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(54) **Particle-reinforced steel with improved E-modulus and method for producing said steel**

(57) The invention relates to a steel product simultaneously combining a high elastic modulus E and high strength and to a method to produce said steel.

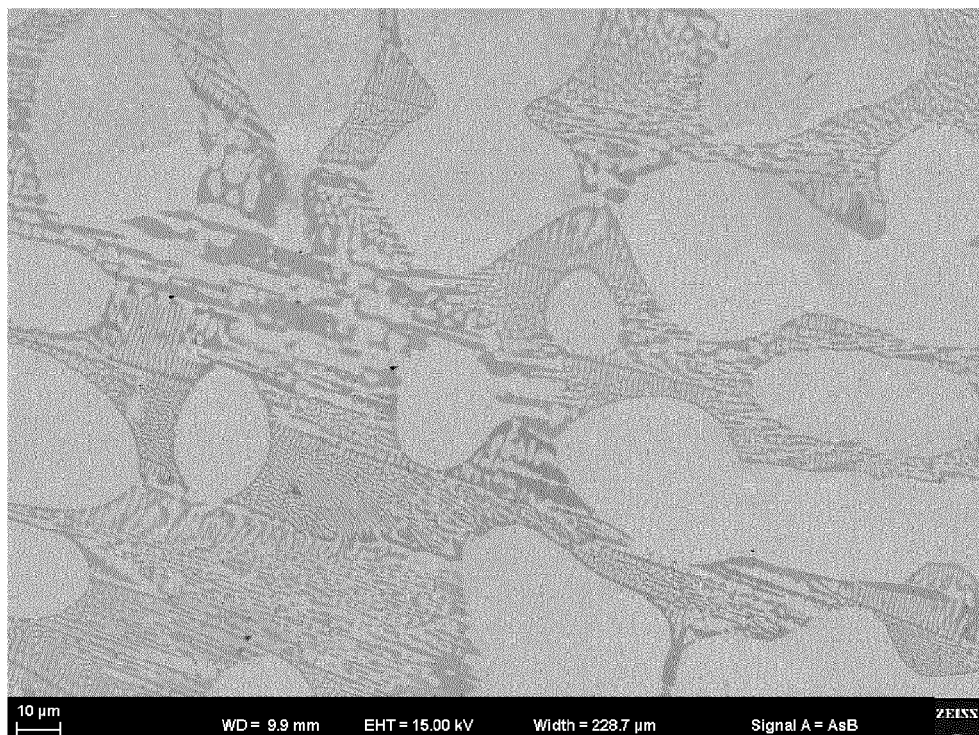


FIGURE 2

Description

[0001] The invention relates to high strength steel with increased E-modulus and to a method for producing said steel.

[0002] In the automotive industry, where lighter vehicles and safety are of constant concern, steel with a higher E-modulus allows the use of thinner gauge parts which still have the stiffness and strength of thicker and thus heavier parts. Also in other types of applications such as in yellow goods, aerospace or construction the combination of high E-modulus and high strength is an interesting combination of properties. A known way to increase the modulus of elasticity and reduce the weight of steel is by incorporating ceramic particles of different natures, such as carbides, nitrides, oxides or borides. These particles have a much higher elastic modulus, ranging from about 300 to 550 GPa, than that of the steel base which has an E-modulus around 205-210 GPa. One way of including ceramic particles uniformly distributed in a matrix of steel is by means of powder metallurgy.

[0003] Despite improved mechanical properties in comparison with conventional steels containing no dispersion of ceramic particles, this type of method like powder metallurgy has problems. Reactions of the metal powders are difficult to prevent because of the high surface area of the metal powders. Even after compacting and sintering, there may be residual porosity that may play a role in inducing fracture during cyclic loading. Uniform distribution of the particles in the matrix is difficult to achieve. Moreover the chemical composition of interfaces matrix/particle, and therefore their cohesion is difficult to control because of the surface contamination of the powders before sintering. In addition, the cost of the process like powder metallurgy is very high. This type of process is therefore potentially suitable for production in small quantities but not for economic production on the scale required for the automotive and construction industry.

[0004] In EP1897963 steel is proposed based on the formation of large quantities of titaniumdiboride particles (TiB_2). It describes steel comprising 2.5 to 7.5% titanium and about 0.8 to about 4% boron. The result of these additions is that large numbers of eutectic TiB_2 -precipitates are formed in the steel matrix and these particles leads to increase of the E-modulus and decrease of the density of the steel. A disadvantage of this steel type is that it is very difficult to produce the TiB_2 -precipitates as fine eutectic precipitates. Because of addition of large amount of Ti, the cost of this type steel is quite high. A similar solution is chosen in JP2007-051341 where the mandatory presence of large amounts of titanium and vanadium is complemented by a mandatory presence of large amounts of chromium to produce and stabilise the formation of V_3B_4 making the costs of the alloy very high.

[0005] It is an object of this invention to provide a steel product with a higher E-modulus than conventional steels.

[0006] It is also an object of this invention to provide a steel product that is much more economic than steel with TiB_2 or vanadium containing borides

[0007] It is also an object of this invention to provide a method of mass producing the steel product of the invention in an economical way.

[0008] One or more of these objects are reached by a steel comprising in wt. %

- $0.001 \leq C < 0.3$
- $1.0 \leq B < 3.0$
- $0.05 \leq \text{Mn} < 3.0$
- $0.0 \leq \text{Cr} < 2.0$
- $0.0 \leq \text{Si} < 1.0$
- $0.005 \leq \text{Al}_{\text{sol}} < 0.5$
- $0 \leq S < 0.030$
- $0 \leq P < 0.10$
- $0 \leq \text{Ni} < 1.0$
- $0 \leq \text{Cu} < 1.0$
- $0 \leq \text{Mo} < 0.4$
- $0.0 \leq \text{Ti} < 2.5$
- $0.0 \leq \text{Nb} < 0.2$
- $0.0 \leq V < 0.2$
- $0.0 \leq N < 0.04$
- balance iron and unavoidable impurities resulting from production,

wherein the steel comprises at least 10 wt% of Fe_2B -particles.

[0009] All compositional percentages are in weight percent (wt.%) unless otherwise indicated. The unavoidable impurities are elements unavoidably contained in the steel due to circumstances such as raw materials, manufacturing facilities, etc.

[0010] Carbon is added to increase the strength of steel matrix.

[0011] Boron is an important element for forming Fe_2B . Fe_2B -particles raise the E-modulus of the steel. Below the lower end of the inventive range the contribution of the precipitates to the increase of the E-modulus is insufficient. On

the other hand, if the content exceeds 3.0% the volume fraction of borides is too high which has a negative impact on ductility and workability.

[0012] Manganese contributes to the strengthening of the matrix by solid solution and increasing quenching-hardening-ability of steels. Manganese is also effective in binding sulphur thereby reducing the risk of hot-cracking during hot rolling. However the amount of Mn above 3% increases the risk of segregation and band formation to an unacceptable level. A suitable minimum manganese content is 0.05%.

[0013] Chromium is an element effective in increasing quenching-hardening-ability of steel and the strength of the matrix. Too high Cr increases the cost of steel and an excessive addition of Cr leads to precipitate (Fe, Cr)-borides which is not desirable in the context of this invention. The chromium content is therefore preferably below 2%. When present as an alloying element then a suitable minimum amount is 0.05% and preferably 0.1%.

[0014] Aluminium is added mainly for deoxidation. An amount of about or higher 0.005% is effective in the deoxidation of the melt. On the other hand, high Al-contents result in deterioration in ductility and castability due to the formation of harmful coarse alumina inclusions. Therefore the maximum content should not exceed 0.5%. The aluminium content in the steel is expressed as Al-sol (acid soluble), meaning that the aluminium is not bound to oxygen. The killing of the steel during steelmaking requires the addition of a deoxidant, usually aluminium and sometimes silicon, to bind the oxygen into alumina.

[0015] Silicon is an element increasing strength of steel. However, a Si-content of more than 1% will negatively affect surface quality of steel and galvanisability of steel products. Therefore the Si-content should be preferably below 1.0%.

[0016] Nitrogen is an impurity element that consumes Ti to form TiN and should be kept as low as possible. Although the maximum allowable nitrogen content is 0.040% (400 ppm), the nitrogen should preferably be controlled below 0.020%.

[0017] If Sulphur is added in amounts exceeding 0.030%, then the risk of MnS formation becomes too great. MnS is known to adversely affect hot and cold formability.

[0018] Phosphorus segregates at the grain boundaries. To maintain sufficient hot ductility and avoid hot-cracking during solidification and welding the amount should not exceed 0.10%.

[0019] Niobium and Vanadium form boride with B that is beneficial to the E-modulus. The amount of Nb and V should be limited to 0.2% due to their very high cost.

[0020] Titanium forms TiB₂ with B that is beneficial to a high E-modulus. However, Ti should be limited to 2.5% due to its high cost.

[0021] Optionally, nickel, copper and molybdenum can be added which increase the strength of and quenching-hardening-ability of the steel matrix. For economic reasons, the additions should be limited to 1%, 1% and 0.4% by weight respectively.

[0022] In an embodiment the E-modulus of the steel is at least 225 GPa, preferably at least 230 GPa.

[0023] In an embodiment the structure of the steel comprises at least 12 wt.% of Fe₂B, more preferably at least 15 wt.%.

[0024] In an embodiment of the invention the boron content is at least 1.5% and/or at most 2.5 wt.%.

[0025] In an embodiment the precipitates have an average size of below 10 μm. preferably the average size is below 3 μm.

[0026] According to a second aspect, a method is provided for producing the steel as claimed in any one of claims 1 to 4. A big advantage is that according to this method the steel according to the invention can be mass produced using conventional steel producing equipment without the need to use powder metallurgy as a production method. Preferably the steel melt from which the steel according to the invention is made by using Ferro-alloys. The steel melt or steel is not produced by powder metallurgy. This makes the steel much easier to produce in mass, and thereby more economically.

[0027] The advised temperature range for reheating is between about 0.8 and 0.95*T_m, T_m=melting temperature in °C. In view of the low melting point of the steel, which may be below 1150°C, depending on the composition, reheating for hot rolling has to be controlled to be below 0.95*T_m. The steel preferably is hot rolled above the Ar_{3r}-temperature. The hot rolling preferably takes place while the steel is still austenitic to achieve a homogeneous structure, although it could be hot rolled in the intercritical or ferritic region.

[0028] The hot rolled steel may subsequently be subjected to cold rolling to further reduce the gauge of the material and annealed at the temperature suitable to recrystallise the grain structure. The steel (cold-rolled or hot-rolled) may also be provided with a metallic coating to increase its corrosion resistance. This metallic coating preferably is a zinc or zinc alloy coating, and wherein the coating is applied by electrocoating or hot-dipping. The alloying elements in the zinc alloy coating may be aluminium, magnesium or other elements. An example of a suitable coating is the Magazinc® coating developed by Tata Steel.

[0029] According to a third aspect the steel according to the invention is used in static constructions such as sections, bridges or bridge parts, buildings, in vehicles such as cars, yellow goods, trucks, or aerospace applications. In automotive applications such as vehicles this type of steel can be applied for example in brakes, suspension components, shock mounts, roof bows, and vehicle floors. In aerospace applications one of the possible applications are gears and bearings etc., in construction the structural steels for sections. For yellow goods the possible applications are e.g. boom and bucket arm structures on backhoes and excavators.

[0030] The invention is now further explained by means of the following, non-limitative example.

[0031] One 50 kg vacuum furnace melts (under Ar atmosphere) were produced. The melts were made from very low carbon steel and Ferro-alloys with addition of relevant alloying elements. The 50 kg melts were cast into two ingots with 100mm x 100mm x 350mm. The chemical compositions of the casts are given in Table 1.

Table 1. Chemical composition of experimental casts, wt. % unless otherwise specified (N in ppm) (n.d. = not determined)

Steel	C	Mn	Al	B
1 (T _m =1150°C)	0.066	0.19	0.07	1.9
2	0.066	0.19	0.07	0.005

[0032] The microstructure of steel 1 is given in the SEM-micrographs at different magnifications.

[0033] The casts were homogenised at 1100°C for up to 10 hours.

[0034] A slice of 50x100x150 mm was saw off from the ingot and was heated up to 1075°C and soaked for 45 min and then hot rolled. The hot rolling from 50mm gauge down to 5mm gauge was performed. Rolling temperature on the surface was higher than 800°C. After hot rolling, hot rolled plates were coiled at 600°C.

[0035] The percentage of Fe₂B (wt.%) and the E- modulus are given in Table 2.

Table 2. Fe₂B (in wt.%) and E modulus for experimental steels

Steel	Fe ₂ B (wt.%)	E (//RD) (GPa)
1	22	230
2	<0.1%	205

Claims

1. Steel having a chemical composition consisting of

- $0.001 \leq C < 0.3$
- $1.0 \leq B < 3.0$
- $0.05 \leq Mn < 3.0$
- $0.0 \leq Cr < 2.0$
- $0.0 \leq Si < 1.0$
- $0.005 \leq Al_{sol} < 0.5$
- $0 \leq S < 0.030$
- $0 \leq P < 0.10$
- $0 \leq Ni < 1.0$
- $0 \leq Cu < 1.0$
- $0 \leq Mo < 0.4$
- $0.0 \leq Ti < 2.5$
- $0.0 \leq Nb < 0.2$
- $0.0 \leq V < 0.2$
- $0.0 \leq N < 0.04$

the rest of the composition comprising iron and unavoidable impurities resulting from production, wherein the steel comprises at least 10 wt% of Fe₂B as particles.

2. Steel according to claim 1 wherein the E-modulus is at least 225GPa, preferably at least 230GPa.

3. Steel according to any one of claims 1 to 2 wherein the structure of the steel comprises at least 12 wt% of Fe₂B, more preferably at least 15 wt%.

4. Steel according to any one of claims 1 to 3 wherein the particles have an average size of below 10 μm, preferably below 3 μm.

5. Method for producing the steel of any one of claims 1 to 4 comprising the steps of:

a. providing a steel melt having a composition

- 5 • $0.001 \leq C < 0.3$
- $1.0 \leq B < 3.0$
- $0.05 \leq Mn < 3.0$
- $0.0 \leq Cr < 2.0$
- $0.0 \leq Si < 1.0$
- 10 • $0.005 \leq Al < 0.5$
- $0 \leq S < 0.030$
- $0 \leq P < 0.10$
- $0 \leq Ni < 1.0$
- $0 \leq Cu < 1.0$
- 15 • $0 \leq Mo < 0.4$
- $0.0 \leq Ti < 2.5$
- $0.0 \leq Nb < 0.2$
- $0.0 \leq V < 0.2$
- $0.0 \leq N < 0.04$

b. casting the melt into a suitable starting material for hot rolling by casting an ingot or bloom or by casting a slab, rod or thin slab, or by casting a strip;

c. heating, reheating or homogenising the ingot, bloom, slab, rod or strip before hot rolling with a controlled heating rate so as to avoid decohesion between the matrix and the at least 10 wt% of Fe_2B as particles;

d. hot rolling the starting material to the finish hot rolling dimensions.

6. Method according to claim 5 wherein the hot rolling temperature is between $0.5 \cdot T_m$ and $0.95 \cdot T_m$.

7. Method according to any of claims 5 to 6 wherein the steel melt is produced by using Ferro-alloys.

8. Method according to any of claims 5 to 7 wherein the hot rolled steel is subsequently subjected to cold rolling to further reduce the gauge of the material and annealed at the temperature suitable to recrystallise the grain structure.

9. Method according to any one of claims 5 to 7 wherein the steel is provided with a metallic coating to increase corrosion resistance.

10. Method according to claim 9 wherein the metallic coating is a zinc or zinc alloy coating, and wherein the coating is applied by electrocoating or hot-dipping

11. Steel part produced from the steel according to any one of claim 1 to 4 for use in static constructions, or in vehicles such as cars, yellow goods, trucks, aerospace applications or in other engineering applications.

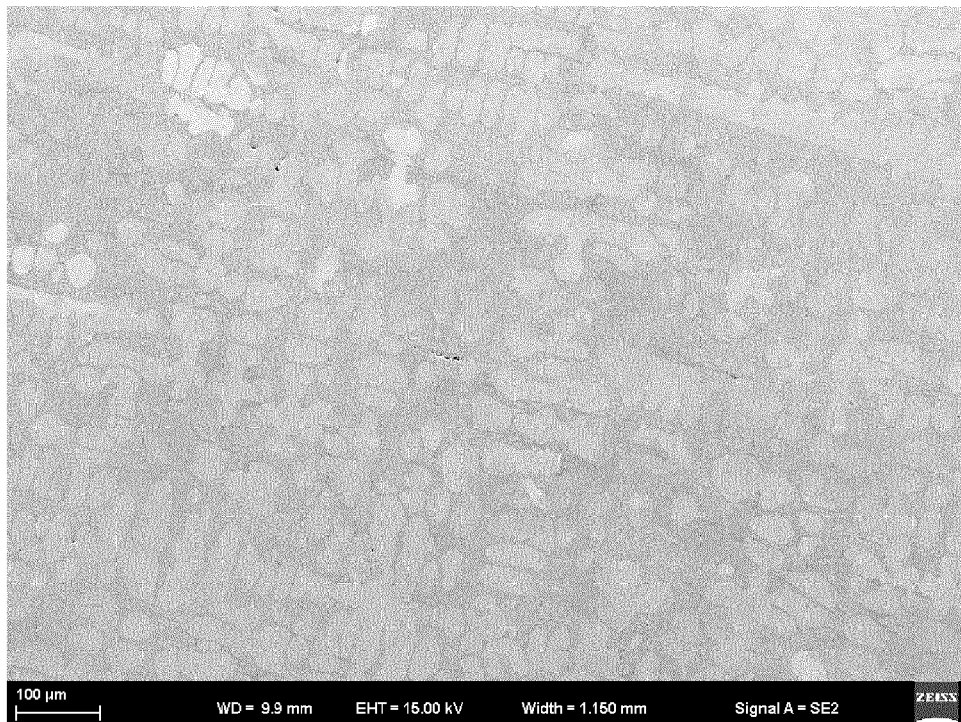


FIGURE 1

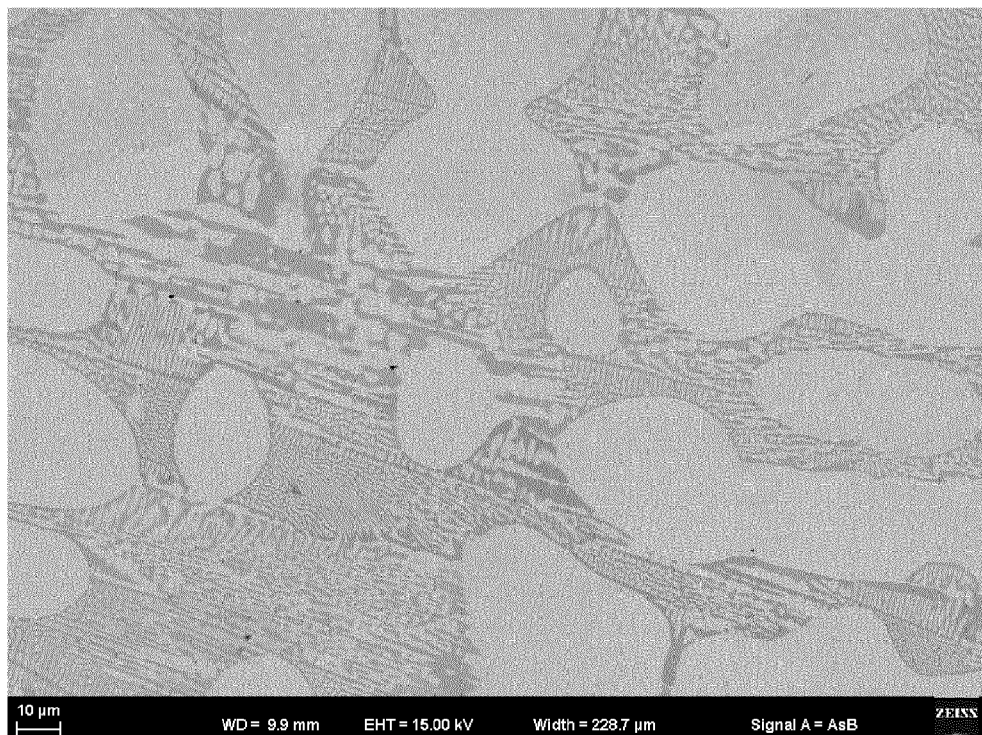


FIGURE 2



EUROPEAN SEARCH REPORT

Application Number
EP 12 18 2080

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	CH 361 824 A (HADFIELDS LIMITED [GB]) 15 May 1962 (1962-05-15) * page 1, lines 7-9 * * page 2, lines 90-100 * -----	1-4	INV. C22C38/00 C22C38/04 C22C38/06 C22C38/32 C22C38/54 C22C1/03 C22C35/00 C22C33/06 ADD. C23C2/06 C25D3/22 C21D8/02
			TECHNICAL FIELDS SEARCHED (IPC) C22C
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 20 February 2013	Examiner González Junquera, J
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**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 12 18 2080

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20-02-2013

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
CH 361824	A	15-05-1962	NONE

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

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