fibers (asbestos, metal, fibreglass and synthetic mineral fibres).

Since the introduction of disc brakes, gray cast iron has been the material of choice for manufacture of the discs or rotors. Compared with nodular cast iron, gray cast iron has greater thermal conductivity, a lower modulus of elasticity and is dimensionally stable above 500°C. Nodular cast irons have been considered to be 20 unsuitable for use in disc brakes because they exhibit a too low thermal resistance.

Although gray cast iron has many properties that make it especially suitable for use in disc brakes, it does have the drawback of relatively low tensile strength. A number of authors have tried to address this drawback.

Jimbo et. al., in SAE Publication No. 900002, entitled "Development of 25 High Thermal Conductivity Cast Iron for Brake Disc Rotors" discussed problems of cracking in disc brakes. The authors concluded that gray cast iron would be the most suitable rotor material in terms of crack resistance, due to its high thermal conductivity. The authors also concluded that the gray cast iron should have a high carbon level (to maximise thermal conductivity), a low silicon level and as 30 low a level as possible of an alloying ingredient to increase strength. The authors decided to add molybdenum as the single alloying agent added to the gray cast iron. The authors tested a number of cast iron alloys having molybdenum contents

in the range of 0.32-0.68% and concluded that the cast iron alloy should have a composition of 3.7-4.0% C, 1.4-2.0% Si and 0.5-0.6 Mo, balance iron and incidental impurities.

Australian Patent No. 426529 (19758/67) in the name of Westinghouse Air Brake Company related to a cast metal composition for disc brake rotors. This patent discusses difficulties encountered in fractures in the web of brake rotors when made from gray cast iron. One postulated solution was to use nodular or ductile cast iron which had sufficient strength to avoid this failure but the braking surface was subject to warping. This clearly caused that material to be unsuitable.

The patent proposed a chromium-nickel cast iron having a composition of 3.20-3.55% carbon, 0.15-0.25% chromium, 1.15 to 1.35% nickel, 0.30 to 0.50% molybdenum, 0.50 to 0.80% manganese, 1.80 to 2.00% silicon, less than 0.10% phosphorus, less than 0.08% sulphur, balance iron. The alloy had a microstructure comprising uniform fine-grained pearlite in which a minimum of 75% type A plate graphite is evenly distributed.

Japanese Patent Application No. 60-52553 in the name of Sumitomo Kinzoku Kogyo K.K. discloses a steel for a disc brake rotor having 0.1-0.6% carbon, less than 0.8% silicon, less than 3% manganese, 0.2-5.0% nickel and optionally containing one or more of 0.5-5.0% aluminium, 0.1-3.0% copper, 0.2-3.0% titanium and 0.1-5.0% Mo. This steel is described as having a braking resistance equivalent to that of cast iron without spoiling the excellent resistance to thermal cracking of the forged steel rotor.

United States Patent No. 5,323,883 in the name of Mibe et. al. (assigned to Nissan Motor Company, Limited) relates to an automotive brake system. The brake system includes a rotor made of graphitic cast iron consisting of 3.5-4.0% carbon, 1.6-2.0% silicon, 0.5-0.8% manganese, 0.4-1.2% molybdenum, the remainder essentially iron. The matrix structure of the composition is in the form of a pearlite. This patent emphasises the importance of obtaining good thermal conductivity in materials used for disc brakes. The patent also states that if more than 1.2% Mo is added, carbides or casting defects can be created, thereby setting the upper level of molybdenum at 1.2%. Manganese is also an essential component of the metal alloy.

United States Patent No. 1,762,109 in the name of Taylor et. al. discloses a cast iron alloy which may be easily hardened and which may be more readily machined than ordinary cast iron. The cast iron alloy consists of 1.0-4.0% carbon, 0.5-2.5% silicon, 1.0-4.0% nickel and up to 1.0% molybdenum, balance iron and 5 incidental impurities. The alloy is useful for manufacturing articles in which some portions have a hardened surface and other portions are relatively soft for machining and other purposes, such as tappets, cylinder blocks and pistons.

United States Patent No. 3,095,300 in the name of Moore et. al. discloses a cast iron composition that includes 1.2-5.3% manganese and 0.40-0.80% 10 molybdenum and that provides a cast iron that is machineable as-cast and which can be hardened in air.

United States Patent No. 3,798,027 to Defrancio et. al. discloses a high strength, low hardness gray cast iron that consists of 1-3% aluminium, 2-4% carbon, up to 1% silicon and the balance iron, the alloy also having been 15 inoculated with an inoculant selected from calcium, strontium and barium. This patent suggests that in order to obtain certain particular properties, such as heat resistance or corrosion resistance, various quantities of alloying elements must be added, including, 0-6% copper, 0-12% nickel, 0-5% chromium, 0-2% molybdenum, and 0-1% zirconium.

20 United States Patent No. 3,902,897 to Sobue et. al., discloses a spheroidal graphite cast iron consisting of 2.3-4.2% C, 1.5-5.0% Si, not more than 1.0% Mn, 1.5-6.0% Ni, 0.1-1.0% Mo, 0.2-2.0% Al, up to 0.1% of a spheroidizing agent, balance Fe. The patent clearly discusses the importance of Al in the alloy and also states that a Mo content of 1.0 results in a large amount of carbide being formed in 25 the as-cast state, which results in a too high hardness. The patent clearly states that the maximum amount of Mo is 1.0%.

United States Patent No. 4,166,756 to Geyes et. al. relates to the metallurgy of wear resistant damping elements used in railroad car trucks. In particular, this 30 patent relates to the chemical composition and process control parameters, such as pouring temperature, dumping from the mould temperature and cooling rate in order to develop the desired microstructure in the castings. The alloy used has a chemical composition consisting of 3.00-3.30% carbon, 1.20-1.50% silicon, 0.85-

1.00% manganese, 0.80-0.90% Molybdenum, 1.40-1.60% (nickel plus copper), balance iron. The process for forming castings from that chemistry is described as critical.

United States Patent No. 4,450,019 to Satou et. al. describes a ductile cast iron which exhibits high resistance to oxidation at high temperatures and thermal fatigue when used as a material for automobile exhaust manifolds. The cast iron consists of 2.5-3.8% carbon, 3.5-4.8% silicon, 1.0% or less manganese, 0.1% or less phosphorus, 0.1% or less sulphur, 0.5-2.0% molybdenum, 0.03-0.1% magnesium, at least one of cerium and lanthanum in an amount of 0.02-0.5%, balance iron. If silicon is present in an amount of less than 3.5%, a protective layer of SiO_2 cannot form on the exhaust manifold and casting defects, such as shrinkage cavities, tend to result due to the degree of saturation of carbon. Cerium and lanthanum are essential elements of the composition. If Ce and La are present at less than the lower limit of 0.02%, silicon will not disperse towards the surface region of the casting (which is required to form the protective SiO_2 layer on the casting) and the property of Mo inhibiting the resistance to oxidation satisfactorily. Thus, Ce and La must be present in order to counteract the deleterious properties of the molybdenum present in the alloy.

In United States Patent No. 4,153,017 to Behnke, tappets for internal combustion engines were made from an iron alloy consisting of 3.10-3.60% carbon, 2.00-2.90% silicon, 0.60-0.90% manganese, 0.20-0.80% chromium, 0.30 to 0.60% nickel, 1.50 to 5.00% molybdenum, 0.10-0.50% vanadium, balance iron. Molybdenum was chosen as the main alloy element for several reasons, one of which was that molybdenum forms two types of carbide: a face-centred cubic M_{23}C_6 iron-molybdenum carbide and an orthorhombic Fe_3C cementite carbide. The M_{23}C_6 type carbide is more stable. The chromium and vanadium are added to the alloy in order to dissolve the cementite type carbides, showing the criticality of adding Cr and V.

Attempts have also been made to manufacture automotive parts, such as brake rotors, from metal matrix composites (MMC's). For example, United States Patent No. 5,261,511 in the name of Libsch describes a brake rotor made from a composition having from 20-80 vol% silicon carbides and 80-20 vol% of an iron

alloy. The patent states that the iron alloy consists essentially of 0.4-4.0% carbon (by weight), 1.8-18.0% silicon, 1.0-10.0% X, where X is selected from a group consisting of Cr, Mo, Cu, Mn, Ni, P and S, balance iron. Although this patent quotes a broad range of 1.0 to 10.0% for X, the only example shows that X is present in an amount of 1.51% by weight and is made up of Cr (0.13), Mo (0.08), Cu (0.28), Mn(0.75), Ni (0.13), P (0.06) and S (0.08). The patent also states that the metal matrix composite, which incorporates 20-80% of silicon carbide particles and 80-20% of the iron alloy, is an effective material for manufacturing brake rotors. No mention at all is made of the suitability of the iron alloy by itself as a material for manufacture of the brake rotor and the patent specifically requires the presence of silicon carbide particles.

United States Patent No. 3,909,252 to Kuriyama et. al. describes a wear resistant and self lubricating cast iron. The cast iron consists of 1.0-3.5% carbon, 0.5-3.5% silicon, 0.1-1.5% manganese, 0.1-2.0% chromium, 1.0-15.0% cobalt, 0.5-10.0% molybdenum, 0.1-5.0% nickel, 0.05-2.0% niobium, 0.001-0.1% boron, balance iron. This cast iron, which contains a large amount of cobalt and additions of chromium and niobium, is especially suitable for manufacturing piston rings.

United States Patent No. 3,559,775 in the name of Miller describes a brake rotor made from a hypereutectic gray cast iron composition consisting of 3.6-4.0% carbon, 2.5-4.0% silicon and up to about 2% of one or more pearlite stabilising elements, and iron. The pearlite stabilising elements may be manganese, chromium, copper, tin and molybdenum. Although the patent states that the specified pearlite stabilising elements may be used alone or in combination, the only example that included molybdenum as a pearlite stabiliser utilised 0.10-0.20% molybdenum, and the molybdenum was used in combination with chromium. The chemically uncombined carbon was present in the form of relatively large discrete bodies of graphite of ASTM type A (i.e. flakes of graphite).

It is an object of the present invention to provide an iron alloy that is particularly suitable for use in manufacturing disc brake rotors, and can also be used in manufacturing a wide variety of other automotive components and other articles.

- 6 -

According to a first aspect, the present invention provides an iron alloy containing from 1.5-4.5% by weight carbon, from 1.5-4.5% by weight silicon and from 1.2 to 6.5% by weight molybdenum, optionally nickel and copper and wherein (molybdenum + nickel + copper) does not exceed 6.5% by weight, balance iron and incidental impurities.

Throughout the specification, all percentages will be expressed as percentage by weight.

The amount of carbon preferably falls within the range of from 1.5 to 3.8, more 10 preferably 3.0 to 3.5%, more preferably from 3.0 to 3.35%, most preferably about 3.25%.

The amount of silicon in the iron alloy preferably falls within the range of from 1.9 to 2.5%, and more preferably from 2.1 to 2.3%.

Molybdenum is an essential component of the alloy and is present in an amount 15 of at least 1.2%. Molybdenum is preferably present in an amount of at least 1.2% to 4.5%, more preferably at least 1.2% to 3.0%. It has been found that an alloy containing 1.5% molybdenum is suitable for use in the disc brake rotors of passenger cars whilst disc brake rotors for racing cars advantageously contain 3.0% molybdenum.

In an especially preferred embodiment of the present invention, the iron alloy is 20 a spheroidal graphite cast iron.

Nickel and/or copper may also be present and function as alloy modifiers to improve the strength and refine the structure of the alloy. Preferably nickel is present in an amount of 0.1 to 4.5%, more preferably 0.1 to 3.5% and most preferably 1%. The amount of copper is preferably 0.1 to 4.5%, more preferably 0.1 to 3.5% and most 25 preferably 1%. The total amount of molybdenum and nickel and/or copper should not exceed 6.5%.

The incidental impurities may include manganese, sulphur and phosphorus. The amount of impurities is generally in the range of 0.1 to 0.8%, preferably 0.04% sulphur and 0.04% phosphorus.

A particularly preferred alloy of the present invention contains 3 to 3.35% carbon, 1.9 to 2.5% silicon and at least 1 to 3% molybdenum, the balance being iron and incidental impurities.

For disc brakes rotors for racing cars, a preferred composition of the alloy 5 includes 3.5 to 4.5% carbon, 2.1 to 2.3% silicon, 2.5 to 3.5% molybdenum, balance iron and incidental impurities, more preferably 3.7-3.8% carbon, about 3.0% molybdenum, 2.1-2.3% silicon, balance iron and incidental impurities. Nickel and/or copper may optionally be included in the amounts specified above.

The carbon equivalent (CE) of this particularly preferred alloy is generally 10 3.8.

Carbon equivalent is determined by the following formula:

$$C.E. = \%C + \frac{1}{3} (\% Si) \quad (1)$$

Although nickel and/or copper may optionally be included in the alloy of the present invention in the amounts indicated above without substantial 15 deleterious effects being observed, in one embodiment it is preferred that deliberate additions of nickel and copper to the alloy be minimised or avoided altogether. It is especially preferred that the iron alloy of the present invention have nickel and/or copper present in impurity amounts only.

Similarly, the addition of further alloying components is preferably avoided. 20 In particular, chromium, manganese, vanadium, and rare earth metals should be present in the iron alloy of the present invention at substantially zero levels, and certainly no higher than impurity levels. Chromium and manganese act to increase the hardness of the alloy, thereby making it difficult to machine. Further alloying elements would also undesirably increase the cost of making the alloy and could 25 have unknown or undesirable effects on the microstructure and/or the physical properties of the alloy.

In preferred embodiments of the present invention where the iron alloy is a spheroidal graphite cast iron (also known as nodular cast iron), the iron alloy will 30 also contain small amounts of one or more spheroidizing agents. Spheroidizing agents typically include some magnesium and accordingly the iron alloy may include small amounts of magnesium. Alternatively or additionally, the iron alloy

may contain small amounts of elements used in other spheroidizing agents known to be suitable to the man skilled in the art. The spheroidizing agent is preferably present in a maximum amount of 0.1% to 0.2%.

5 The most preferred iron alloy of the present invention comprises 3 to 3.35% carbon, 2.1-2.3% silicon, at least 1.0 to 3% molybdenum, balance iron and incidental impurities, in which the iron alloy is a spheroidal graphite cast iron.

Molybdenum is the main alloying element added to the iron alloy of the present invention. It has been found that molybdenum has a stabilising effect on the alloy in that it acts to suppress phase transitions in the alloy as temperature 10 changes occur. When used in the manufacture of disc brake rotors, braking causes the rotors to heat up and cool down. The stabilising effect of the molybdenum minimises or avoid phase transitions which thereby assist in maintaining dimensional stability of the rotors and minimises or avoids cracking of the rotor. It is believed that molybdenum also increases the thermal conductivity of the alloy to 15 thereby assist in improving heat dissipation from the rotors. Molybdenum also refines the grain to produce an alloy having a fine grain size.

The present inventor has conducted extensive searching of prior art literature and has not located any document that discloses an iron alloy having the composition specified herein. Another distinguishing feature of the present 20 invention lies in providing the specified composition in the form of a spheroidal graphite cast iron.

The iron alloy of the present invention is especially suitable for use in manufacturing disc brake rotors for vehicles, such as automobile, airplanes and trains.

25 According to another aspect, the present invention provides a disc brake rotor, characterised in that it is composed wholly or partly of the iron alloy of the first aspect of the present invention. When the iron alloy of the present invention is used in the manufacture of disc brake rotors, it has been found that the disc rotors exhibit reduced wear. Shudder, cracking and squealing, when compared 30 with conventional disc brakes manufactured from gray cast iron, is also reduced.

Although the iron alloy of the present invention is especially suitable for manufacturing disc brake rotors, it will be appreciated that a wide variety of other

articles may be made from the iron alloy of the present invention. Examples of other articles that may be made from the iron alloy of the present invention include vehicle, aircraft or ship parts including, keels, cylinder heads, cylinder blocks and wheels; ash and dust systems, pulverised fuel lines, wear plates for air control or 5 burner boxes, particularly for use in power stations; pump bodies and covers; pipework; crusher parts; gear wheels and pinions; wear plates; dust feeding valves; water supply valves; couplings and other pipe connectors; cast flights; manhole covers and frames; grates; rollers; camshafts; crankshafts; knuckle joints on suspension systems; flywheels; and clutch plates; truck brake rotors; and brake drums 10 for vehicles.

According to another aspect of the present invention there is provided a process for the production of an iron alloy as described herein comprising the steps of:

- 15 a) providing a melt including iron, silicon, carbon, molybdenum and optionally copper and/or nickel; and
- b) casting the melt.

Preferably, step (a) includes the step of melting cast iron, ferro silicon alloy, recarburiser and ferro molybdenum alloy. An inoculant may also be added to the melt. The melt is also preferably treated with a spheroidizing agent to cause any 20 chemically uncombined carbon to be present in the cooled alloy in the form of spheres or nodules, rather than flakes.

The melting step (a) may be performed in any suitable apparatus such as a furnace, for example, an induction furnace. The ingredients melted are preferably well mixed so that the alloy elements are distributed throughout. The 25 temperature of the furnace is preferably above about 1350°C. The melt in the furnace is then advantageously tapped into a preheated ladle. The iron alloy may be cast iron, spheroidal graphite (SG) iron or structural steel. Preferably the iron alloy is, for example, BHP-300PLUSTM which contains 0.22% C, 0.50% Si, 1.6% Mn, 0.040% P, 0.040% S and a CE of 0.45. Other elements such as 0.40% Cu, 0.50% Ni, 30 0.30% Cr and 0.10% Mo may be present in the base iron alloy added to the melt, provided that their total content does not exceed 1.00%.

Preferably, the ferro silicon alloy contains 70 to 75% Si and 1.5 to 2% Al, the balance being iron and incidental impurities.

The recarburiser serves to increase the amount of carbon present in the alloy and may be a crushed electrode material, for example, CarboninTM 101 which contains 5 98.0% carbon, 1.0% moisture, 0.5% volatile matter, 1.0% ash, 0.07% sulphur and 0.02% nitrogen.

Preferably the ferro molybdenum alloy contains 67% Mo, 1% Si, 0.6% S and 0.04% P, the balance being iron and incidental impurities.

After step (a), the melt may be optionally subjected to a metal treatment such 10 as spheroidizing which converts flakes into spheres. This can be achieved by adding a magnesium ferro silicon alloy which suitably contains 6.3% Mg, 46.6% Si, 0.82% Al, 1.09% Ca and 0.99% Re, the balance being iron and incidental impurities. Other spheroidizing agents known to the person of skill in the art may also be used, including nickel magnesium ferro silicon spheroidizing agents.

15 The inoculant of step (b) refines the grains of the alloy and is preferably ZL80TM which contains 71% Si, 1.6% Al, 1.89% Zr and 0.83% Ca, the balance being iron and incidental impurities.

A nodularity modifier such as SpherofluxTM may then be added to the melt if 20 desired.

The casting step preferably occurs before fade takes place otherwise the castings may be inferior. It is generally preferred that casting occur up to 10 minutes after addition of the inoculant, more preferably about 7 minutes. Castings are advantageously allowed to cool in the moulds, preferably overnight.

The invention will now be described with reference to the following 25 examples and Figures. These examples and Figures are not to be construed as limiting the invention in any way. In the Figures:

Figure 1 is a graph showing the results of an inertial dynamometer disc brake wear test for a disc rotor made from an iron alloy in accordance with the present invention;

30 Figure 2 is a graph showing the results of an inertial dynamometer disc brake wear test for an original equipment (OE) disc rotor;

Figures 3 and 4 show the results of low pressure wear tests using rotors made in accordance with the present invention and OE rotors;

Figure 5 shows a photomicrograph of the cast edge of an etched test bar in accordance with the present invention at magnification x100;

5 Figure 6 shows a photomicrograph at magnification x100 of a mid-radius section of the test bar in accordance with the present invention;

Figure 7 shows a photomicrograph of the general area of the test bar shown in Figure 6, but at magnification x500; and

10 Figure 8 is a photomicrograph similar to Figure 7 but at a magnification of x200.

Example 1

The following ingredients were added to an induction furnace in the specified amounts:

	<u>Ingredient</u>	<u>Amount (kg)</u>
15	BHP-300 PLUS iron alloy	400
	Ferro silicon alloy	13.2
	Carbonin 101 recarburiser	16.2
	Ferro molybdenum alloy	8

The ingredients were melted in the furnace at 1400°C. The melt was then 20 treated with 7 kg of a magnesium ferro silicon alloy which acts as a spheroidizing agent, 1.2 kg of an inoculant ZL80 and 0.8 kg of Spheroflux which is a nodularity modifier. The melt was stirred thoroughly so as to ensure adequate distribution of the alloy. Casting of the melt in a teapot ladle occurred within 7 minutes so as to ensure that there was no fade. The castings were then poured into moulds and allowed to 25 cool overnight.

The resultant iron alloy had the following composition:

3.25% carbon;
2.1% silicon;
1.5% molybdenum; and
30 93.15% iron and incidental impurities.

This alloy product was shown to reduce shudder and squeal in the disc brakes of normal passenger cars.

Example 2

The same procedure as described in Example 1 was followed except that the following ingredients were added to the induction furnace in the specified amounts:

Ingredient	Amount (kg)
5	BHP-300 PLUS iron alloy 400
	Ferro silicon alloy 13.2
	Carbonin 101 recarburiser 16.2
	Ferro molybdenum alloy 16

The resultant iron alloy had the following composition:

10 3.25% carbon;
2.1% silicon;
3.0% molybdenum; and
91.65% iron and incidental impurities.

This alloy product was shown to reduce shudder and squeal in the disc brakes of racing cars.

Example 3

In order to test the suitability of the iron alloy in accordance with the present invention for use in the manufacture of disc rotors for disc brakes, a set of disc rotors were manufactured using the iron alloy of Example 1. These disc rotors were then subjected to testing by a leading Australian brake company. The testing included:

- Low pressure wear test, which simulates rotor wear in a low pressure, off-load position;
- DTV dynamometer test, which equates to 20,000km of normal vehicle usage;
- full inertia dynamometer test, which simulate wear in normal driving conditions;
- damping test, which measures disc rotor noise; and
- cracking test, which involves bench testing at various simulated speeds at different standard rates.

Tables 1 and 2 below give the raw data obtained from the inertia dynamometer disc brake wear test for rotors made from the iron alloy in accordance with the present invention (Table 1) and for original equipment (OE) disc rotors (Table 2). These results are shown graphically in Figures 1 and 2.

TABLE 1

Part Number	Part A (mm)	Part B (mm)	SD (mm)	Mean (mm)	SD (mm)	Mean (mm)
1	23.958	23.945	23.929	23.914	23.912	23.893
2	23.96	23.95	23.93	23.915	23.911	23.889
3	23.959	23.947	23.931	23.913	23.911	23.891
4	23.961	23.949	23.932	23.914	23.914	23.891
5	23.959	23.947	23.931	23.914	23.914	23.871
6	23.958	23.948	23.931	23.913	23.911	23.889
7	23.96	23.948	23.929	23.913	23.913	23.889
8	23.959	23.946	23.923	23.912	23.914	23.889
9	23.958	23.945	23.921	23.912	23.914	23.89
10	23.957	23.944	23.922	23.912	23.916	23.891
11	23.958	23.943	23.924	23.912	23.916	23.892
12	23.956	23.943	23.927	23.912	23.916	23.892
13	23.957	23.944	23.929	23.912	23.917	23.888
14	23.958	23.945	23.93	23.914	23.917	23.885
15	23.96	23.946	23.932	23.914	23.917	23.885
16	23.961	23.946	23.93	23.914	23.912	23.89
Avg Wear (um)	0.005	0.013	0.018	0.015	-0.001	0.025
D.T.V. (um)	0.005	0.007	0.011	0.003	0.006	0.008
Weight	6923.7	6921.6	6917.9	6915.2	6913.5	6908.6
Weight Loss		2.1	3.7	2.7	1.7	4.9

TABLE 2

Position	Pre-Roll	Post-Roll	30 Deg C	75 Deg C	100 Deg C	125 Deg C
1	23.904	23.9	23.893	23.858	23.849	23.798
2	23.905	23.902	23.894	23.86	23.852	23.802
3	23.904	23.901	23.894	23.859	23.854	23.801
4	23.903	23.9	23.895	23.86	23.852	23.798
5	23.904	23.901	23.894	23.857	23.849	23.801
6	23.904	23.902	23.894	23.86	23.848	23.8
7	23.905	23.902	23.893	23.86	23.851	23.8
8	23.904	23.903	23.893	23.86	23.848	23.8
9	23.905	23.903	23.895	23.86	23.849	23.801
10	23.905	23.903	23.894	23.86	23.854	23.803
11	23.905	23.902	23.806	23.857	23.85	23.802
12	23.904	23.901	23.895	23.861	23.85	23.802
13	23.905	23.902	23.895	23.861	23.85	23.803
14	23.903	23.901	23.894	23.861	23.85	23.803
15	23.904	23.901	23.895	23.86	23.851	23.806
16	23.904	23.902	23.895	23.862	23.855	23.806
Avg Wear (um)		0.003	0.007	0.035	0.009	0.049
D.T.V. (um)	0.002	0.003	0.003	0.005	0.007	0.008
Weight	0	0	0	0	0	0
Weight Loss		0	0	0	0	0

5 The total wear determined by this test for rotors made from the alloy of the present invention was 0.069mm, whereas the original equipment (OE) rotors showed total wear of 0.102 mm.

Figures 3 and 4 shows the results of the low pressure wear test using rotors made in accordance with the present invention (referred to in Figures 3 and 4 as 10 "Camcast rotor") and OE rotors. Unfortunately, difficulties with the testing procedure, possibly in the data capture, resulted in Figures 3 and 4 showing some anomalous results, particularly with regard to wear appearing to decrease at increased

loads. These tests are being run again but the results are not yet available. However, the data in Figures 3 and 4 that can be reliably interpreted shows that disc rotors in accordance with the present invention display superior wear properties to the OE rotors.

5 Shudder tests were also conducted. The brake company that conducted these tests used an internal ranking scale and rated disc rotors in accordance with the present invention at 8.5 out of 10. OE rotors normally rate at 5-6 out of 10. The shudder test also noted that there was no apparent shudder recorded.

Example 4

10 A disc thickness variation (DTV) test was conducted on four disc rotors made from an alloy in accordance with the invention. The results of this test are tabulated in Table 3, which show only a very small variation in the thickness of the disc rotor.

TABLE 3

DISC NO 1		D T V
10mm from outer edge		
outer	inner	
0	0	0
0	-1	-1
1	-2	-1
2	-3	-1
3	-4	-1
4	-5	-1
5	-6	-1
6	-6	0
7	-6	1
9	-7	2
9	-8	1
11	-10	1
12	-11	1
13	-11	2
13	-11	2
13	-11	2
14	-11	3
14	-12	2
15	-12	3
15	-13	2
15	-14	1
16	-14	2
15	-14	1
15	-13	2
15	-12	3
14	-12	2
13	-11	2
12	-10	2
11	-9	2
10	-8	2

DISC NO. 2		D T V
10mm from outer edge		
outer	inner	
0	-1	-1
1	-1	0
1	0	1
2	-3	-1
3	-3	0
	-4	-1
4	-3	1
4	-5	-1
5	-5	0
5	6	-1
5	-6	-1
6	-6	0
6	-8	-2
7	-9	-2
9	-10	-1
10	-9	1
11	-12	-1
12	-13	-1
13	-13	0
14	-13	1
14	-14	0
15	-15	0
15	-14	1
14	-13	1
14	-14	0
14	-14	0
13	-13	0
13	-13	0
12	-13	-1
12	-13	0
12	-12	0

DISC NO. 3		D T V
10mm from outer edge		
outer	inner	
0	0	0
1	-1	0
1	0	1
2	0	2
3	-2	1
4	-3	1
5	-4	1
6	-4	2
7	-5	2
8	-6	2
8	-6	2
9	-6	3
9	-7	2
9	-8	1
9	-7	2
9	-6	3
8	-6	2
7	-5	2
6	-5	1
5	-4	1
5	-3	2
4	-3	1
4	-3	1
4	-3	1
3	-2	1
3	-1	2
3	0	3
2	0	2
3	1	4
3	0	3
3	0	3
4	-1	3
3	-1	2
3	0	3
3	0	3
4	-1	3
3	-1	2
3	0	3
2	0	2
2	0	2
2	0	2
2	0	2
2	0	2

DISC NO. 4		D T V
10mm from outer edge		
outer	inner	
0	2	2
0	0	0
1	0	1
1	-1	0
2	-2	0
3	-2	1
4	-2	2
4	-3	1
5	-3	2
5	-2	3
4	-2	2
4	-2	2
4	-2	2
3	-2	1
3	-1	2
3	0	3
2	0	2
3	1	4
3	0	3
3	0	3
4	-1	3
3	-1	2
3	0	3
2	0	2
2	0	2
2	0	2
2	0	2
2	0	2

8	-7	1
6	-5	1
4	-3	1
3	-2	1
2	-1	1
2	-1	1
0	0	0
0	0	0
0	1	1
0	0	0
0	0	0
0	0	0
0	0	0

11	-12	-1
10	-11	-1
8	-9	-1
7	-8	-1
6	-7	-1
4	-5	-1
4	-5	-1
3	-3	0
2	-2	0
1	-2	-1
1	-2	-1
0	0	0
0	0	0
0	0	0
0	0	0

2	-1	1
2	-2	0
2	-2	0
2	-1	1
1	-2	-1
2	-2	0
2	-2	0
1	-2	-1
1	-1	0
0	-1	-1
0	-1	-1
0	-1	-1
0	0	0
0	0	0

2	-1	1
2	-1	-1
2	0	2
2	0	2
2	0	2
1	0	1
1	0	1
1	0	1
1	0	1
0	0	0
0	0	0

Runout outer	runout inner	d t v
16	15	4

runout outer	runout inner	d t v
15	15	3

runout outer	runout inner	d t v
9	8	4

runout outer	runout inner	d t v
5	5	4

5

The testing conducted to date on disc rotors in accordance with the invention is only at an early stage and further testing is required before conclusive results can be obtained. However, the early testing conducted to date indicate that disc rotors in accordance with the invention have superior performance to OE disc rotors. Indeed, 10 it is believed that disc rotors in accordance with the present invention will provide the following benefits, when compared with OE disc rotors:

- Eliminates shudder;
- Will not crack;
- Lower disc thickness variation values;

15 - Lower co-efficient of drag;

- Safer product;
- Longer life;
- Minimises rust;
- Lower deposits of black residue on alloy wheels;

20 - More stable material;

- Easy to manufacture.

Preliminary micrographic metallurgical analysis of a test sample having a composition in accordance with the present invention have been conducted. The test sample was in the form of a test bar of 30mm diameter and having the following 25 composition:

Carbon	3.7%
Silicon	2.58%
Manganese	0.259%
Phosphorous	0.037%
5 Sulphur	0.010%
Chrome	0.034%
Nickel	0.070%
Molybdenum	1.28%
Magnesium	0.039%
10 Iron	Balance

Figure 5 shows a photomicrograph taken at magnification x100 of the cast edge of the test bar. The test bar was etched in 2% nital solution.

Figure 5 shows a typical nodular cast iron structure showing well defined spheroidal graphite (particularly in the surface to sub-surface regions) in a matrix that 15 consists of ferrite and pearlite and a complex carbide formed during initial solidification. It is postulated that as the melt cools from liquid, graphite forms nodules which then act as nuclei around which ferrite grows. As the ferrite grows, the remaining liquid (rich in carbon and alloying ingredients, especially molybdenum) goes into the interstitial space. This liquid contains the complex 20 carbide and it forms an austenite phase having the complex carbide associated therewith. The austenite is then transformed into pearlite as the casting further cools. The complex carbides are thought to be formed from the liquid and hence they are fairly uniformly distributed.

As the field of view moves back into the bulk of the casting (away from the 25 edge), the spheroidal morphology of the graphite tends to degrade (from form VI back to forms V and IV).

Figure 6 shows a photomicrograph at magnification x100 of the test bar etched in 2% nital solution. This shows a microstructure showing the presence of the spheroidal graphite (predominantly in "degraded" or less spherical morphologies) 30 together with the ferrite, pearlite and complex carbide constituents. The pearlite is present and approximately 20% (by area fraction) of the microstructure.

Figure 7 shows a photomicrograph at magnification x500, etched in 2% nital solution, of the same general region of the test bar as shown in Figure 6. Figure 8 is similar to Figure 7, but magnification was x200. Details of the microstructure have been labelled in Figure 7. Microhardness testing of the phases was also conducted 5 using 100g Hv (vickers hardness) and are also reported below:

- A - degraded graphite nodule (form IV)
- B - ferrite surrounding the graphite nodules, microhardness using Hv 100gm is typically 200
- C - pearlite occupying the previously interdendritic regions, microhardness 10 is typically 400
- D - complex carbide, believed to be of the type M_6C , where M would be variable combinations of Fe, Mo and other carbide-forming elements. The complex carbide is present as a skeleton-like compound in the previously interdendritic regions and representing approximately 5% (by area fraction) of the microstructure.
- 15 Microhardness measurements of the "skeletons" (including the carbide plus pearlite) is typically 550 plus.

Prior to cutting and polishing the sections of the test bars, macrohardness measurements using Hv20kg averaged 214 (mid radius) and 204 (rear edge).

The test bar showed degraded spheroidal graphite towards the centre of the 20 bar. However, the test bar was still clearly classified as a spheroidal graphite cast iron. The degradation near the centre was possibly caused by slower cooling in that region due to the relatively large diameter (30mm) of the test bar. It is expected that articles of thinner section, such as disc brake rotors that are typically of thickness 10- 12mm, would not suffer from spheroidal graphite degradation or that the degradation 25 would be minimised.

The presence of the complex carbide phase in the alloy of the present invention was unexpected and the testing officer commented that he had never before seen such a phase in a cast iron. The alloy had a microstructure comprising very soft nodules of graphite surrounded by relatively soft and ductile ferrite. These soft parts 30 are strengthened and hardened by the pearlite phase and the very hard complex carbide phase. Interestingly, the preliminary micrographic analysis conducted to date

did not locate any bainite. Importantly, the microstructure discussed above can be obtained from the as-cast condition.

Those skilled in the art will appreciate that the invention described herein is susceptible to variations and modifications other than those specifically described. It 5 will be understood that the present invention encompasses all such variations and modifications that fall within the spirit and scope.

Claims

1. An as cast component comprising a spheroidal graphite cast iron alloy consisting essentially of 1.5 to 4.5 wt% carbon, 1.5 to 4.5 wt% silicon, 1.2 wt% to 6.5 wt% molybdenum, 0 to 5.3 wt% nickel and 0 to 5.3 wt% copper and wherein (wt% molybdenum + wt% nickel + wt% copper) does not exceed 6.5 wt%, up to 0.02 wt% of a spheroidizing agent, and balance iron and incidental impurities, wherein the alloy contains manganese at incidental impurity levels or less.
2. An as cast component as claimed in claim 1 wherein carbon is present in an amount of from 1.5 to 3.8 wt%.
- 10 3. An as cast component as claimed in claim 1 or 2 wherein carbon is present in an amount of 3.0 to 3.5 wt%.
4. An as cast component as claimed in any one of claims 1 to 3 wherein silicon is present in an amount of from 1.9 to 2.58 wt%.
5. An as cast component as claimed in any one of claims 1 to 4 wherein silicon is present in an amount of from 2.1 to 2.3 wt%.
- 15 6. An as cast component as claimed in any one of claims 1 to 5 wherein molybdenum is present in an amount of from 1.2 to 4.5 wt%.
7. An as cast component as claimed in any one of claims 1 to 6 wherein molybdenum is present in an amount of from 1.2 to 3.0 wt%.
- 20 8. An as cast component as claimed in any one of claims 1 to 7 wherein nickel is present in an amount of from 0.1 to 4.5 wt%.
9. An as cast component as claimed in any one of claims 1 to 8 wherein nickel is present in an amount of from 0.1 to 3.5 wt%.

10. An as cast component as claimed in any one of claims 1 to 9 wherein copper is present in an amount of from 0.1 to 4.5 wt%.

11. An as cast component as claimed in any one of claims 1 to 10 wherein copper is present in an amount of from 0.1 to 3.5 wt%.

5 12. An as cast component as claimed in any one of claims 1 to 7 wherein the alloy is essentially free of nickel.

13. An as cast component as claimed in any one of claims 1 to 7 and 12 wherein the alloy has substantially no copper.

14. An as cast component as claimed in claim 1 wherein the spheroidal graphite 10 cast iron alloy consists essentially of 3 to 3.5 wt% carbon, 1.9 to 2.58 wt% silicon and 1.2 to 1.5 wt% molybdenum, up to 0.02 wt% of a spheroidizing agent, balance iron and incidental impurities.

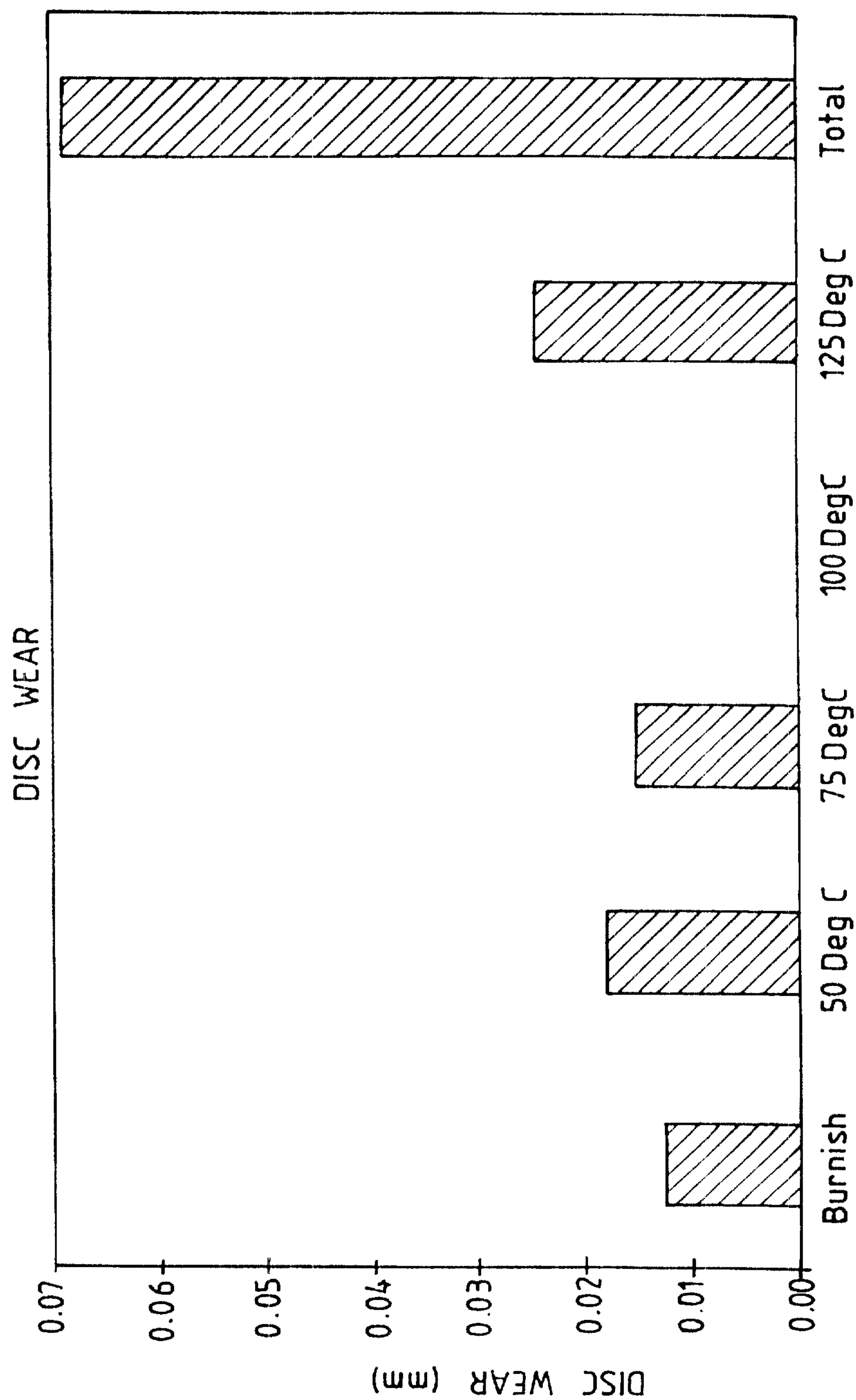
15. An as cast component as claimed in claim 1 wherein the spheroidal graphite 15 cast iron alloy consists essentially of 3 to 3.35 wt% carbon, 1.9 to 2.58 wt% silicon and about 3.0 wt% molybdenum, up to 0.02 wt% of a spheroidizing agent, balance iron and incidental impurities.

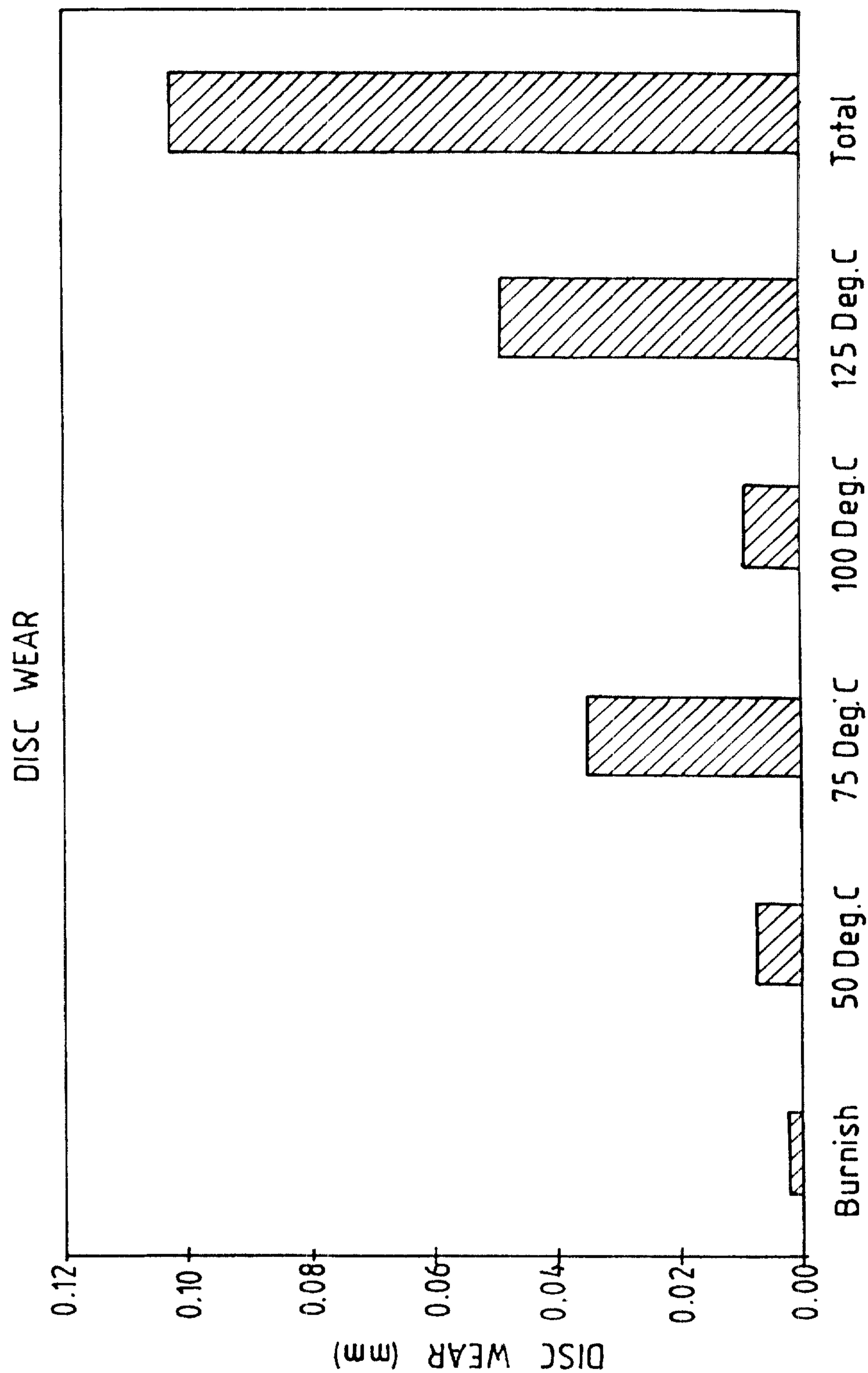
16. An as cast component as claimed in claim 1 wherein the spheroidal graphite 20 cast iron alloy consists essentially of from 3.5 to 4.5 wt% carbon, from 2.1 to 2.3 wt% silicon and from 2.5 to 3.5 wt% molybdenum, up to 0.02 wt% of a spheroidizing agent, balance iron and incidental impurities.

17. An as cast component as claimed in any one of claims 1 to 16 wherein the weight percentage of the incidental impurities does not exceed 0.8 wt%.

18. An as cast component as claimed in claim 17 wherein the incidental impurities include up to 0.04 wt% sulphur and up to 0.04 wt% phosphorus.

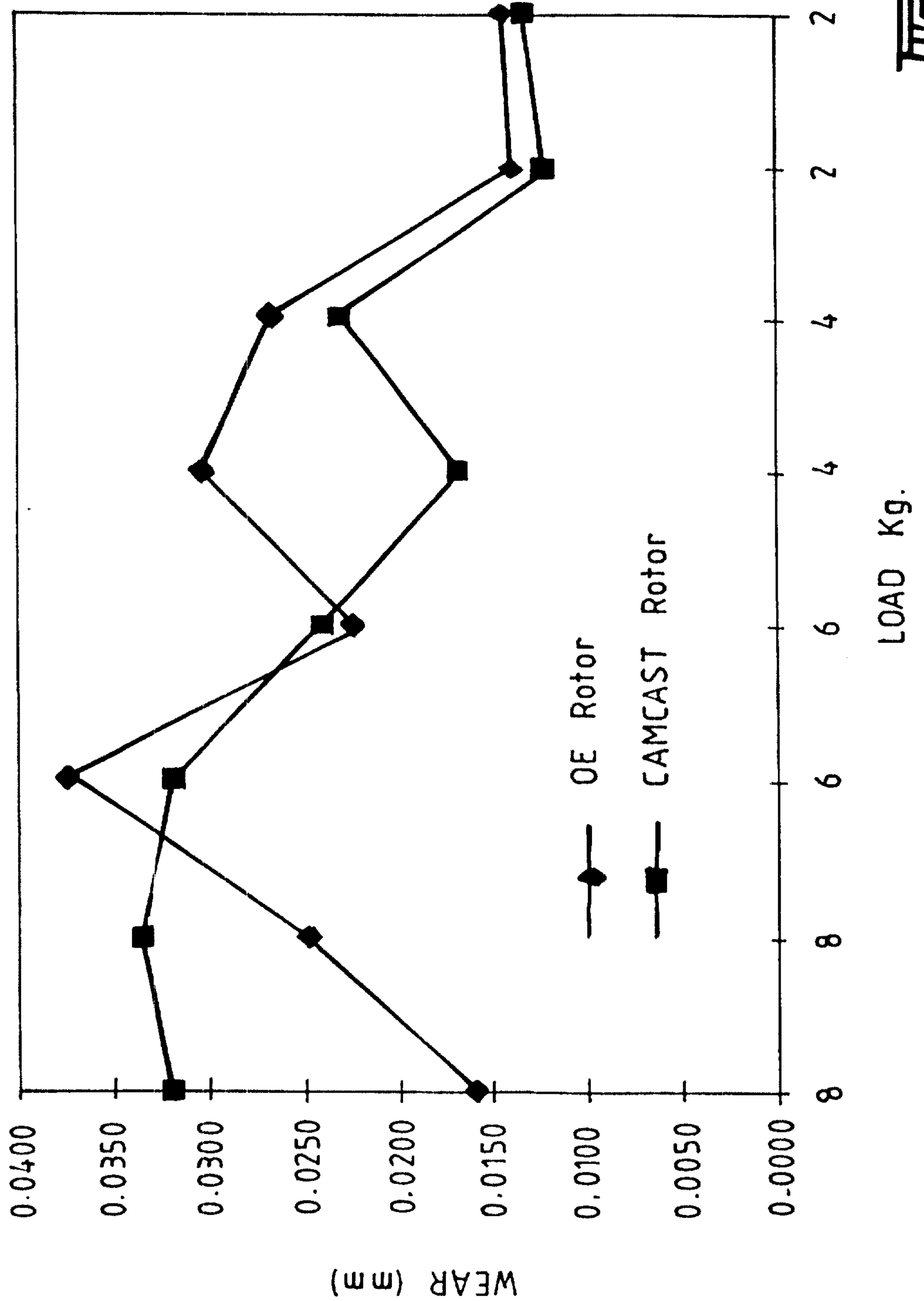
19. An as cast component as claimed in any one of claims 1 to 18 wherein the as cast component is a disc brake rotor.
20. A disc brake rotor comprising a spheroidal graphite cast iron alloy consisting essentially of 1.5 to 4.5 wt% carbon, 1.5 to 4.5 wt% silicon, 1.2 wt% to 6.5 wt% 5 molybdenum, 0 to 5.3 wt% nickel and 0 to 5.3 wt% copper and wherein (wt% molybdenum + wt% nickel + wt% copper) does not exceed 6.5 wt%, up to 0.02 wt% of a spheroidizing agent, balance iron and incidental impurities and wherein the alloy contains manganese at incidental impurity levels or less.





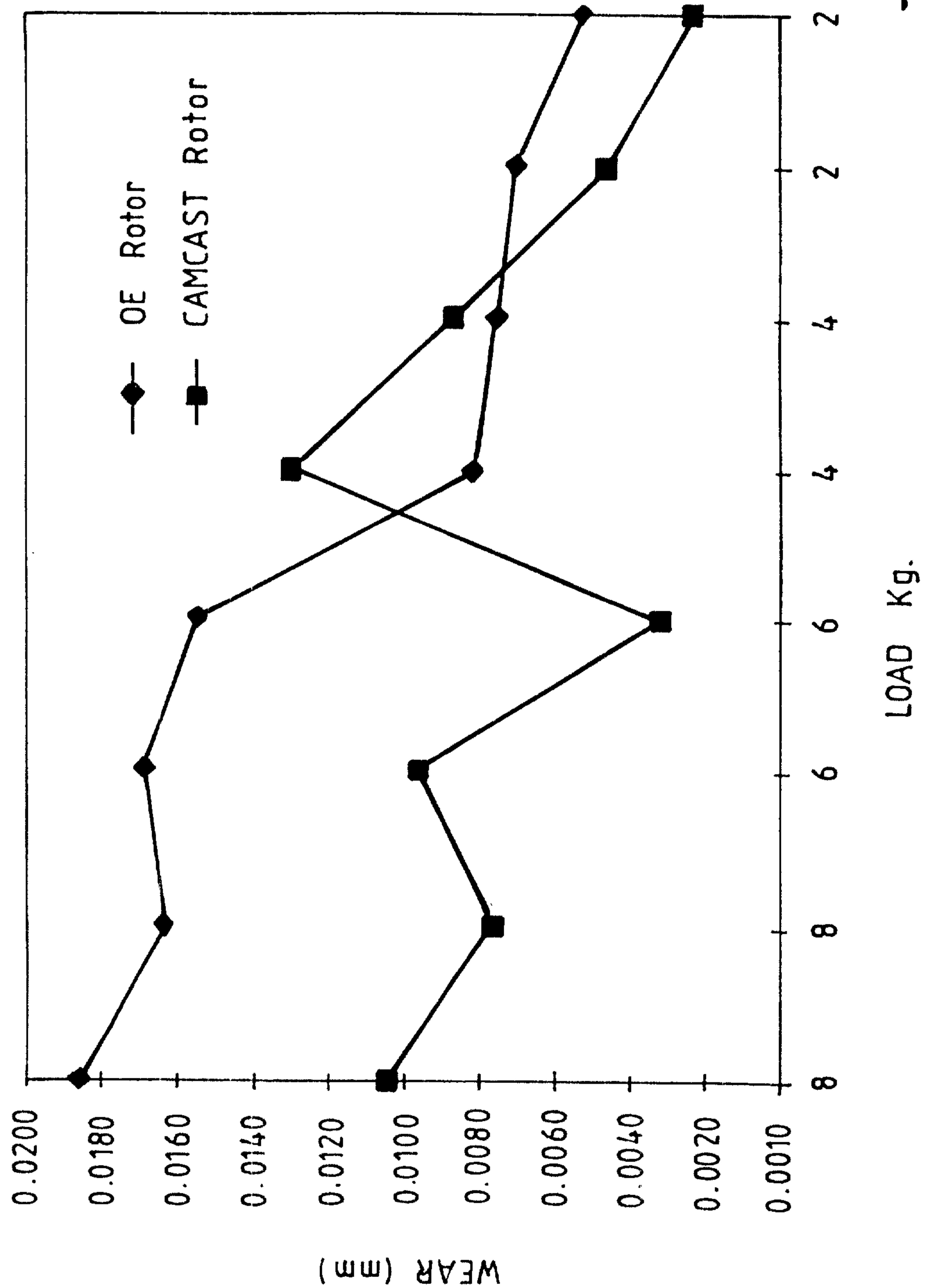
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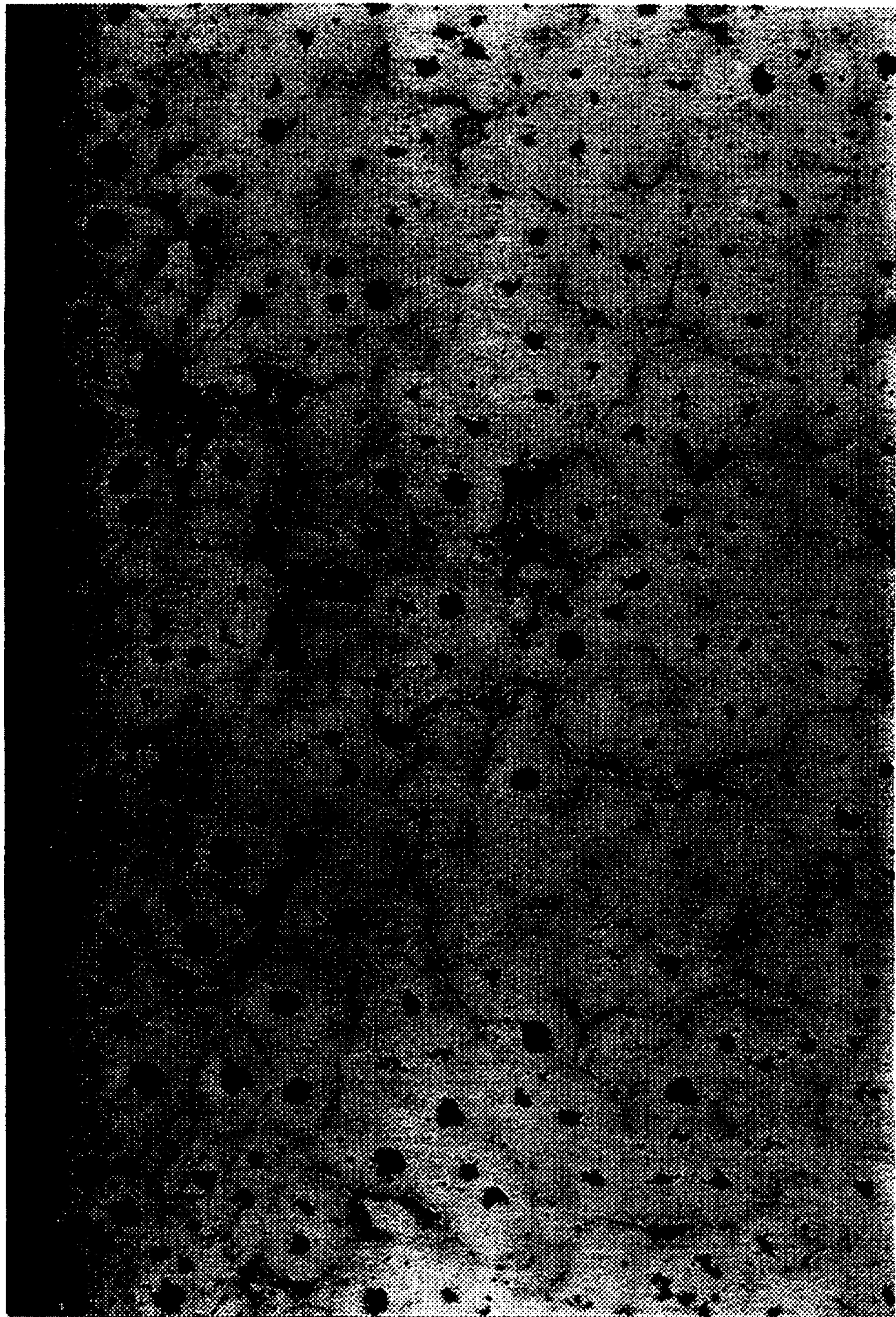
ROTOR WEAR REPORT



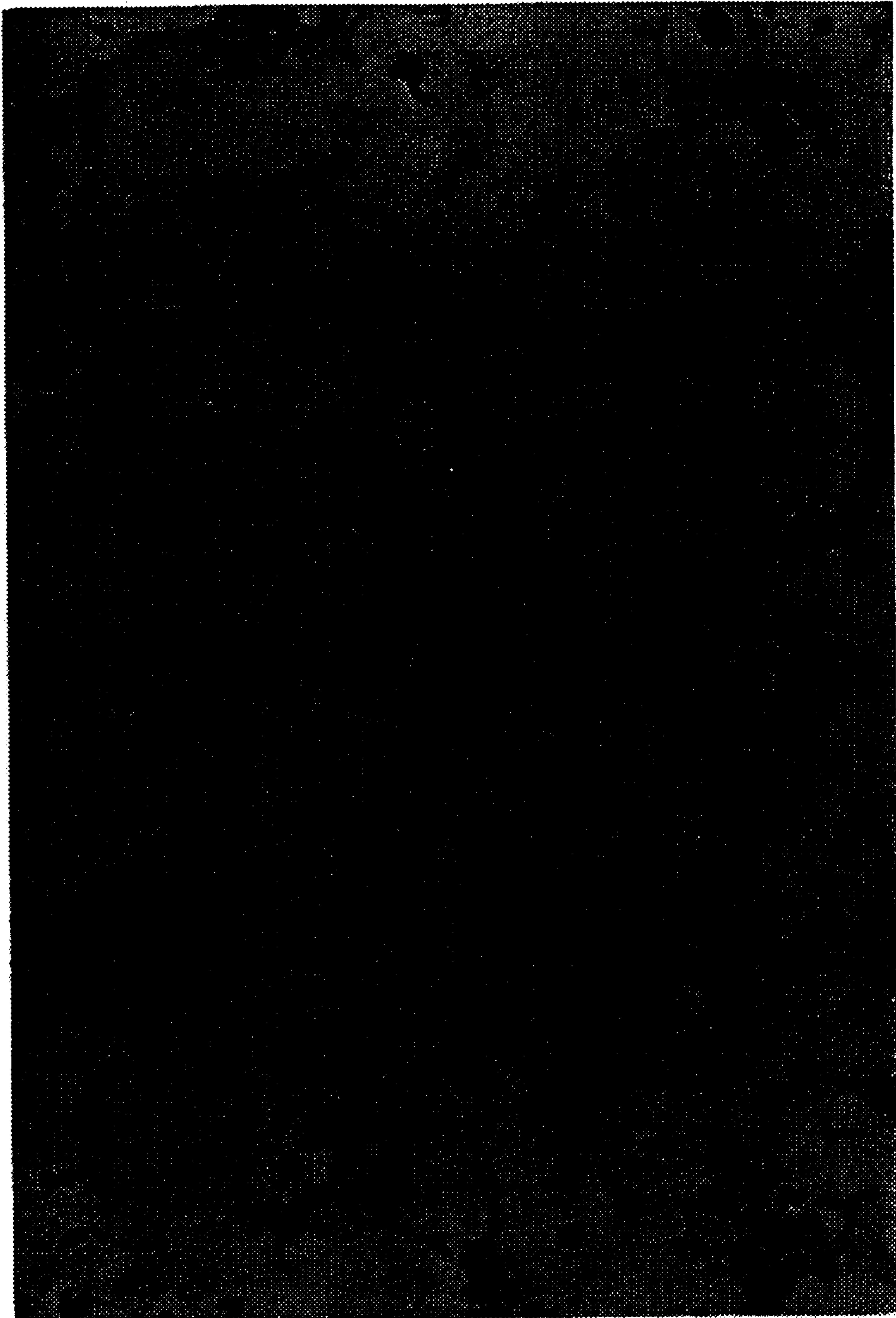
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ROTOR WEAR REPORT





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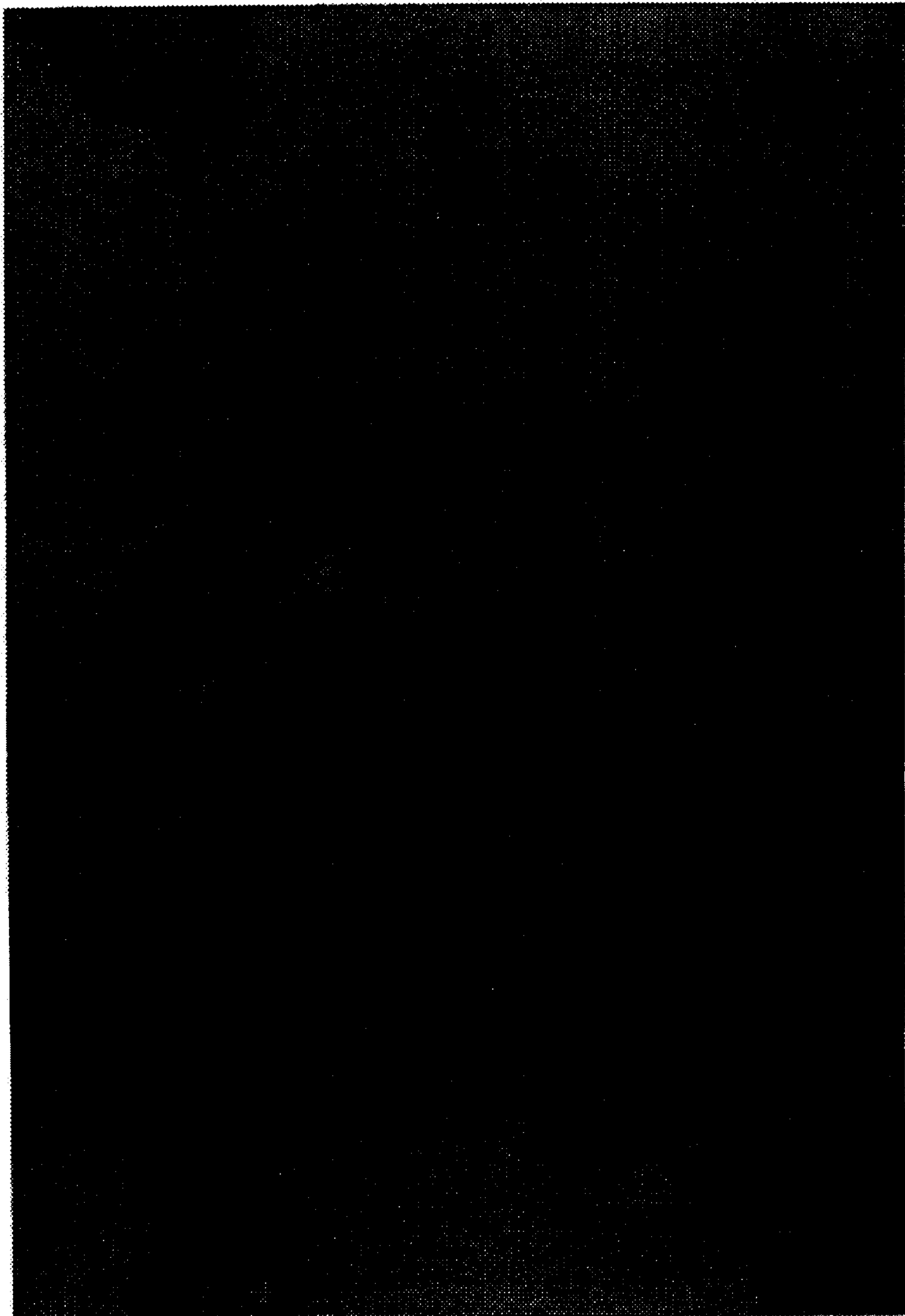


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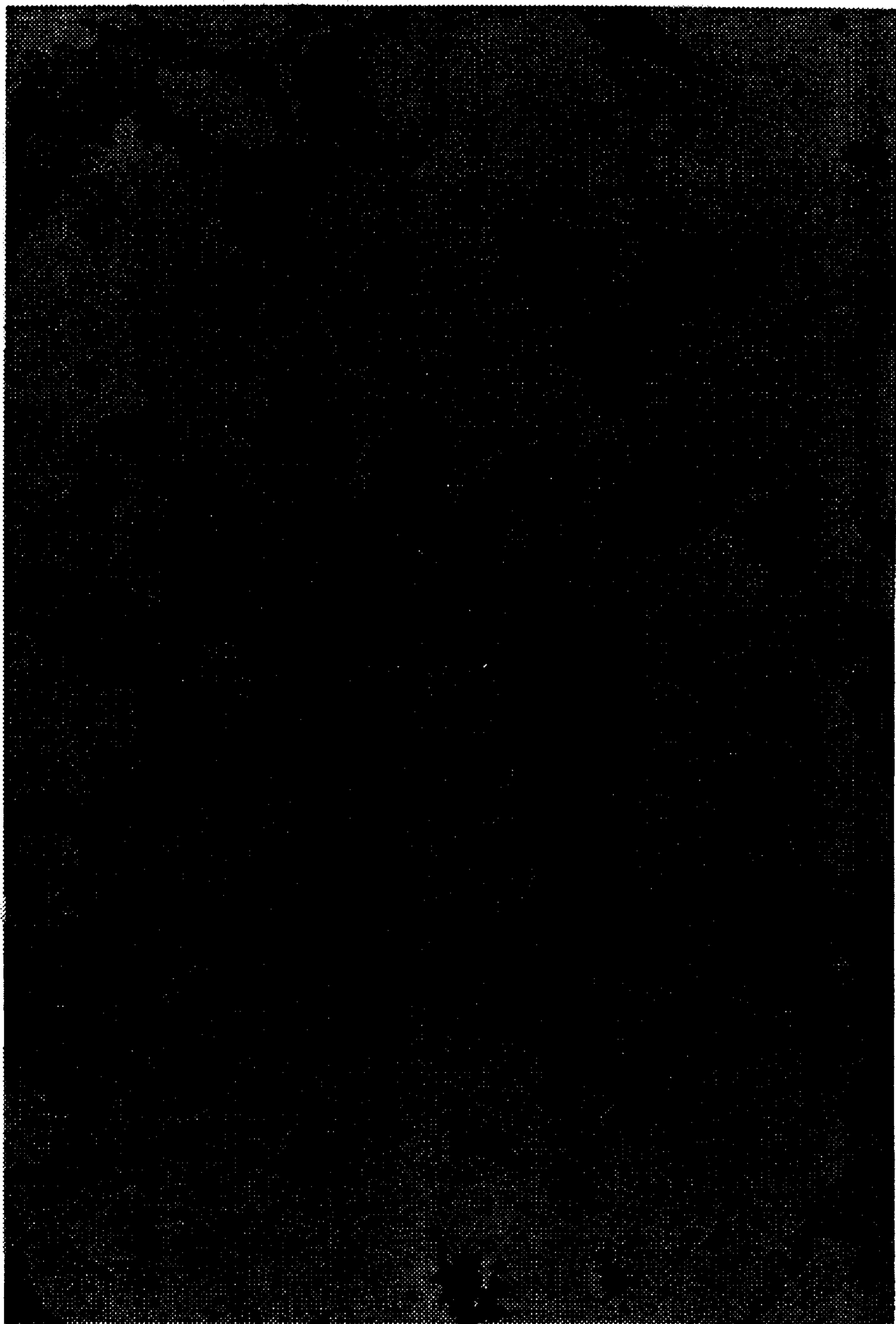


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8/8



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