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Eipper et al.(10) **Pub. No.: US 2007/0125454 A1**(43) **Pub. Date: Jun. 7, 2007**(54) **HIGH-STRENGTH DUPLEX/TRIPLEX STEEL
FOR LIGHTWEIGHT CONSTRUCTION AND
USE THEREOF**(76) Inventors: **Konrad Eipper**, Rottenburg (DE);
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C22C 38/06 (2006.01)
(52) **U.S. Cl.** **148/329; 420/72**(57) **ABSTRACT**

The invention concerns a steel for lightweight construction, consisting of a multiphase structure. In the case of a duplex steel, it consists of mixed ferrite (α) and austenite (γ) crystals. In the case of a triplex steel, it comprises, additionally to said two phases, martensitic (ϵ) and/or (κ) phases. The volumetric weight of the inventive steel is low as a result of the high proportion of light alloys Al, Si Mn, Mg, Ga and Be. The inventive alloys have a volumetric weight of less than 7b/cm³.

HIGH-STRENGTH DUPLEX/TRIPLEX STEEL FOR LIGHTWEIGHT CONSTRUCTION AND USE THEREOF

Background of the Invention

[0001] 1. Field of Invention

[0002] The invention relates to a high-strength duplex or triplex lightweight structural steel with excellent deep-drawing properties, and to its use.

[0003] High-strength steel with various properties has been developed for the automotive industry, the construction industry and in aeronautical and aerospace applications and is already used in production. In this context, in particular for use in the automotive industry, there is an increasing desire for the weight of the vehicle to be reduced by the use of new materials. The objective in this context is to produce more lightweight steel alloys which otherwise retain or further improve the previous favorable properties.

[0004] 2. Related Art of the Invention

[0005] DE 43 03 316 has disclosed steels containing 13-16% by weight of Al and in some cases higher levels of further alloying elements, such as Cr, Nb, Ta, Si, B, Ti, for oxidation- and corrosion-resistant components. At temperatures above 700° C., alloys of this type are distinguished by a high resistance to oxidation and corrosion and are used in components which, although they can be employed at high temperatures, are preferably only exposed to oxidizing and corrosive conditions under low mechanical loads.

[0006] Furthermore, by way of example, DE 199 00 199 has disclosed high-strength lightweight structural steels which have a higher content of aluminum, chromium and nickel, as well as manganese, and consequently have a lower density than iron. As is to be expected, the steel alloy is distinguished by a good resistance to corrosion and stress corrosion cracking as well as a high strength. Steels of this type have aluminum contents of up to 10% by weight.

[0007] By way of example, the austenitic or austenitic/ferritic lightweight structural steel has a composition comprising 7-27% by weight of Mn, 1-10% by weight of Al, less than 10% by weight of Cr, less than 10% by weight of Ni, more than 0.7-4% by weight of Si, less than 3% by weight of Cu, less than 0.5% by weight of C, remainder iron and melting-related impurities. The further alloying constituents may comprise small amounts of nitrogen, niobium, titanium, vanadium and phosphorus.

[0008] Moreover, DE 12 62 613 B1 has disclosed the use of lightweight structural steels for aircraft components and engines and bullets and the like, which contain high levels of lightweight alloying constituents, comprising 4 to 20% of Al, 18 to 40% of Mn and 0.15 to 2% of C. These may also be supplemented if desired by 0 to 3% of Si and 0 to 4% of Nb.

[0009] It is also known from DE 197 27 759 to use a cold-workable austenitic lightweight structural steel, in particular an austenitic lightweight structural steel with good deep-drawing properties, which has a tensile strength of up to 1100 MPa and TRIP and/or TWIP properties. With a composition comprising 1 to 6% of Si, 1 to 8% of Al, where (Al+Si)<12%, 10 to 30% of Mn, remainder substantially

iron including standard steel accompanying elements, it is used as a material for reinforcing sheet-metal bodyparts.

[0010] Although the known lightweight structural steels mentioned above have important advantageous properties for use in the fields of technology mentioned, they are nevertheless beset with significant drawbacks. With the known steels, further weight savings, for example in the automotive industry, can only be achieved by a further reduction in the sheet-metal thickness or by using additional design measures. Deep-drawing steels which are readily deformable, i.e. can be deep-drawn and stretch-formed, are cold-rollable and have undergone a recrystallizing anneal and have a relatively high aluminum content, as are required in particular for use in automotive engineering, are not known from the prior art in this form on account of their specific density still being too high.

SUMMARY OF THE INVENTION

[0011] The invention is based on the object of providing a high-strength lightweight structural steel which has good cold-working properties, in particular good deep-drawing and stretch-forming properties, and the density of which is lower than the specific density of steels which have been disclosed hitherto.

[0012] The invention is given by the subject matter of claim 1. The further claims give advantageous developments and refinements of the invention.

[0013] The solution according to the invention relates to a high-strength α/γ duplex or $\alpha/\gamma/\epsilon(\kappa)$ triplex lightweight structural steel having the following composition (contents in % by weight):

[0014] 18 to 35% of Mn

[0015] 8 to 12% of Al

[0016] up to 6% of Si, with Al + Si > 12%,

[0017] 0.5 to 2% of C,

[0018] at most 0.05% of B,

[0019] 0 to 3% of Ti

at least one of the elements Mg, Ga, Be in an amount of in each case up to 3%,

remainder substantially iron including standard steel accompanying elements.

[0020] In this context, a refinement of the invention containing more than 3% of the light element Si is particularly expedient.

[0021] According to a highly expedient refinement of the invention, the contents of the elements Mg, Ga and Be, where present, are in each case greater than 0.3%.

[0022] According to refinements of the alloy according to the invention, it is preferable for the elements N, Nb, V and if appropriate Ti to be used as further alloying elements, in the following contents:

[0023] 0.03 to 2% of Ti,

[0024] N less than 0.3%

[0025] Nb less than 0.5%,

[0026] V less than 0.5%.

[0027] The lightweight structural steel according to the invention is formed from a multiphase microstructure, in the case of the duplex steel from α -ferrite and γ -austenite solid solutions. In the case of the triplex steel, there is a martensitic ϵ -phase and/or κ -phase in addition to the first two phases mentioned. The relative density of the steel according to the invention is reduced to low values by the high levels of the lightweight alloying elements Al, Si, C and Mn and at least one of the elements Mg, Ga, Be and optionally Ti. Both alloys achieve a density of less than 7 g/cm³, which is significantly reduced by up to 15% compared to conventional steels, which have densities of between 7.3 and 7.5 g/cm³. The solution according to the invention also further reduces the density compared to the lightweight structural steels containing up to 8% of aluminum which are known from the literature.

[0028] The element Mg, if it is present in the alloy of the lightweight structural steel according to the invention, further reduces its density, on account of the very low relative density of Mg. A similar statement is true of Be, if it is present in the alloy; in this case, the strength is also increased, while maintaining the ductility. The element Ti, if it is present in the alloy, further increases the strength by grain refining and solid-solution hardening. The element Ga, if it is present in the alloy, also serves to increase the strength and hardness. Moreover, it improves the casting properties of the alloy, since the Ga content makes it more liquid at similar temperature conditions.

[0029] The duplex or triplex lightweight structural steel according to the invention, in the cold-rolled and recrystallized state, is distinguished by a fine-grained two-phase or three-phase microstructure with an equiaxial, i.e. isotropic morphology of the α -ferrite, γ -austenite and ϵ -martensite grains.

[0030] The hardening exponent of the duplex/triplex steel is $n=0.23$ to 0.24 , and the mean r value (planar anisotropy) is: $r=(r_0^\circ+r_{90^\circ}+2r_{45^\circ})/4\approx 1$, i.e. this lightweight structural steel, in terms of a planar shape change during deep-drawing and stretch-forming, behaves quasi-isotropically ($\Delta r\approx 0$).

[0031] The fine-grained two-phase or three-phase microstructure increases the energy absorption—the dissipation of energy—of this steel when it is subjected to load at a high strain rate, as occurs, for example, as a result of impact loads or in the event of a crash.

[0032] The lightweight structural steel is distinguished by flow stresses of over 400 MPa. High strain hardening resulting from extensive interaction between the dislocations of the co-existing α/γ or $\alpha/\gamma/\epsilon(\kappa)$ phases results in tensile strengths at the hot strip of up to 1000 MPa and uniform elongations of up to 40% and maximum elongations of up to 50%. The cold strip which has undergone recrystallization annealing has strengths in the region of 900 MPa with maximum elongations of 70%.

[0033] The significantly reduced density compared to conventional steels is particularly advantageous. The lightweight structural steel according to the invention also has a reduction in density which has not hitherto been discovered compared to the lightweight structural steels comprising aluminum constituents which are known from the prior art.

[0034] A further advantage of the solution according to the invention is that, despite its high strengths, the material has

a very good workability. These properties had hitherto only been achieved with high-alloy special steels. Its casting properties during processing, which, as has already been mentioned, are improved still further if Ga is present, should be particularly emphasized.

[0035] The spectrum of properties described, i.e. a high component strength, the greater freedom of design in terms of geometry and the reduced density of the material, achieves the objective of obtaining a reduced component weight by the use of lightweight materials and shape structures.

[0036] Therefore, the α/γ duplex or $\alpha/\gamma/\epsilon(\kappa)$ triplex lightweight structural steel according to the invention leads to a further improvement in the combination of advantageous properties which has not hitherto been known.

[0037] The high proportion of alloying constituents with a relative density below the relative density of iron and lightweight structural steels which have been disclosed hitherto results in a reduction in weight, which is advantageous for the automotive industry, while retaining the method of construction which has hitherto been customary. Furthermore, the lightweight structural steel has an excellent ductility, a high strength and an extremely high hardening rate. The property of a high loading rate in the event of a crash in an accident should be particularly emphasized, since it means that this steel alloy is especially suitable for the construction of motor vehicles. Furthermore, there is a high resistance to corrosion, and in particular stress corrosion cracking, so that this steel alloy is also suitable for use in other fields of technology, for example in the construction industry.

[0038] The lightweight structural steels according to the invention are eminently suitable for use in concrete structures, i.e. in particular as prestressed concrete steels and Monier steels or guard rails and sheet pile walls. Furthermore, the resistance to corrosion can be improved by chemical, electrochemical, organic, non-metallic or metallic coatings.

[0039] It is also possible to harden the steel alloy by means of a chemical, electrochemical or thermal treatment.

[0040] A protective covering layer can be achieved by enriching and/or coating the surface with aluminum.

[0041] The aluminum-containing steel which is suitable for deep-drawing and stretch-forming is, in its production process, melted down, cast using the continuous-casting process, rolled down in the temperature range above the recrystallization temperature, or fully cast as a near net shape strip by rolling and casting, preferably thin-strip casting.

[0042] The steel can either be processed further directly as a hot strip or can be processed further in the cold-rolled state after hot rolling.

[0043] In addition to the possible uses which have been mentioned above in the automotive sector, the lightweight structural steel according to the invention is in particular also suitable for producing components for bodysheet components/bodywork, integral beams, chassis structures and space frames. Further lightweight components in automobiles include steering, axles and axle components, add-on

parts, seat rails, securing parts and passive safety systems, wheel suspensions, drive train and fuel tank.

[0044] The range of applications also extends to rail-borne and water-borne vehicles and into the aeronautical and aerospace sectors, preferably in thin-walled, strength-relevant components.

[0045] In addition to the abovementioned use in the construction industry, in particular in building, the material is also suitable for conveying installations, conveyor belts and in metallurgy applications.

1-10. (canceled)

11. A high-strength α/γ duplex or $\alpha/\gamma/\epsilon$ triplex lightweight structural steel, characterized by the following composition (contents in % by weight):

18 to 35% of Mn,

8 to 12% of Al,

3 to 6% of Si, with Al+Si>12%,

0.5 to 2% of C,

at most 0.05% of B,

at most 3% of Ti,

at least one of the elements Mg, Ga, Be in an amount of in each case 0.3% to 3%,

remainder mainly iron including standard steel minor constituents.

12. The high-strength lightweight structural steel as claimed in claim 11, wherein said Ti content is from 0.03 to 2%.

13. The high-strength lightweight structural steel as claimed in claim 11, comprising the following contents of further alloying elements

up to 0.3% of N

up to 0.5% of Nb

up to 0.5% of V.

14. The high-strength lightweight structural steel as claimed in claim 11, characterized by a fine-grained two-phase α/γ duplex microstructure or three-phase $\alpha/\gamma/\epsilon$ triplex microstructure with an equiaxial morphology in the cold-rolled and recrystallized state.

15. The high-strength lightweight structural steel as claimed in claim 11, characterized by a planar isotropy with $r=1$.

16. The high-strength lightweight structural steel as claimed in claim 11, characterized by a steel which in the plane of the metal sheet has virtually isotropic mechanical properties in terms of strength and elongation.

17. A high-strength lightweight structural steel article,

wherein said article is formed by a casting process, and

wherein said steel is A high-strength α/γ duplex or $\alpha/\gamma/\epsilon$ triplex lightweight structural steel, characterized by the following composition (contents in % by weight):

18 to 35% of Mn,

8 to 12% of Al,

3 to 6% of Si, with Al+Si>12%,

0.5 to 2% of C,

at most 0.05% of B,

at most 3% of Ti,

at least one of the elements Mg, Ga, Be in an amount of in each case 0.3% to 3%,

remainder mainly iron including standard steel minor constituents.

18. A lightweight structural steel article, wherein said article is selected from the group consisting of bodyshell and bodywork components, integral beams, chassis structures and space frames in vehicles, and wherein said steel is a high-strength α/γ duplex or $\alpha/\gamma/\epsilon$ triplex lightweight structural steel, characterized by the following composition (contents in % by weight):

18 to 35% of Mn,

8 to 12% of Al,

3 to 6% of Si, with Al+Si>12%,

0.5 to 2% of C,

at most 0.05% of B,

at most 3% of Ti,

at least one of the elements Mg, Ga, Be in an amount of in each case 0.3% to 3%,

remainder mainly iron including standard steel minor constituents.

19. A lightweight structural steel article, wherein said article is selected from the group consisting of building materials, conveying installations, metallurgy applications and guard rails and sheet pile walls, and wherein said steel is a high-strength α/γ duplex or $\alpha/\gamma/\epsilon$ triplex lightweight structural steel, characterized by the following composition (contents in % by weight):

18 to 35% of Mn,

8 to 12% of Al,

3 to 6% of Si, with Al+Si>12%,

0.5 to 2% of C,

at most 0.05% of B,

at most 3% of Ti,

at least one of the elements Mg, Ga, Be in an amount of in each case 0.3% to 3%,

remainder mainly iron including standard steel minor constituents.

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