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Bruckner et al.

(54) **METHOD FOR MANUFACTURING A STEEL STRIP OR SHEET CONSISTING MAINLY OF MN-AUSTENITE**

(76) Inventors: **Gabriele Bruckner**, Essen (DE); **Wolfgang Schlump**, Essen (DE); **Hans-Joachim Krautschick**, Solingen (DE)

Correspondence Address:
Charles Guttman
Proskauer Rose
1585 Broadway
New York, NY 10036 (US)

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(57) **ABSTRACT**

The method according to the invention can be used for the economic manufacture of a steel strip (W) or sheet consisting mainly of Mn-austenite which possesses enhanced strength compared with the prior art. For this purpose a steel is melted which contains at least the following alloying components (in wt. %), 15.00-24.00% Cr, 5.00-12.00% Mn, 0.10-0.60% N, 0.01-0.2% C, max. 3.00% Al and/or Si, max. 0.07% P, max. 0.05% S, max. 0.5% Nb, max. 0.5% V, max. 3.0% Ni, max. 5.0% Mo, max. 2.0% Cu as well as iron and unavoidable impurities as the remainder. This steel is cast into a thin strip (D) having a maximum thickness of 10 mm in a casting gap formed between two rotating rollers (**2, 3**) or rolls. The rollers (**2, 3**) or rolls are cooled so intensively that the thin strip (D) in the casting gap (**4**) is cooled at a cooling rate of at least 200 K/s.

METHOD FOR MANUFACTURING A STEEL STRIP OR SHEET CONSISTING MAINLY OF MN-AUSTENITE

[0001] The invention relates to a method of manufacturing a steel strip or sheet consisting mainly of Mn-austenite. Steels suitable for manufacturing these products are assigned to AISI 200 and bear the designation S20100 to S24000. Steel materials of this type are distinguished by a high strength which is conserved after welding even in the region of the weld seam.

[0002] These good strength properties are achieved by interstitial and substitutional mixed crystal hardening. Carbon and nitrogen are particularly effective in this respect. Higher carbon contents are avoided however because of the undesirable carbide formation. Thus, nitrogen is preferentially used for interstitial mixed crystal hardening in steels of the type in question. However, the production of steels having an elevated nitrogen content is expensive in relation to the alloying constituents or the apparatus required for the production.

[0003] In a known method for producing steels having higher nitrogen contents the melt is molten under the application of a compressive load. The pressure acting on the melt in this case is so far above the nitrogen partial pressure that the nitrogen in the appropriate steel goes into solution. The advantage of this procedure is that steels having higher nitrogen contents can be produced without adding particular quantities of other alloying elements. A disadvantage however is the high expenditure on apparatus required for this.

[0004] An alternative method for dissolving the nitrogen by applying a compressive load during melting involves increasing the solubility of the melt itself. This can be achieved by high contents of chromium and manganese. A description of the properties of steels having corresponding compositions compiled by M. du Toit can currently be found on the internet at "www.tecnet.co.za/mags/steel/feature1.htm". The known steels can be melted and cast conventionally without applying any compressive load, but not in continuous casting. Casting of known steels thus incurs high costs.

[0005] A further increase in the strength of conventionally castable steels of the type described previously can be achieved by alloying with aluminium and/or silicon. These two elements support the mixed crystal hardening and thus lead to a further increase in strength. Furthermore, the addition of aluminium and silicon can influence the stacking fault energy which again influences the deformation processes.

[0006] Thus, the addition of aluminium leads to an increase in the stacking fault energy and favours deformation by twinning. Silicon however, reduces the stacking fault energy but favours deformation by martensite formation. As a result of the combined addition of silicon and aluminium the strengthening of the material during deformation can thereby be specifically influenced. The formation of martensite leads to high strengthening whereas the strengthening is reduced by twinning.

[0007] The advantages of adding amounts of aluminium and silicon to steels of the type in question are offset by the disadvantage that they are ferrite formers and favour primary ferritic solidification. The resulting ferrite only has a low solubility for nitrogen.

[0008] Consequently the nitrogen is eliminated in the form of gas bubbles during the solidification. In order to achieve a high-strength austenitic steel whilst retaining the increased nitrogen content however, the austenite must thus be stabilised. In addition to increasing the raw material costs, the further increased manganese contents required for this give rise to appreciable problems in the production of such high-manganese steels in steelworks.

[0009] The problem for the invention is thus to provide a method of manufacturing a steel consisting mainly of Mn-austenite which can be manufactured economically and at the same time exhibits increased strength compared with the prior art.

[0010] The problem is solved by a method for manufacturing a steel strip or sheet consisting mainly of Mn-austenite in which a steel is melted which contains the following alloying constituents (in wt. %):

15.00–24.00% Cr,
5.00–12.00% Mn,
0.10–0.60% N,
0.01–0.2% C,
max. 3.00% Al and/or Si,
max. 0.07% P,
max. 0.05% S,
max. 0.5% Nb,
max. 0.5% V,
max. 3.0% Ni,
max. 5.0% Mo,
max. 2.0% Cu,
and iron and unavoidable impurities as the remainder,

[0011] and in which the steel is cast into a thin strip having a maximum thickness of 10 mm in a casting gap formed between two rotating rollers or rolls, whereby the rollers or rolls are cooled so intensively that the thin strip in the casting gap is cooled at a cooling rate of at least 200 K/s. The thickness of the thin strip is preferably between 1 and 5 mm. Naturally, the details of the steel composition used according to the invention also include such alloys for which the content of these alloying elements is zero for which only a maximum permissible upper limit of the content is given.

[0012] According to further refinements of the invention, the chromium content of the steel can be limited to 17.00-21.00 wt. % Cr, the manganese content can be limited to 8.00-12.00 wt. % Mn and/or the nitrogen content can be limited to 0.40-0.60 wt. % N. In addition, contents of Ni, Mo and/or Cu can be present in the steel.

[0013] The contents of the alloying elements contained in the steel composition used according to the invention are optimised in each case in terms of the action of these elements. Thus, Cr, Mn, Mo, V, Nb and Al increase the nitrogen solubility in the melt whereas Ni and Cu, being austenite formers, and Si reduce the nitrogen solubility. As mentioned, Si also acts as a mixed crystal hardener. In addition, it is also used for grain refinement and lowers the stacking fault energy. Aluminium on the other hand increases the stacking fault energy. Molybdenum also acts as a mixed crystal hardener and improves the corrosion behaviour. Vanadium also has a grain-refining action and enhances the strength. The addition of Nb leads to an increase in strength by precipitation hardening.

[0014] The invention makes use of the fundamentally known technique of a strip casting plant where the steel is cast in the casting gap formed between the rollers or rolls of, for example, a double-roller casting apparatus, and is cooled so intensively that there is a shift from primary ferritic towards primary austenitic solidification. This makes it possible to transfer the nitrogen dissolved in the melt into the steel since the austenite possesses a high solubility for nitrogen. Such intensive cooling is only made possible by casting a thin strip in a casting gap whose walls formed by the casting rolls or rollers move essentially at the same speed as the cast strip so that a continuous intensive heat exchange is ensured between the walls (casting roll/roller) and the cast steel in the casting gap.

[0015] The intensive cooling taking place at a high cooling rate ensures that nitrogen gas bubbles possibly forming in the solidifying melt remain small and the pressure directed towards them is high. This prevents any nitrogen outgassing in the course of the solidification. In addition, such an escape of nitrogen is also suppressed by the high ferrostatic pressure which occurs as a result of the large height of the melt pool in the casting gap. In this way it is ensured that the pressure P_N in any forming nitrogen gas bubbles is always lower than the sum of the ambient pressure P_A, the ferrostatic pressure P_F and twice the surface tension a of the gas bubbles relative to the bubble radius r (i.e. $P_N<P_A+P_F+2\sigma/r$).

[0016] The rapid solidification of the cast strip during strip casting thus offers great freedom in terms of the choice of steel composition especially in connection with steels of the type used according to the invention. As explained, as a result of the rapid solidification larger quantities of nitrogen can be dissolved. Alloying elements which improve the material properties can thus be added in larger quantities than in the conventional method of manufacture without regard to their possible negative influence on the nitrogen solubility. For example, if the steel contains higher quantities of Si, the risk of nitrogen outgassing present in conventional manufacture as a result of the slow solidification and the associated increased ferrite formation is eliminated in the method according to the invention. Also in the case of increased Al contents the formation of AlN which occurs during slower cooling is avoided by the rapid cooling provided according to the invention. Thus, without regard to the harmful influences caused by slow cooling, the invention allows the deformation mechanism of each alloy used to be specifically adjusted by a suitable choice of Al and Si content so that an end product having optimised properties is obtained.

[0017] The cost advantage achieved by the invention in the processing of steels of the type used according to the invention which are inherently difficult to deform is quite considerable. This applies both to those steels containing up to 7.5 wt. % Mn which can be cast by conventional continuous casting and also to those containing more than 7.5 wt. % Mn which conventionally can only be cast by block casting and then rolled to the desired end thickness by several passes with reheating if necessary.

[0018] At the present time hot strip made of continuously castable alloy can only be manufactured with minimum thicknesses of 3.5 mm in a conventional hot wide-strip mill. The production of cold strip having target thicknesses of 0.8-1.2 mm is only feasible by intermediate annealing. In the method involving strip casting according to the invention intermediate annealing is no longer necessary however because of the smaller thickness of the hot strip obtained. Since a thin strip having final thicknesses between 1 and 3 mm can be produced by the strip casting provided by the invention, in many cases it is also possible to adjust the final thickness of the strip produced so that cold rolling can be dispensed with completely. In this way the problems caused by the low deformability of Mn-austenites in the conventional method of manufacture can be avoided.

[0019] The method according to the invention can be used to produce steel strip and sheet having particularly high nitrogen contents of 0.4 to 0.6 wt. % and alloyed with up to 3% aluminium and/or silicon without the steel production needing to take place under excess pressure or particularly high manganese contents being required. The steel products thus produced possess a fine-grained isotropic structure with slight macro-segregation or a small number of coarse inclusions. As a result of their Al and/or Si content, these products also exhibit an enhanced strength and ductility compared with the prior art. For a steel strip or sheet produced according to the invention the strengthening and thus the energy absorption during deformation can be specifically adjusted by the choice of alloy.

[0020] Casting of the thin strip preferably takes place in a protective gas atmosphere. As a result of casting in a protective gas atmosphere it is easy to produce a thin strip having a modified surface whose degree of oxidation can be specifically influenced. In this way scale formation can be avoided.

[0021] The strip thus produced can then be hot-rolled "in-line" in a roll stand without the risk of the rollers sticking. It is particularly advantageous in this respect if the thin strip is heated to an initial rolling temperature before hot rolling. As a result of this increase in temperature, higher degrees of deformation can be achieved during hot rolling.

[0022] By subjecting the hot strip to heat treatment after the hot rolling its structure can be specifically optimised. The heat treatment can comprise annealing followed by controlled cooling.

[0023] As a result of its spectrum of properties, steel sheet produced according to the invention is especially suitable for the manufacture of automobile-body sheet metal parts, stiffening structural components used particularly in general vehicle building and especially in automobile building, landing-gear or chassis parts, vehicle wheels and fuel tanks. In all these applications the especially good strength properties of the steel sheet produced by the method according to the invention have an advantageous effect. In addition, the good corrosion resistance of the steel sheet and strip according to the invention is advantageous in such applications where they come in contact with aggressive media, such as fuels for example.

[0024] The invention is subsequently explained in greater detail with reference to a drawing showing an example of embodiment.

[0025] The FIGURE shows a schematic diagram of a strip casting plant **1**. In this plant for example, a steel is processed which in addition to the usual unavoidable impurities contains (in wt. %) 0.08% C, 0.5% Si, **10**% Mn, **19**% Cr, 0.5% N, 0.3% Al and the remainder is iron.

[0026] The strip casting plant 1 comprises a double-roller casting apparatus called a "double roller" of which the rollers 2, 3 each rotating in opposite directions about an axis of rotation are shown in the FIGURE. Between the rollers 2, 3 there is formed a casting gap 4 which is continuously filled with melt so that a melt pool S forms above the casting gap 4.

[0027] The rollers 2, 3 are intensively cooled during the casting process by cooling devices not shown so that the melt entering the casting gap 4 solidifies primarily austenitically at cooling rates higher than 200 K/s and leaves the casting gap 4 as a thin strip D having a thickness of 1 to 5 mm. The thin strip D thus produced then passes through a furnace 5 in which it is heated to an initial rolling temperature.

[0028] Both the double-roller casting device with the rollers 2, 3 and the furnace 5 are accommodated in a housing 6 which contains a protective gas atmosphere. As a result of casting the thin strip D and re-heating it in the furnace 5 in a protective gas atmosphere the formation of scale on the surface of the thin strip D is largely avoided.

[0029] The thin strip D heated to the initial rolling temperature enter a roll mill 7 in which it is hot-rolled to a final size. As a result of the high initial rolling temperature high degrees of deformation are possible. The hot strip W rolled from the thin strip D entering the roll mill essentially scale-free exhibits a particularly high-quality surface after the hot rolling.

[0030] After the hot rolling in the roll mill 7 the hot strip W is annealed in a continuous annealing furnace 8 and then cooled in a controlled fashion under a cooling device 9 in order to specifically improve its structure. The hot strip W thus heat-treated is then coiled to form a coil 10.

[0031] Steel strip produced in the manner described previously exhibits particularly high strength accompanied by good deformability and equally good energy absorption capacity compared with steel strips having the convention composition and produced by conventional methods as a result of the high nitrogen content achieved by the rapid cooling between the rollers 2, 3 of the double-roller casting apparatus.

[0032] The following table compares the superior strength values of the hot strip W produced in the casting roller plant 1 according to the invention with the strength values of Mn austenite steels produced conventionally by continuous casting.

	$R_{P0.2}$ [Mpa]	Rm [MPa]	A80 [%]
Invention	550–650	850–900	35–45
Conventional	420	750–800	50

[0033]

SYMBOLS	
1	Casting roller plant
2, 3	Rollers
4	Casting gap
5	Furnace
6	Housing
7	Roll mill
8	Continuous annealing furnace
9	Cooling device
10	Reel
D	Thin strip
W	Hot strip
S	Melt pool

1. Method for manufacturing a steel strip (W) or sheet consisting mainly of Mn-austenite,

in which a steel is melted which contains the following alloying constituents (in wt. %):

15.00–24.00% Cr,
5.00–12.00% Mn,
0.10–0.60% N,
0.01–0.2% C,
max. 3.00% Al and/or Si,
max. 0.07% P,
max. 0.05% S,
max. 0.5% Nb,
max. 0.5% V,
max. 3.0% Ni,
max. 5.0% Mo,
max. 2.0% Cu,
and iron and unavoidable impurities as the remainder,

and

in which the steel is cast in a casting gap formed between two rotating rollers (2, 3) or rolls into a thin strip (D) having a maximum thickness of 10 mm, whereby the rollers (2, 3) or rolls are cooled so intensively that the thin strip (D) in the casting gap (4) is cooled at a cooling rate of at least 200 K/s.

2. Method according to claim 1, characterised in that the thickness of the thin strip (D) is 1 to 5 mm.

3. Method according to one of the preceding claims, characterised in that the steel contains 17.00-21.00 wt. % Cr.

4. Method according to one of the preceding claims, characterised in that the steel contains 8.00-12.00 wt. % Mn.

5. Method according to one of the preceding claims, characterised in that the steel contains 0.40-0.60 wt. % N.

6. Method according to one of the preceding claims, characterised in that the steel additionally contains Ni, Mo and/or Cu.

7. Method according to one of the preceding claims, characterised in that the casting of the thin strip (D) takes place in a protective gas atmosphere.

8. Method according to one of the preceding claims, characterised in that following the casting, the thin strip (D) is continuously hot-rolled to give a hot strip (W).

9. Method according to claim 8, characterised in that before hot rolling the thin strip (D) is heated to an initial rolling temperature.

10. Method according to claim 9, characterised in that the heating takes place under protective gas.

11. Method according to one of claims 8 to 10, characterised in that after hot rolling the hot strip (W) is subjected to a heat treatment.

12. Use of a steel strip manufactured according to one of claims 1 to 11 as material for automobile-body sheet-metal parts.

13. Use of a steel strip manufactured according to one of claims 1 to 11 as material for stiffening structural components.

14. Use of a steel strip manufactured according to one of claims 1 to 11 as material for landing-gear or chassis parts.

15. Use of a steel strip manufactured according to one of claims 1 to 11 as material for vehicle wheels.

16. Use of a steel strip manufactured according to one of claims 1 to 11 as material for fuel tanks.

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