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54 **A method of heat treating high chromium cast ferrous-based alloys and a wearing element formed of a high chromium cast ferrous based alloy.**

57 A method of heat treating a component formed of a high-chromium cast ferrous-based alloy consisting of 11–28 wt% chromium, 1 – 3.6 wt% carbon and at least 0.2 wt% molybdenum and/or at least 0.6 wt% tungsten, the remainder (apart from any incidental ingredients and impurities) being iron, said method comprising the steps of:–

a) holding said component at a temperature between the solidus temperature of the alloy and 1050°C for a period of time not exceeding 3 days in a non-oxidising atmosphere or vacuum so as to produce a partially spheroidised hard

carbide phase in an austenitic matrix throughout the component, and

b) quenching the component at a mean rate of from 40°C/min to 3°C/min in the critical temperature range in order to retain the austenitic matrix.

Before heat treatment, carbon and chromium form a hard sharp, angular carbide phase and the molybdenum and/or tungsten serves to increase the rate of change in the morphology of the carbide phase during heat treatment from sharp angularity to a partly spheroidised morphology.

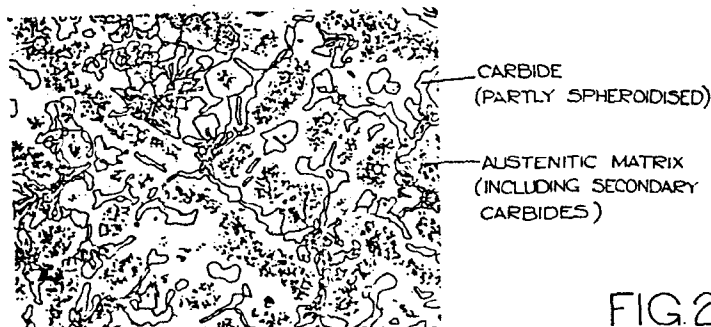


FIG.2.

A METHOD OF HEAT TREATING HIGH CHROMIUM CAST FERROUS-  
BASED ALLOYS AND A WEARING ELEMENT FORMED OF A  
HIGH CHROMIUM CAST FERROUS BASED ALLOY.

5 The present invention relates to a method of producing tough, wear resistant components from a high chromium cast ferrous-based alloy and to a wearing element which is formed of a high chromium ferrous-based alloy and which is for a breaking, grinding or crushing machine.

10 There exists a number of material handling processes which require the use of a tough, wear resistant material. Such applications include swing hammers used for the crushing of building or quarried material ie. cement, clinker and limestone, wherein the hammer material must be capable of withstanding the wear  
15 conditions imposed by the feed material and at the same time be sufficiently tough to prevent fracture due to the severe impacts encountered during service.

20 However, traditionally alloyed and processed high chromium white cast irons do not possess sufficient toughness to withstand high impact conditions.

25 A number of attempts have been made to produce a material combining the required degree of toughness and wear resistance. These materials have frequently been in the form of composites, in which an initially tough but malleable core is combined with a hard, wear resistant work face. Typical examples of this technique include the hard facing of steels and the fabrication of wear resistant cast iron onto tough steel shanks.

A method for improving the toughness of high chromium cast irons has been previously proposed (Suleyman Bulent Biner "The Effects of Metallurgical Variables on the Mechanical Properties of High-Chromium Cast Irons" PhD thesis, The University of Aston in Birmingham Sept. 1981) in which the high-chromium cast iron includes an addition of molybdenum or tungsten as a catalyst for enabling the production of spheroidised carbides upon heat treatment. However, whilst such a proposed process is capable of producing good laboratory samples, it was found to be inappropriate for the commercial production of industrial cast components such as the wearing elements of breaking, crushing and grinding machines (e.g. swing hammers.)

In order to obtain the microstructure of a partially spheroidised hard carbide phase supported by an austenitic matrix in industrial cast components, we have found that, after the chemical addition of molybdenum or tungsten and holding at an elevated temperature, it is necessary to control the cooling rate of the component so that the austenitic matrix is retained in a stable state throughout the section of the component.

Therefore, in accordance with the present invention there is provided a method of heat treating a component formed of a high-chromium cast ferrous-based alloy consisting of 11 - 28 wt% chromium, 1-3.6 wt% carbon and at least 0.2 wt % (preferably 0.2 to about 4 wt%) molybdenum and/or at least 0.6 wt% (preferably 0.6 to about 6 wt%) tungsten the remainder (apart from any incidental ingredients and impurities) being iron, said method comprising the steps of:-

a) holding said component at a temperature between the solidus temperature of the alloy and 1050°C for a period of time not exceeding about 3 days in a

non-oxidising atmosphere or vacuum so as to produce a partially spheroidised hard carbide phase in an austenitic matrix throughout the component, and

- 5 b) quenching the component at a mean rate of from 40°C/min to 3°C/min in the critical temperature range (as defined hereinafter) in order to retain the austenitic matrix.

Also according to the present invention, there is provided a wearing element of a breaking, crushing or grinding machine, said wearing element being (a) formed of a high chromium, ferrous-based alloy consisting of 11-28 wt% chromium, 1-3.6 wt % carbon and at least 0.2 wt% (preferably 0.2 to about 4 wt%) molybdenum and/or at least 0.6 wt% (preferably 0.6 to about 6 wt%) tungsten, the remainder (apart from any incidental ingredients and impurities) being iron, and (b) having a stable austenitic matrix in which is dispersed a partially spheroidised hard carbide phase.

Before heat treatment, carbon and chromium form a hard sharp, angular carbide phase (see Fig. 1) and the molybdenum and/or tungsten serves to increase the rate of change in the morphology of the carbide phase during heat treatment from sharp angularity (as shown in Fig 1) to a partly spheroidised morphology (see Fig 2).  
25 Approximately 2.5 times more tungsten than molybdenum is required to achieve similar toughness results.

As incidental ingredients, the following may be present (in wt%):-

	silicon	0 - 1.5
	manganese	0 - 1.5
	nickel	0 - 1.5
	copper	0 - 1.2
5	sulphur	0 - 0.05
	phosphorus	0 - 0.05

Of the incidental ingredients, Si, Mn, Ni, and Cu all form a solid solution within the matrix. Hence the diffusion controlled transformation of the austenitic matrix is retarded. The remaining two elements, S and P have a deleterious effect on the toughness and are therefore maintained at low levels. They are not deliberate alloying additions.

Preferably, the chromium content of the alloy is 14-20 wt%.

It is also preferred that the carbon content of the alloy is 1.5 - 3 wt%, more preferably 2-3 wt%.

Some of the carbon and chromium form a solid solution in austenite and thereby influence the matrix transformation characteristics. In addition, these two elements are of paramount importance in determining the volume fraction of hard carbides, (%K), within the micro-structure of the material.

The volume fraction of hard carbides is given by the following relationship (Ref. F. Maratray, 1971, A.F.S. Transactions).-

$$\%K = 12.33 (\%C) + 0.55 (\%Cr) - 15.2$$

Preferably the molybdenum content when present is 1 - 4 wt% and the tungsten content, when present, is 2- 5.5 wt%.

When heating the component from ambient temperature to the temperature of heat treatment, the heating rate should be sufficiently slow to avoid cracking of the castings.

5 Typically, the component is heated to a treatment temperature of 1180°C and maintained at this temperature for up to 72 hours, preferably up to 24 hours, more preferably 4 to 24 hours, most preferably 4 to 10 hours. However, for reasons of cost it is  
10 desirable to minimise the heat treatment time. Furthermore, heat treatment for longer than 72 hours produces no significant improvement in properties over an extended heat treatment on an alloy containing no molybdenum or tungsten as catalyst.

15 Quenching of the component must be sufficiently fast to retain an austenitic matrix. The quenching rate in the critical temperature range is the important factor. The limits of the critical temperature range are defined by the treatment temperature employed in  
20 step a) above and the upper critical temperature ( $A_3$ ). The quenching rate is the mean cooling rate of the furnace load, for example as measured by a thermocouple inserted into the furnace load.

The heat treatment used in the present invention may  
25 also be carried out under pressure e.g by hot isostatic pressing, typically at 105 MPa.

It is preferred that the quenching rate in the critical temperature range is 37°C/min to 3°C/min. The non-oxidising atmosphere may for example be a  
30 protective atmosphere such as nitrogen. In the case

where the holding at temperature is effected in a vacuum, it is preferred to effect quenching by back filling with an inert gas such as nitrogen.

5 The quenching rate in the critical temperature range is typically affected by the factors such as size of furnace load, type of furnace etc.

The present invention will now be further described in the following Examples.

EXAMPLE 1.

10 Castings having a section size of between 40 mm and 100 mm are produced with the following chemical composition (wt %):-

C	Si	S	P	Mn	Ni	Cr	Cu	Mo	Fe
2.35	0.36	0.030	0.037	0.32	0.19	14.05	0.16	1.92	Balance

15 The heat treatment is carried out in an Ipsen 924 vacuum furnace to the following schedule:

heat from ambient to 750°C at 150°C/hour

heat from 750°C to 1180°C at 250°C/hour

held at 1180°C for 8 hours

20 quench through the critical temperature range at an average rate of 3.03°C/minute using a fan assisted nitrogen backfill.

25 The temperature of the furnace load (20 castings arranged as a single layer) is measured using a load thermocouple positioned as near as possible to the centre of the load (i.e the slowest part of the load to heat up and cool down). In this example, each casting has a pivot hole therein and the load thermocouple is placed in that pivot hole which is the nearest to the  
30 centre of the load.

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The material exhibits the following typical mechanical properties:

Hardness: 420 Hv<sub>30</sub>

Fracture Toughness: using a short bar specimen  
tested in accordance with S.A.E.  
ARP 1704

5

\*K<sub>ICSB</sub> - 44.0 MN/m<sup>3/2</sup>

\* K<sub>ICSB</sub> is the plane strain fracture toughness as determined using a short bar specimen.

10      EXAMPLES 2 - 7

Various samples of high chromium cast iron having alloying ingredients as set out in Table 1 below are heated to 1180°C at an average rate of 290°C/hour and quenched at an average rate of 36°C/minute through the critical temperature range.

15



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TABLE 1

## ALLOYING ELEMENTS (WT %)

EXAMPLE C		Si	S	P	Mn	Ni	Cr	Cu	Mo	W	
5	2	2.79	0.66	0.017	0.028	0.29	0.12	16.0	0.14	0.69	-
	3	2.60	0.68	0.018	0.030	0.28	0.12	15.7	0.15	2.23	-
	4	2.60	0.72	0.020	0.031	0.27	0.12	15.2	0.15	3.98	-
	5	2.79	0.62	0.016	0.028	0.31	0.12	15.5	0.15	-	1.15
	6	2.75	0.63	0.017	0.028	0.31	0.12	15.2	0.15	-	3.09
10	7	2.70	0.65	0.017	0.034	0.31	0.12	14.8	0.16	-	5.43
	In Table 1 above, the balance of the ingredients is iron.										

Table 2 below identifies the hardness and toughness values exhibited by the above materials after the specified times at 1180°C.

Table 2

15	EXAMPLE	Time at Temperature (hours)	Hardness (Hv <sub>30</sub> )	Fracture Toughness (MN/m <sup>3/2</sup> ) K <sub>IC</sub>
	2	4	507	25.9
		8	515	25.0
		24	515	26.3
20	3	4	505	28.8
		8	478	30.1
		24	441	27.8
	4	4	474	27.4
		8	465	26.3
		24	438	24.0
25	5	8	516	24.3
		24	510	23.1
		6	8	506
24	475		25.3	
30	7		8	448
		24	440	27.7

Comparative Example 1.

A high chromium cast iron having the following chemical composition in wt%:-

	C	Si	S	P	Mn	Ni	Cr	Cu	Mo	Fe
5	2.59	0.53	0.042	0.034	0.59	0.18	15.9	0.17	2.22	balance

is heated in vacuum from ambient to 750°C at 150°C/hour from 750°C to 1180°C at 250°C/hour, held at 1180°C for 8 hours and then quenched at an average rate of 2.5°C/minute through the critical temperature range.

- 10 This fails to produce the required matrix microstructure, see Fig. 3, and combination of mechanical properties. Due to the slow cooling rate in the critical temperature range, the matrix is destabilised by the formation of secondary carbides.
- 15 This results in partial transformation of the matrix to martensite, thus rendering the material unsuitable for use under high impact conditions.

Hardness: typically Hv<sub>30</sub> - 690

Fracture Toughness, typically: K<sub>ICSB</sub> - 45.0 MN/m<sup>3/2</sup>

20 Comparative Example 2.

A high chromium ferrous-alloy containing the following alloying ingredients in wt%:-

	C	Si	S	P	Mn	Ni	Cr	Fe
25	0.82	0.44	0.044	0.031	0.56	0.18	16.3	balance

is heated to 1150°C for 8 hours results in the segregation of carbides into an embrittling grain boundary film. This is due to the low carbon content.

Comparative Example 3

A tungsten and molybdenum-free, high chromium cast iron containing the following ingredients in wt%:-

	C	Si	S	P	Mn	Ni	Cr	Cu	Fe
5	2.79	0.65	0.017	0.028	0.28	0.12	16.2	0.13	balance

does not exhibit satisfactory toughness or hardness properties after being subjected to the 8 hour treatment described in Examples 2 - 7 (Table 2).

10 This material has a microstructure in which the absence of Mo or W has resulted in the absence of spheroidisation and consequently this material is not satisfactory

Hardness typically : Hv<sub>30</sub> - 596

Fracture Toughness typically : K<sub>IC</sub> - 18.6 MN/m<sup>3/2</sup>

15 Comparative Example 4.

The materials of Examples 3 and 6 are heat treated as stated but for an extended period of over about 72 hours. After this extended treatment, it is found that the beneficial catalytic effect of the molybdenum or tungsten addition is lost.

20

A material within the preferred ranges regarding other components but with a carbon content in excess of 3.6% by weight contains a significant volume fraction of large primary chromium carbides which promote an embrittling effect within the material.

25

If the chromium content is less than 11 wt%, a low volume fraction of hard chromium carbides is formed. If the chromium content falls to about 8 wt% (or less)

then the chemical composition of the carbide phase changes and a less hard carbide is formed.

At higher chromium levels than 28 wt%, there is a profound tendency to form a soft primary ferrite phase.

CLAIMS

1. A method of heat treating a component formed of a high-chromium cast ferrous-based alloy consisting of 11-28 wt% chromium, 1-3.6 wt% carbon and at least 0.2 wt% molybdenum and/or at least 0.6 wt% tungsten, the remainder (apart from any incidental ingredients and impurities) being iron, said method comprising the steps of:-
- a) holding said component at a temperature between the solidus temperature of the alloy and 1050°C for a period of time not exceeding 3 days in a non-oxidising atmosphere or vacuum so as to produce a partially spheroidised hard carbide phase in an austenitic matrix throughout the component, and
- b) quenching the component at a mean rate of from 40°C/min to 3°C/min in the critical temperature range in order to retain the austenitic matrix.

2. A method as claimed in claim 1 wherein the alloy contains as incidental ingredients, the following (in wt%):-

	silicon	0 - 1.5
	manganese	0 - 1.5
	nickel	0 - 1.5
	copper	0 - 1.2
25	sulphur	0 - 0.05
	phosphorus	0 - 0.05

3. A method as claimed in claim 1 or 2 wherein the molybdenum content of the alloy is 0.2 - 4 wt%.

4. A method as claimed in claim 3 wherein the molybdenum content of the alloy is 1 - 4 wt%.
5. A method as claimed in any preceding claim wherein the tungsten content of the alloy is 0.6 - 6 wt%.
- 5 6. A method as claimed in claim 5 wherein the tungsten content of the alloy is 2 - 5.5 wt%.
7. A method as claimed in any preceding claim wherein the chromium content of the alloy is 14 - 20 wt%.
8. A method as claimed in any preceding claim wherein  
10 the carbon content of the alloy is 1.5 - 3 wt%.
9. A method as claimed in claim 8 wherein the carbon content of the alloy is 2 - 3 wt%.
10. A method as claimed in any preceding claim wherein  
15 the component is heated to a treatment temperature of about 1180°C.
11. A method as claimed in any preceding claim, wherein the component is maintained at the treatment temperature for up to 24 hours.
12. A method as claimed in claim 11 wherein the  
20 component is maintained at the treatment temperature for 4 to 24 hours.
13. A method as claimed in claim 12 wherein the component is maintained at the treatment temperature for 4 to 10 hours.
- 25 14. A method as claimed in any preceding claim wherein the quenching rate is 37°C/min to 3°C/min.

15. A wearing element of a breaking, crushing or grinding machine, said wearing element being (a) formed of a high chromium, ferrous-based alloy consisting of 11-28 wt% chromium, 1-3.6 wt% carbon and at least 0.2 wt% molybdenum and/or at least 0.6 wt% tungsten, the remainder (apart from any incidental ingredients and impurities) being iron, and (b) having a stable austenitic matrix in which is dispersed a partially spheroidised hard carbide phase.



CARBIDE  
(SHARP ANGULAR)  
MARTENSITIC MATRIX

FIG.1.



CARBIDE  
(PARTLY SPHEROIDISED)  
AUSTENITIC MATRIX  
(INCLUDING SECONDARY  
CARBIDES)

FIG.2.



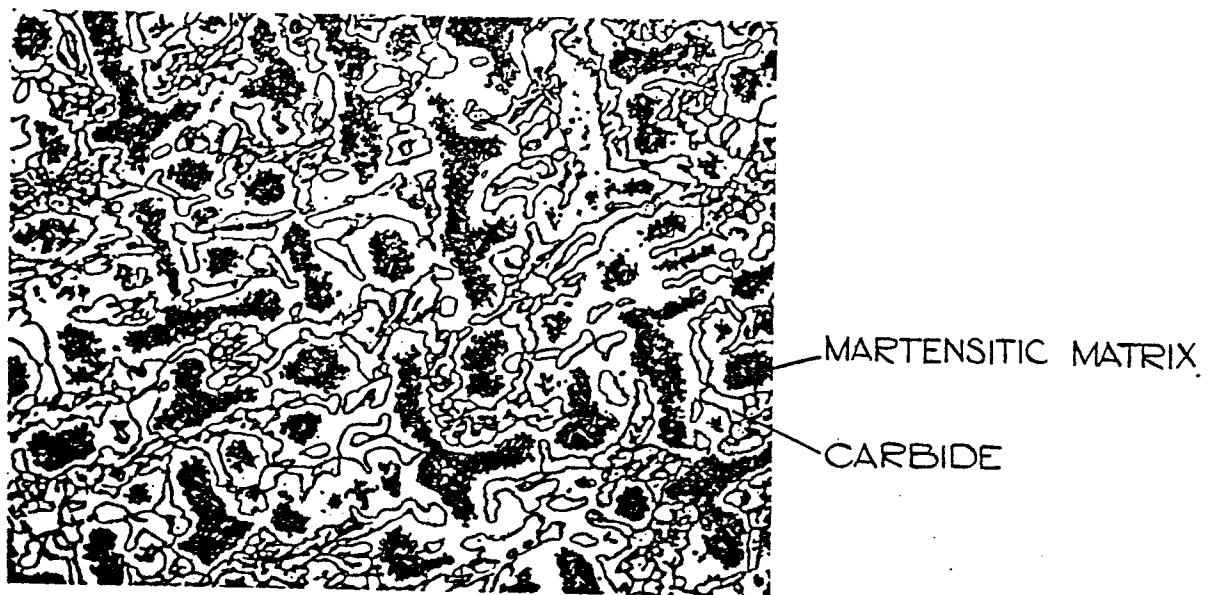


FIG.3.