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(54) **A wear resistant tool steel produced by HIP**

(57) The invention relates tool steel produced by powder metallurgy and hot isostatic pressing resulting in that the steel is isotropic has a non-amorphous micro-structure and has a theoretical density (TD) of > 98 %, the steel consists of in weight % (wt.%):

C 0.2 - 1.5

Si 0.1 - 2.5

Mn 0.1 - 2.5

Mo 10-35

B 0.5-3

balance optional elements, iron and impurities.

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Description

TECHNICAL FIELD

5 **[0001]** The invention relates to a wear resistant tool steel produced by HIP. The tool steel is alloyed with boron.

BACKGROUND OF THE INVENTION

10 **[0002]** Nitrogen and vanadium alloyed powder metallurgy (PM) tool steels attained a considerable interest because of their unique combination of high hardness, high wear resistance and excellent galling resistance. These steels have a wide range of applications where the predominant failure mechanisms are adhesive wear or galling. Typical areas of application include blanking and forming, fine blanking, cold extrusion, deep drawing and powder pressing. The basic steel composition is atomized, subjected to nitrogenation and thereafter the powder is filled into a capsule and subjected to hot isostatic pressing (HIP) in order to produce an isotropic steel. A high performance steel produced in this way is described in WO 00/79015 A1.

15 **[0003]** Although the known steel has a very attractive property profile there is a continuous strive for improvements of the tool material in order to further improve the surface quality of the products produced as well as to extend the tool life, in particular under severe working conditions, where galling is the main problem.

20 DISCLOSURE OF THE INVENTION

[0004] The object of the present invention is to provide powder metallurgy (PM) produced tool steel having an improved property profile for advanced cold working like fine blanking. Another object of the present invention is to provide a powder metallurgy (PM) produced tool steel having a composition and microstructure leading to improvements in the surface quality of the produced parts.

25 **[0005]** The foregoing objects, as well as additional advantages are achieved to a significant measure by providing a tool steel having a composition as set out in the claims.

[0006] The invention is defined in the claims.

30 DETAILED DESCRIPTION

[0007] The present invention relates to a HIPed tool steel comprising a hard phase consisting mainly of multiple borides containing Fe in a hardenable matrix. The double boride is of the type $M_2M'B_2$, where M and M' stand for metals of the multiple boride. Said boride forming elements are generally selected from Cr, Mo, W, Ti, V, Nb, Ta, Hf and Co. In the present case M is Mo and M' is Fe. However, the boride may contain substantial amounts of one or more of the other boride forming elements. However, in the following the double boride will simply be referred to as Mo_2FeB_2 although the boride also may contain Ni and one or more of the above mentioned boride forming elements.

35 **[0008]** The importance of the separate elements and their interaction with each other as well as the limitations of the chemical ingredients of the claimed alloy are briefly explained in the following. All percentages for the chemical composition of the steel are given in weight % (wt. %) throughout the description. The upper and lower limits of the individual elements may be freely combined within the limits set out in claim 1.

Carbon (0.2 - 1.5 %)

45 **[0009]** Carbon is to be present in a minimum content of 0.2 %, preferably 0.3 % or 0.35 %. The upper limit for carbon is 1.5 %. Carbon is important for the formation of carbides and for the hardening. Preferably, the carbon content is adjusted in order to obtain 0.4-0.6 % C dissolved in the matrix at the austenitizing temperature. In any case, the amount of carbon should be controlled such that the amount of carbides of the type $M_{23}C_6$, M_7C_3 , M_6C and MC in the steel is limited. The upper limit may therefore be set to 0.8, 0.6, 0.5 or 0.45 %

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Chromium (≤ 25 %)

[0010] Chromium is an optional component. However, Cr is for most applications present in contents of at least 2.5 % in order to provide a sufficient hardenability. Cr is preferably higher for providing a good hardenability in large cross sections during heat treatment. If the chromium content is too high, this may lead to the formation of undesired carbides, such as M_7C_3 . In addition, this may also increase the propensity of retained austenite in the microstructure. The lower limit may be 2.8 %, 3.4 % or 4.2 %. The upper limit may be 6.0, 5.4 %, or 4.6 %. On the other hand, Chromium contents of more than 10 %, preferably more than 12 % are used for stainless applications.

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Molybdenum (10 - 35 %)

[0011] Mo is the main element forming the hard boride. In the present invention, a high amount of Molybdenum is used in order to obtain a desired precipitation of the boride Mo_2FeB_2 in an amount of 5-35 vol. %. Preferred ranges include 12-30 % and 15-25%. Mo is also known to have a very favourable effect on the hardenability is essential for attaining a good secondary hardening response. For this reason it is preferred that the amount of Mo remaining in the matrix after quenching from 1100°C is 1.5-2.5 %.

Boron (0.5 - 3 %)

[0012] Boron, which is the main hard phase-forming element, should be at least 0.5 % so as to provide the minimum amount of 5 % hard phase Mo_2FeB_2 . The amount of B is limited to 3 % for not making the alloy to brittle.

Tungsten (≤ 3 %)

[0013] The effect of tungsten is similar to that of Mo. However, for attaining the same effect it is necessary to add twice as much W as Mo on a weight % basis. Tungsten is expensive and it also complicates the handling of scrap metal. The maximum amount is therefore limited to 3 %, preferably 1%, more preferably 0.3 % and most preferably W is not deliberately added at all.

Vanadium (≤ 15 %)

[0014] Vanadium forms evenly distributed primary and secondary precipitated carbides of the type MC. In the inventive steel M is mainly vanadium but Cr and Mo may be present to some extent. The maximum addition of V is restricted to 15 % and the preferred maximum amount is 5 %. However, in the present case V is mainly added for obtaining a desired composition of the steel matrix before hardening. The addition may therefore be limited to 2.0 % or even to 0.5 %. A preferred range is 0.1-0.5 % V.

Niobium (≤ 15 %)

[0015] Niobium is similar to vanadium in that it forms MC. However, for attaining the same effect it is necessary to add twice as much Nb as V on a weight % basis. Nb also results in a more angular shape of the MC. Hence, the maximum addition of Nb is restricted to 15 % and the preferred maximum amount is 5 %. Preferably, no niobium is added.

Silicon (0.1 - 2.5 %)

[0016] Silicon is used for deoxidation. Si also increases the carbon activity and is beneficial for the machinability. Si is therefore present in an amount of 0.1 - 2.5 %. For a good deoxidation, it is preferred to adjust the Si content to at least 0.2 %. The lower limit may be set to 0.3 %, 0.35 % or 0.4 %. However, Si is a strong ferrite former and should be limited to 2.5 %. The upper limit may be set to 1.5%, 1 %, 0.8 %, 0.7 % or 0.6 %. A preferred range is 0.2 - 0.8 %.

Manganese (0.1 - 2.5 %)

[0017] Manganese contributes to improving the hardenability of the steel and together with sulphur manganese contributes to improving the machinability by forming manganese sulphides. Manganese shall therefore be present in a minimum content of 0.1 %, preferably at least 0.2 %. At higher sulphur contents manganese prevents red brittleness in the steel. The steel shall contain maximum 2.5 % Mn. The upper limit may be set to 1.5 %, 1.2 %, 1.0 %, 0.8 % or 0.6%. However, preferred ranges are 0.2 - 0.8 % and 0.2 - 0.6 %.

Nickel ($\leq 5\%$)

[0018] Nickel is optional and may be present in an amount of not more than 5 %. It gives the steel a good hardenability and toughness. Because of the expense, the nickel content of the steel should be limited as far as possible. Accordingly, the Ni content is preferably limited to 2%, more preferably to 1.0% or 0.3%.

Copper ($\leq 3.0\%$)

[0019] Cu is an optional element, which may contribute to increasing the hardness and the corrosion resistance of the

steel. If used, the preferred range is 0.02 - 2% and the most preferred range is 0.04 - 1.6%. However, it is not possible to extract copper from the steel once it has been added. This drastically makes the scrap handling more difficult. For this reason, Copper is normally not deliberately added.

5 Cobalt ($\leq 10\%$)

10 [0020] Co is an optional element, which may be present in an amount of not more than 10 %. Co dissolves in iron (ferrite and austenite) and strengthens it whilst at the same time imparting high temperature strength. Co increases the M_s temperature. Co can substitute mainly Fe in the Mo_2FeB_2 boride. A preferred maximum content is 2 %. However, scrap handling will be more difficult. For this reason, Co is not deliberately added

Ti, Ta, Zr and Hf

15 [0021] These elements are boride and carbide formers and may be present in the alloy in the claimed ranges for altering the composition of the hard phases. However, normally none of these elements are added.

Phosphorous

20 [0022] P is an impurity element and a solid solution strengthening element. However, P tends to segregate to the grain boundaries, reduces the cohesion and thereby the toughness. P is therefore normally limited to $\leq 0.05\%$.

Sulphur ($\leq 0.5\%$)

25 [0023] S contributes to improving the machinability of the steel. At higher sulphur contents there is a risk for red brittleness. Moreover, a high sulphur content may have a negative effect on the fatigue properties of the steel. The steel shall therefore contain $\leq 0.5\%$, preferably $\leq 0.03\%$.

EXAMPLE

30 [0024] 10 kg of an alloy having the composition given below was melted in a laboratory furnace and subjected to Ar-gas atomizing.

C	0.3
Si	0.3
Mn	0.3
Mo	19
B	2.1
Fe	balance.

40 [0025] The powder was sieved to $< 500\ \mu\text{m}$, filled in steel capsules having a diameter of 63 mm and a height of 150 mm. HIPing was performed at a temperature of 1150 °C, the holding time was 2 hours and the pressure 110 MPa. The cooling rate was $< 1\ ^\circ\text{C/s}$. The material thus obtained was forged at 1130 °C to the dimension 20x30 mm. Soft annealing was performed at 900 °C with a cooling rate of 10 °C/h down to 750 °C and thereafter cooling freely in air. Hardening was performed by austenitizing at 1100 °C for 30 minutes followed by quenching in water followed by tempering. The result of the hardness testing after tempering is given in Table 1.

45 [0026] The amount of the hard phase was found to be 24 vol. % and the borides were found to have a small size. The area fraction of borides in different size classes is given in Table 2 below.

50 Table. 1. Hardness as a function of the tempering temperature after hardening from 1100°C.

Tempering temperature (°C)	Hardness HRC
200	60
300	56
400	54

(continued)

Tempering temperature (°C)	Hardness HRC
500	53
525	53
550	54
600	49

Table. 2. Size distribution of the borides.

Size range (μm)	Area fraction (%)
0-1	6.3
1-2	13.5
2-3	4.0
3-4	0.2

[0027] The microstructure is shown in Fig. 1. The high area fraction and the uniform distribution of the Mo_2FeB_2 borides results in a material having excellent anti-galling properties such that it would be possible to dispense with surface treatments like PVD, CVD and TD.

INDUSTRIAL APPLICABILITY

[0028] The tool steel of the present invention is particular useful in applications requiring very high galling resistance.

Claims

1. A tool steel produced by powder metallurgy and hot isostatic pressing resulting in that the steel is isotropic has a non-amorphous microstructure and has a theoretical density (TD) of > 98 %, the steel consists of in weight % (wt.%):

C	0.2 - 1.5
Si	0.1 - 2.5
Mn	0.1 - 2.5
Mo	10 - 35
B	0.5 - 3
Cr	≤ 25
V	≤ 15
Nb	≤ 15
Ti	≤ 5
Ta	≤ 5
Zr	≤ 5
Hf	≤ 5
Ni	≤ 5
Co	≤ 10
Cu	≤ 3
W	≤ 3
S	≤ 0.5

Fe and impurities balance.

2. A steel according to claim 1, wherein the steel fulfils at least one of the following conditions,

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5	C	0.3 - 0.6
	Si	0.2 - 1.5
	Mn	0.2 - 1.5
	Mo	12 - 30
	B	0.7 - 2.5

10 3. A steel according to claim 1 or 2, wherein the steel fulfils at least one of the following conditions

15	Cr	≤ 20
	V	≤ 5
	Nb	≤ 5
	Ti	≤ 1
	Ta	≤ 1
	Zr	≤ 1
20	Hf	≤ 1
	Ni	≤ 2
	Co	≤ 2
	Cu	≤ 1
	W	≤ 1
25	S	≤ 0.03

4. A steel according to any of the preceding claims, wherein the steel fulfils at least one of the following conditions

30	C	0.3 - 0.5
	Si	0.2 - 0.8
	Mn	0.2 - 0.8
	Mo	15 - 25
35	B	1.8 - 2.2
	Cr	3.0 - 16
	V	0.1 - 2.0

40 5. A steel according to any of the preceding claims, wherein the steel fulfils at least one of the following conditions

45	C	0.35 - 0.45
	Si	0.2 - 0.6
	Mn	0.2 - 0.6
	Cr	3.0 - 6.0
	V	0.1 - 0.5

50 6. A steel according to any of claims 1-4, wherein the steel fulfils at least one of the following conditions

55	C	0.35 - 0.45
	Si	0.2 - 0.6
	Mn	0.2 - 0.6
	Cr	10.0 - 15.0
	V	0.1 - 0.5

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7. A steel according to any of the preceding claims, wherein the steel fulfils at least one of the following conditions

5	V	0.2 - 0.4
	P	< 0.05
	S	< 0.003
	O	< 0.005

10 8. A steel according to any of claims 1-4, wherein the metallic matrix fulfils the following requirements after quenching from 1100 °C

15	C	0.4 - 0.5
	Si	0.3 - 0.5
	Mn	0.3 - 0.5
	Mo	1.5 - 2.5
	Cr	4.0 - 5.0
20	V	0.3 - 0.4

9. A steel according to any of the preceding claims, wherein the steel comprises 5 - 35 volume % hard phase, wherein the hard phase comprises at least one of borides, nitrides, carbides and/or combinations thereof.

25 10. A steel according to any of the preceding claims, wherein the maximal Equivalent Circle Diameter of the hard phase is less than 5 μm , preferably less than 3 μm .

11. A steel according to any of the preceding claims, wherein the steel comprises 15 - 25 volume % hard phase and wherein the maximal Equivalent Circle Diameter of the hard phase is less than 3 μm .

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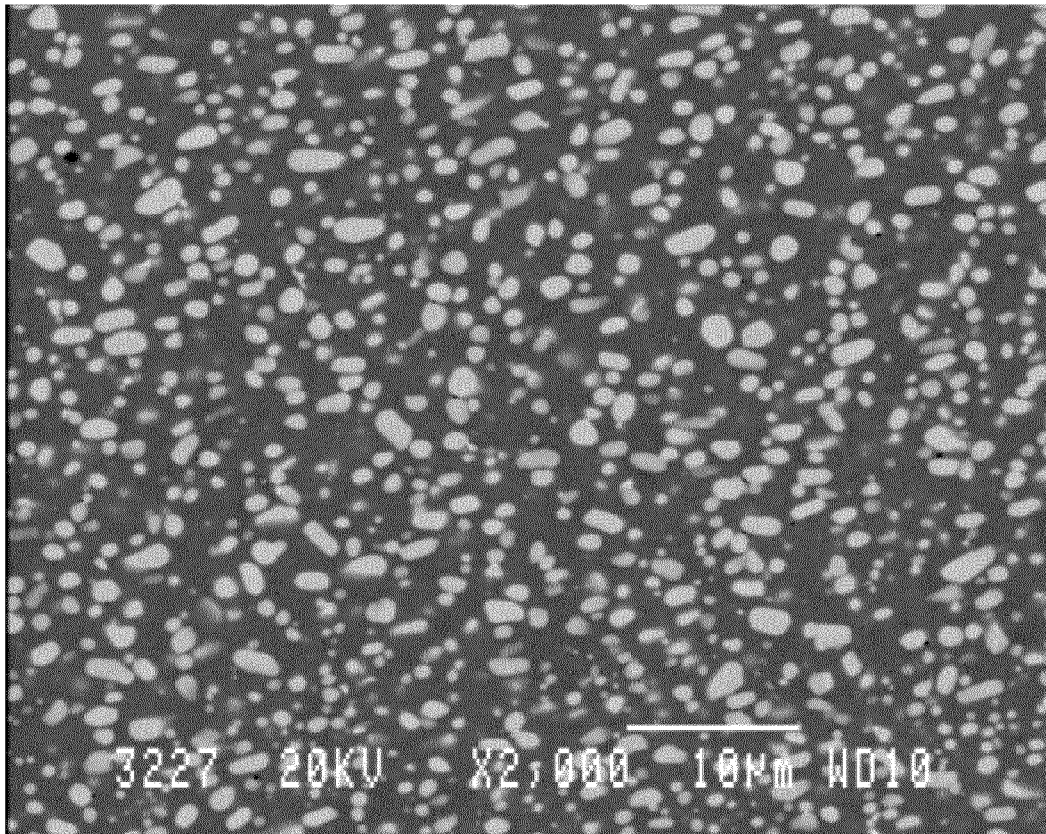


Fig. 1. Microstructure of the inventive steel. The white phase is Mo₂FeB₂. The length of the bar is 10 µm.



EUROPEAN SEARCH REPORT

Application Number
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EPO FORM 1503 03/82 (P04C01)

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Place of search The Hague		Date of completion of the search 3 June 2015	Examiner Morra, Valentina
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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