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(54) **STAINLESS STEEL PRODUCT, USE OF THE PRODUCT AND METHOD OF ITS MANUFACTURE**

EDELSTAHLPRODUKT, VERWENDUNG DES PRODUKTS UND HERSTELLUNGSVERFAHREN
PRODUIT EN ACIER INOXYDABLE, UTILISATION DE CE PRODUIT, ET PROCÉDÉ DE
FABRICATION CORRESPONDANT

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WO-A1-02/27056 WO-A1-03/038136
WO-A1-2006/041344 WO-A1-2008/018242
WO-A2-2008/000347 JP-A- 7 090 471
US-A- 4 500 351 US-A- 4 500 351
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• **SCHRAMM BERND ET AL: "Lean Duplex
stainless steels for pump applications",
STAINLESS STEEL WORLD 2007 : SSW 2007 ;
[CONFERENCE AND EXHIBITION ;
MAASTRICHT, THE NETHERLANDS, 6 - 8
NOVEMBER 2007] ; CONFERENCE PAPERS, KCI
PUBL, NL; MAASTRICHT, NETHERLANDS, 1
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Description

[0001] The invention relates to a casting produced of stainless steel, which has a duplex ferrite-austenite microstructure and which has high structural stability and an improved combination of properties, particularly machinability and weldability. The invention further relates to a use of the product and to a method of manufacturing the casting.

[0002] Ferritic-austenitic or duplex stainless steel castings are in general defined as alloys with a mixture of almost equal proportions of ferrite and austenite in contrast to austenitic castings that mainly contain up to 10-15% ferrite. For duplex castings according to ASTM A890 standard the ferrite levels are not specified, but listed alloys will develop a range of approximately 30 to 60 % ferrite with the balance austenite. With the two-phase structure interesting property profiles can be designed. The first duplex stainless steels were developed almost 80 years ago and most probably they emerged from austenitic castings where certain amounts of ferrite in the microstructure proved to be advantageous. In fact duplex compositions generally show better castability than austenitic ones. Other favourable properties of duplex materials are high mechanical strength, superior fatigue strength, good wear resistance and good corrosion resistance. Hence, both cast and wrought products have found many attractive applications. Several duplex alloy compositions have been described with various optimisations. In many cases also cast articles have been included as articles in patents of duplex compositions. In recent years, with greatly increased raw material costs, special concern has been paid to reduce the nickel and molybdenum levels in the alloys and still maintain appropriate properties.

[0003] The favourable properties of the duplex stainless steels can be achieved for phase balances in the range of 30 to 70 % ferrite and austenite. The interactions of the major alloying elements, particularly chromium, nitrogen, nickel and molybdenum are quite complex. To achieve a stable duplex structure that responds well to processing and fabrication, care must be taken to obtain the correct level of each of these elements. Beside the phase balance, the formation of detrimental intermetallic phases at the elevated temperatures is the second major concern with duplex stainless steels. Sigma and chi phases form in high chromium, high molybdenum stainless steels and precipitate preferentially in the ferrite. The addition of nitrogen changes the phase balance in a favourable way to avoid formation of such phases.

[0004] The US patent 4,500,351 relates to a cast duplex stainless steel, in which the microstructure in a casting comprises a ferritic matrix containing at least about 30 % austenite after the solution treatment at 1200 °C and rapid cooling with water quenching in order to avoid the formation of sigma phase. The casting contains in weight percent about 0,02 percent carbon, 24 percent chromium, about 9,5 percent nickel, about 6 percent molybdenum, about 0,5 percent manganese, about 0,2 percent silicon and about 0,25 percent nitrogen. The castings of this US patent 4,500,351 are useful in pump parts such as impellers and housings and in valve parts such as seats and gates.

[0005] The WO publication 2008/000347 relates to a steel piston which is cast by low-pressure casting method as a single component from a steel alloy. One of those steels in the publication has a composition in weight % 0,01-0,03 % carbon, 0,3-1 % silicon, 3-9 % manganese, 15-27 % chromium, 1-3 % nickel, 0,2-1 % copper and 0,05-0,17 % nitrogen. Having the nitrogen content essentially low there is a risk of formation of intermetallic phases. Further, the range for chromium is very large and, therefore, the balance between the austenite phase and ferrite phase is not clear.

[0006] The WO publication 2008/018242 describes a duplex stainless steel which contains among others titanium (Ti) making possible the feature $f_{Ti} \times Ti \times N$ mentioned also in the claim 1 of the publication. The cast ingots are heat treated, hot rolled and further heat treated. In these tests, because of at least rolling, the material is not any more in the as-cast condition. A duplex stainless steel having good combination of properties in the as-cast condition and resisting thermal transformation to martensite is described in the US patent 4,828,630. The steel contains in weight percent up to 0,07 percent carbon, 17 to 21,5 percent chromium, 1 to 4 percent nickel, 4 to 8 percent manganese, 0,05 to 0,15 percent nitrogen, less than 2 percent silicon, less than 2 percent molybdenum and less than 1,5 percent copper. The steel of this patent contains 30 to 60 % ferrite and it is particularly suited for thin-walled castings for automotive underbody components. The steel has as-cast properties including a 10 % minimum elongation, a 0,2 % yield strength greater than 50 ksi (350 N/mm²), a toughness of at least 20ft.-lbs (30 Nm) at 0 °C and no nitrogen porosity.

[0007] The WO publication 03/038136 describes a duplex stainless steel with very many embodiments having different compositions. It is even said that in those compositions carbon, manganese, silicon, molybdenum, copper and cobalt are optional components (page 7, lines 2-4) and thus the only components necessary for the steels of the document D4 are chromium, nickel, nitrogen and in one embodiment boron. In spite of the optionality or not, a duplex stainless steel with only chromium, nickel, nitrogen and possibly boron is not stable and, therefore, the steel needs at least some of those optionally named components.

[0008] The US patent 6,033,497 relates to a pitting resistance duplex steel alloy with improved machinability containing in addition to iron in weight percent less than 0,1 percent carbon, 25-27 percent chromium, 5-7,5 percent nickel, less than 0,5 percent molybdenum, less than 0,15 percent nitrogen, less than 1,5 percent silicon, less than 2,0 percent manganese, 1,5-3,5 percent copper. In the prior art of this US patent it is said, that machinability of austenitic stainless steels can be enhanced by additions of alloying elements such as sulphur and selenium that may reduce the corrosion performance. Further, it is said that the addition of copper without molybdenum allows the duplex stainless steel alloy to be very slowly control cooled in a tightly closed heat treatment furnace so that harmful tensile residual stresses are minimized while

excellent ductility and corrosion resistance were retained.

[0009] In accordance with the US patent 6,033,497 the steel grade is treated by an accelerated in-mould heat treatment after casting without using a separate and slow heat treatment step. The steel grade of the patent is particularly for a hollow cylindrical centrifugal casting and it is used for instance for paper machine suction roll shell applications. The in-mould heat treatment comprises controlling the rate of cast cooling in the temperature range of about 260 °C to about 1090 °C and keeping the temperature of the alloy in the mould within about 450 °C of the temperature outside of the mould. The steel grade has improved machinability when treated in the mould after casting by an accelerated heat treatment as compared to the same alloy composition that is slowly control cooled in a tightly closed heat treatment furnace. The alloy without the in-mould treatment has a nominal internal diameter tensile residual stress of 24 MPa, while the respective value for the alloy treated in the mould after casting is 52 MPa.

[0010] The EP patent 1,327,008 describes a ferritic-austenitic stainless steel having a microstructure, which essentially contains of 35-65 vol % ferrite and 35-65 vol % austenite. The composition of this steel grade contains as main alloying components in weight percent 0,02-0,07 percent carbon, 19-23 percent chromium, 1,1-1,7 percent nickel, 0,15-0,30 percent nitrogen, 3-8 percent manganese, optionally molybdenum and/or copper less than 1 percent. The steel of this EP patent is produced by Outokumpu under the trademark LDX 2101® and wrought products have been received with great commercial interest.

[0011] Duplex stainless steel castings in general show good castability. However, there is a risk of formation of nitrogen gas pores during solidification because of limited nitrogen solubility in the ferrite phase that normally solidifies from a steel melt with a composition of a duplex stainless steel alloy. In general it can be stated that most stainless steel castings are subjected to various machining operations to be fitted into the system wherein the castings will be used. In this regard duplex stainless steels are considered more difficult to machine than for instance austenitic stainless steels. The higher strength levels of the former steel type explain this behaviour. Additions of carbon and nitrogen both increase the strength and the degree of strain hardening of the steel and should therefore be kept low to achieve good machinability. However, modern duplex stainless steels are alloyed with high nitrogen contents for good weldability and best weldability properties at the sacrifice of machinability.

[0012] One application where cast or wrought duplex stainless steels are used is a steel shell for a suction roll of paper machines. One important material property for this application is also machinability, because cast or wrought steel shells are subjected to substantial machining to produce the final suction roll. As said in connection with the US patent 6,033,497 one way to improve the machinability is to add sulphur or selenium, which elements, however, reduce the corrosion performance.

[0013] The WO publication 2006/041344 describes a steel shell for a suction roll of paper machines, in which the wrought steel grade LDX 2101® of the EP patent 1,327,008 is used without any addition of sulphur. Further, any treatment improving machinability is not carried out as well as the optional additions of copper and molybdenum are remarkable smaller when compared the US patent 6,033,497.

[0014] Schramm et al published in the presentation of "Lean Duplex Stainless Steels for Pump Applications" in Stainless Steel World 2007 Conference, Maastricht, 6-8 November 2007, results of studies on lean duplex materials for pump-specific applications. One alloy "cast 2101" was made of cast bars having a composition in weight percent of 0,028 percent carbon, 0,97 percent silicon, 5,04 percent manganese, 0,011 percent phosphorus, 0,004 percent sulphur, 20,73 percent chromium, 0,31 percent molybdenum, 1,73 percent nickel, 0,20 percent nitrogen and 0,30 percent copper. As results for this alloy "cast 2101" after solution-annealing at the temperature of 1050 °C and water-quenching Schramm et al mention for instance the values of 473 MPa for 0.2 % proof strength and 37.3 % A5 elongation. As to the corrosion properties Schramm et al say that the alloy "cast2101" has the pitting potential lower than in the alloy 2304 having a composition in weight percent of 0,024 percent carbon, 0,64 percent silicon, 1,32 percent manganese, 0,015 percent phosphorus, 0,001 percent sulphur, 22,50 percent chromium, 0,28 percent molybdenum, 4,92 percent nickel, 0,09 percent nitrogen and 0,26 percent copper. However, Schramm et al do not mention any information of the applicability of this alloy "cast 2101" for desired applications.

[0015] The object of the present invention is to eliminate some drawbacks of the prior art and to achieve a casting of a duplex stainless steel, which in the method of manufacturing a casting is sufficiently stable against formation of detrimental precipitates, such as intermetallic phase and which has as properties a combination of high strength and good corrosion resistance, good castability and high machinability. The essential features of the invention are enlisted in the appended claims.

[0016] The present invention relates to a duplex stainless steel casting with high machinability comprising, in weight percent, up to 0,07 percent carbon, up to 2 percent silicon, 4 to 6 percent manganese, 19 to 23 percent chromium, 0,5 to 1,7 percent nickel and 0,20 to 0,26 percent nitrogen. The alloys to be used in production of the duplex stainless steel casting with foresaid range may contain small amounts of other elements or impurities and optionally elements such as up to 1 percent copper, up to totally 1 percent of molybdenum and/or tungsten according to the formula $(Mo + \frac{1}{2} W)$ less than 1 percent, the remainder being iron and incidental impurities. The microstructure of the duplex stainless steel casting of the invention contains 30 - 70 vol percent ferrite and 30 - 70 vol percent austenite. The invention also relates to a cast

method for producing the casting as well as to the use of the casting.

[0017] In the manufacturing of large stainless steel castings it is important to have a microstructure that is sufficiently stable against formation of detrimental precipitates such as intermetallic phase as such phases have adverse effects on properties. For this a lean, balanced duplex composition of the casting of the invention is desirable. Preferably the microstructure of the duplex stainless steel of the invention contains 50 vol percent ferrite and 50 vol percent austenite.

[0018] Another important property for steel castings is the ease to perform repair welding. In addition to their good castability the casting of the invention is in general quite resistant to hot cracking during welding. If repair welding is needed it is in most cases necessary to perform a post weld heat treatment as weld metal and heat affected zone easily will be exposed to rapid cooling due to a small weld pool surrounded by a large cast section. This may result in a microstructure with high ferrite content that is sensitive to cracking and reduction in properties why heat treatment must follow. For this reason it is desirable with the duplex stainless steel composition of the invention having high austenite reformation during rapid thermal cycles such as in welding. To obtain such a feature high nitrogen content in the duplex stainless steel casting of the invention is advisable.

[0019] The duplex stainless steel casting of the invention consists of in weight percent, preferably up to 0,05 percent carbon and more preferably up to 0,03 percent carbon, preferably up to 1 percent silicon, preferably greater than 4 up to 6 percent manganese, preferably greater than 21 up to 22 percent chromium, preferably greater than 1,1 up to 1,7 percent nickel and more preferably greater than 1,35 up to 1,7 percent nickel and preferably greater than 0,20 and up to 0,26 percent nitrogen, and optionally elements up to 1 percent copper, up to totally 1 percent of molybdenum and/or tungsten according to the formula $(Mo + \frac{1}{2} W)$ less than 1 percent, the remainder being iron and incidental impurities.

[0020] The invention is described in more details in the following referring to the drawings in which

Fig. 1 shows the test results when compared the machinability the casting of the invention with the prior art austenite stainless steel,

Fig. 2 shows the microstructure of a simulated weld repair in a casting of the invention.

[0021] The duplex stainless steel casting of the present invention was tested in machinability and welding, especially in weld repair.

[0022] For testing the machinability a casting was produced having the following chemical composition in weight percent in table 1:

Table 1

C	Si	Mn	P	S	Cr	Ni	Mo	Cu	N
0,026	0,76	4,93	0,021	0,001	21,37	1,44	0,23	0,34	0,226

[0023] A cast billet with a square section 140 mm was subjected to different tests in the as-cast condition without any previous heat treatment. The mechanical properties of the casting were as follows in table 2:

Table 2

Yield strength $R_{p0,2}$ MPa	Ultimate tensile strength R_m MPa	Fracture elongation A5 %
451	634	40

[0024] The strength level is far above that for austenitic castings, which typically exhibit yield strengths of about 200 MPa and an ultimate strength of about 500 MPa. Testing of machinability was made with turning of cylindrical test pieces and results are shown in Figure 1. The figure illustrates allowable cutting speed for a tool life of 15 minutes in turning. The tool insert was of cemented carbide type. The machinability of casting according to the invention is superior to that of an austenitic steel of type 304L. This is in contradiction to the expected outcome where the austenitic steel is considered having better machinability.

[0025] Further tests were performed with a casting according to present invention which was produced with the following chemical composition, in weight percent in table 3:

Table 3

C	Si	Mn	P	S	Cr	Ni	Mo	Cu	N
0,024	0,69	4,89	0,020	0,001	21,45	1,60	0,20	0,25	0,230

[0026] From a 140mm thick cast section 30mm thick square samples were removed and the samples were subjected to simulated repair welding using shielded metal arc welding. The base metal was in the as-cast condition. Grooves were made in the sample and afterwards filled by welding using a filler material suited for this alloy. The arc energy was 0,7 to 0,8 kJ/mm. The resulting welds were free of cracks and showed a normal microstructure, also in the heat-affected zone. This is illustrated in Figure 2.

[0027] Castings according to the present invention can be cast by different casting processes such as centrifugal casting, chill casting, die casting, investment casting, pressure casting, permanent mould casting, sand casting and vacuum casting. The castability is good showing no tendency to cracking or pore formation in spite of the high nitrogen content. This is because the high level range of 4-6% manganese can be used. Cast items are preferably solution annealed at a temperature of 1020 to 1100°C followed by rapid cooling. However, thinner sections can be used in as-cast condition. Although microstructure is not a property and can be difficult to measure correctly the present invention will contain roughly equal amounts of austenite and ferrite, the allowable phase range being 30 to 70%. Furthermore, the microstructure is very resistant to precipitation of intermetallic phases, which in turn gives a low sensitivity to embrittlement. Castings of present invention exhibit superior machinability in as-cast as well as in solution annealed conditions.

[0028] Thus duplex castings of the present invention offer desirable and inexpensive cost alternatives to austenitic cast materials due to their high machinability, high strength and good weldability. Castings of the present invention can be especially favourable for use in various solutions and parts for pumps, valves, impellers or for use in other solutions wherein a combination of high machinability, high strength and good weldability in a casting is needed as as-cast condition or after some further treatment, such as solution-annealed and quenched condition.

Claims

1. A duplex stainless steel casting with high machinability, **characterized in that** the microstructure of the casting contains 30 - 70 vol percent ferrite and 30 - 70 vol percent austenite and the casting consisting of in weight percent: up to 0,07% carbon, up to 2% silicon, 4-6% manganese, 19-23% chromium, 0,5-1,7% nickel, optionally up to 1% of molybdenum and/or tungsten with the formula $(Mo+\frac{1}{2}W)$ less than 1%, optionally up to 1% copper and 0,20-0,26% nitrogen, the remainder being iron and incidental impurities.
2. The duplex stainless steel casting of claim 1, **characterized in that** it contains up to 0,05% carbon.
3. The duplex stainless steel casting of claim 2, **characterized in that** it contains up to 0,03% carbon.
4. The duplex stainless steel casting of any of the preceding claims, **characterized in that** it contains 21-22% chromium.
5. The duplex stainless steel casting of any of the preceding claims, **characterized in that** it contains 1,1-1,7% nickel.
6. The use of the duplex stainless steel casting with high machinability of any of the claims 1 - 5 in pumps, valves or impellers.
7. Method for producing the duplex stainless steel casting with high machinability of any of the claims 1 - 5, **characterized in that** the casting is produced by centrifugal casting, chill casting, die casting, investment casting, pressure casting, permanent mould casting, sand casting or vacuum casting.

Patentansprüche

1. Gussteil aus nichtrostendem Duplexstahl mit hoher Maschinenbearbeitbarkeit, **dadurch gekennzeichnet, dass** das Gefüge des Gussteils 30 - 70 Vol.-% Ferrit und 30 - 70 Vol.-% Austenit enthält und das Gussteil, in Gewichtsprozent, aus Folgendem besteht: bis zu 0,07 % Kohlenstoff, bis zu 2 % Silicium, 4 - 6 % Mangan, 19 - 23 % Chrom, 0,5 - 1,7 % Nickel, optional bis zu 1 % Molybdän und/oder Wolfram mit der Formel $(Mo+\frac{1}{2}W)$ weniger als 1 %, optional bis zu 1 % Kupfer und 0,20 - 0,26 % Stickstoff, wobei der Rest Eisen und zufällige Verunreinigungen sind.
2. Gussteil aus nichtrostendem Duplexstahl nach Anspruch 1, **dadurch gekennzeichnet, dass** es bis zu 0,05 % Kohlenstoff enthält.
3. Gussteil aus nichtrostendem Duplexstahl nach Anspruch 2, **dadurch gekennzeichnet, dass** es 0,03 % Kohlenstoff

enthält.

4. Gussteil aus nichtrostendem Duplexstahl nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** es 21 - 22 % Chrom enthält.
5. Gussteil aus nichtrostendem Duplexstahl nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** es 1,1 - 1,7 % Nickel enthält.
6. Benutzung des Gussteils aus nichtrostendem Duplexstahl mit hoher Maschinenbearbeitbarkeit nach einem der Ansprüche 1 - 5 in Pumpen, Ventilen oder Laufrädern.
7. Verfahren zur Herstellung des Gussteils aus nichtrostendem Duplexstahl mit hoher Maschinenbearbeitbarkeit nach einem der Ansprüche 1-5, **dadurch gekennzeichnet, dass** das Gussteil durch Schleudergießen, Gießen mit Kühlkokille, Druckgießen, Feingießen, Niederdruckgießen, Kokillengießen, Sandgießen oder Vakuumgießen hergestellt wird.

Revendications

1. Produit moulé en acier duplex inoxydable présentant une usinabilité élevée, **caractérisé en ce que** la microstructure du produit moulé contient 30 à 70 % en volume de ferrite et 30 à 70 % en volume d'austénite, le produit moulé ayant les constituants suivants, en pourcentage en poids : jusqu'à 0,07 % de carbone, jusqu'à 2 % de silicium, 4 à 6 % de manganèse, 19 à 23 % de chrome, 0,5 à 1,7 % de Nickel, optionnellement jusqu'à 1 % de molybdène et/ou de tungstène selon la formule $(Mo + \frac{1}{2} W)$ inférieur à 1 %, optionnellement jusqu'à 1 % de cuivre et 0,20 à 0,26 % d'azote, le reste étant du fer et des impuretés inévitables.
2. Produit moulé en acier duplex inoxydable selon la revendication 1, **caractérisé en ce qu'il** contient jusqu'à 0,05 % de carbone.
3. Produit moulé en acier duplex inoxydable selon la revendication 2, **caractérisé en ce qu'il** contient jusqu'à 0,03 % de carbone.
4. Produit moulé en acier duplex inoxydable selon l'une quelconque des revendications précédentes, **caractérisé en ce qu'il** contient 21 à 22 % de chrome.
5. Produit moulé en acier duplex inoxydable selon l'une quelconque des revendications précédentes, **caractérisé en ce qu'il** contient 1,1 à 1,7 % de nickel.
6. Utilisation du produit moulé en acier duplex inoxydable, présentant une usinabilité élevée, selon l'une quelconque des revendications 1 à 5 dans des pompes, des vannes ou des roues de turbine ou de pompes.
7. Procédé de fabrication du produit moulé en acier duplex inoxydable, présentant une usinabilité élevée, selon l'une quelconque des revendications précédentes 1 à 5, **caractérisé en ce que** le produit moulé est fabriqué par coulée par centrifugation, par coulée continue, par moulage permanent, par moulage à modèle perdu, par coulée sous pression, par coulée à coquille permanent, par moulage au sable ou par coulée sous vide.

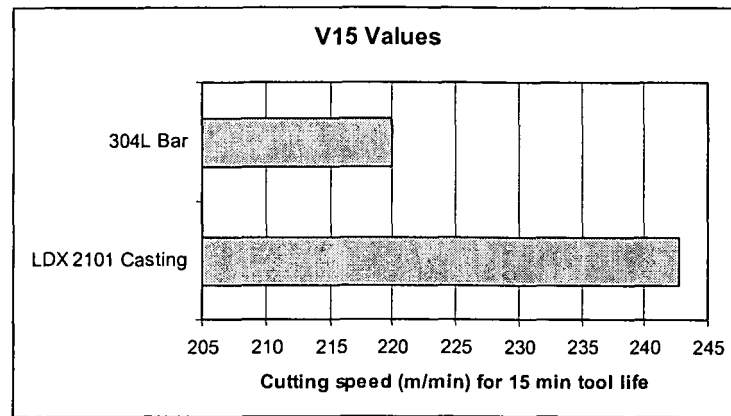


Fig. 1

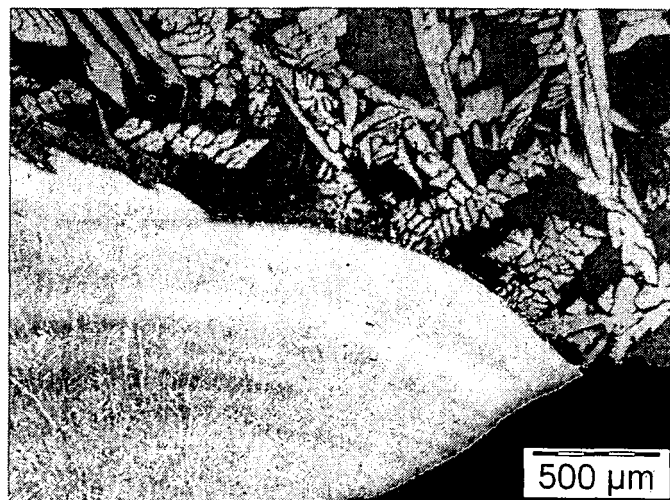


Fig. 2

REFERENCES CITED IN THE DESCRIPTION

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