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(71) Applicant: **Corus Staal BV**
1970 CA Ijmuiden (NL)

(72) Inventors:
- **Berkhout, Basjan**
  2021 SP Haarlem (NL)
- **Bracke, Lieven**
  1911 VP Uitgeest (NL)
- **Cornelissen, Marcus Cornelis Maria**
  1901 BZ Castricum (NL)

(74) Representative: **Bodin, Andre**
Corus Technology BV
P.O. Box 10000
1970 CA Ijmuiden (NL)

Remarks:
Amended claims in accordance with Rule 137(2) EPC.

(54) Method of producing a high strength steel and high strength steel produced thereby

(57) This invention relates to a process for producing a high strength steel product, wherein the product is produced from a hot-rolled and/or cold-rolled and annealed TWIP steel and having an initial ratio of yield strength and tensile strength, R_i, and wherein a part of the TWIP steel is subsequently subjected to a cold reduction which is chosen such that the desired ratio of yield strength and tensile strength, R_d, in the part is obtained. The invention also relates to a process for producing a tailor-rolled blank and to such a blank.

EP 2 090 668 A1

Description

[0001] This invention relates to a method for producing a high strength steel, and a high strength steel produced by this method.

[0002] In many cases, when producing a stronger steel, this higher strength is obtained at the expense of the elongation. The higher the strength, the lower the elongation. Consequently, the steel industry have been researching and developing new steel grades which allow higher strengths and ductility levels. Particularly steels having a high yield strength/tensile strength ratio are nowadays sought-after, for instance for heavy earth moving equipment or mobile cranes, or for reinforcement beams in cars. Usually these steels are produced by alloying the steels with precipitating elements which, in combination with an intricate and complicated thermo-mechanical production process in the hot rolling mill and dedicated thermal treatment after hot rolling, yields the desired properties. The dedicated thermal treatment after hot rolling may comprise a controlled cooling after hot rolling, a quench and temper treatment, or an after-annealing of the finished hot-rolled products. In all cases the product quality is difficult to reproduce and each combination of strength and elongation properties necessitates another combination of chemical composition, thermo-mechanical treatment and dedicated thermal treatment after hot rolling. This makes the production process inflexible, increases the risk of not producing the desired product quality and each added chemical composition adds to the logistical burden. Moreover, the elongation values of these high strength steels are insufficient to satisfy the high demands the designers of cars and earth moving equipment nowadays set.

[0003] It is an object of this invention to provide method for producing a high strength steel which allows easy adaptation of the combination of strength and elongation properties.

[0004] The object according to the invention can be achieved by a process for producing a high strength steel product, wherein the product is produced from a hot-rolled and/or cold-rolled and annealed TWIP steel and having an initial ratio of yield strength and tensile strength, R_i, and wherein at least part of the TWIP steel is subsequently subjected to a cold reduction which is chosen such that the desired ratio of yield strength and tensile strength, R_d, in the part is obtained.

[0005] It should be noted that the cold reduction of the hot-rolled TWIP steel starting material or the cold-rolled and annealed TWIP steel starting material may be performed by a cold rolling step which is able to impose different cold reductions over length and/or width of the rolled product. The rolled product may be a strip, plate or sheet of steel. From this product blanks may be produced which can e.g. be used for a stamping or pressing operation.

[0006] The TWIP-steel used in the process according to the invention preferably comprises 0.05-0.78% C , 11 to 23% Mn, at most 5% Al, at most 5% Cr, at most 2.5% Ni, at most 5% Si, up to 0.5% V, remainder iron and unavoidable impurities. All compositional percentages are given in weight percent unless indicated otherwise. Preferably, the microstructure of the formed part comprises at least 75% in volume of austenite.

[0007] In an embodiment of the invention the TWIP-steel also comprises up to 0.5% of Vanadium. The alloying with vanadium will promote the formation of VC-precipitates which contribute to the strength of the steel and the prevention of delayed cracking by providing sinks for hydrogen at the predominantly semi-coherent interface between the VC-precipitates and the matrix. Preferably, at least 0.05% V is added to the steel to obtain this effect. To optimise this effect, a minimum vanadium content of 0.1 or even 0.2% is preferable.

[0008] To benefit from the addition of aluminium a preferable minimum aluminium content of the steel is at least 1 %. The aluminium content of the steel of at least 1% ensures an increased stability of the austenite.

[0009] In an embodiment, the chromium content is at most 0.5% and/or at least 0.05%. A suitable minimum chromium content is 0.10 or even 0.15%.

[0010] TWIP steels in general, and those having a composition in the claimed range in particular, have a high tensile strength and a relatively low initial yield strength in combination with high total elongation values. This makes these steels suitable for forming purposes. The process according to the invention uses these steels suitable for selectively tuning the properties, particularly the yield strength, i.e. the stress at which the steel starts to deform, by cold deforming the steel. The level of cold deformation determines the level of the yield strength which is obtained. The inventors found that, when appropriately selecting the steels composition within the claimed range, the level of elongation after the tuning of the properties is still sufficient to enable application of the steels in heavy earth moving equipment, mobile cranes, heavy transport vehicles or lorries or as impact absorbing or lead bearing means in cars. The residual formability is sufficient to sustain significant post-cold deformation forming operations. No annealing is to take place after the cold deformation has taken place, because this will adversely affect the yield strength.

[0011] In an embodiment of the invention, the steel sheet comprises 0.05 to 0.78 % C, 11.0 to 18% Mn, 1.0 to 5.0% Al, 0 to 2.5% Ni, 0 to 5% Si, 0 to 0.5% Cr, 0 to 0.5% V, the remainder being iron and unavoidable impurities, wherein the microstructure of the formed part comprises at least 75% in volume of austenite.

[0012] In an embodiment the Ni and Mn contents are chosen such that (Ni+Mn) is from 11.0 to 23. A preferable maximum for Ni+Mn is 18%. More preferably the maximum is chosen to be 17 or even 15.9%.

[0013] In an embodiment of the invention the microstructure of the formed part, in particular after cooling, comprises at least 80%, preferably at least 85%, more preferably at least 90% and even more preferably at least 95% in volume of austenite. The inventor found that a further improvement of the cold rolling and mechanical properties could be obtained if the steel was chosen such that the austenite content in the microstructure comprises at least 80%, preferably at least 85%, more preferably at least 90% and even more preferably at least 95% in volume of austenite. Due to the metastability of the austenite, and the occurrence of transformation induced plasticity, the amount of austenite tends to decrease during subsequent processing steps. In order to ensure good formability and high strength, even during a later or its last processing step, it is desirable to have an austenite content which is as high as possible at any stage of the processing, but in particular after cold-rolling and annealing.

[0014] Prior to rolling the TWIP steel is provided into a shape and geometry suitable for further processing. The TWIP steel may be provided as a conventional thick slab and hot rolled to a thickness of about 1 to 5 mm before being cold-reduced to obtain the desired properties. The TWIP-steel may also be provided by thin slab casting and direct (hot) rolling, preferably using a soaking step between the casting and the rolling step to homogenise the temperature and the starting structure of the steel prior to hot-rolling. The TWIP-steel may also be provided by strip casting, optionally followed by a hot-rolling step in one or more reduction steps, for instance in a tandem rolling device comprising two or more rolling stands. Strip casting may for instance be performed in a twin-roll casting device or in a belt casting device. Belt casting allows thicker strips to be cast, leaving potential for a larger hot rolling reduction after solidification, and thus potentially influencing the microstructure and texture of the hot-rolled strip.

[0015] It is preferable that the cold deformation is chosen such that the ratio of the yield strength to the tensile strength after cold deformation is below 0.98. If the ratio is higher than this value, the yield strength practically attains the same level as the tensile strength, leading to immediate failure if the yield strength is exceeded. Preferably the ratio after cold deformation is at least 0.60, 0.70 or 0.80. More preferably the minimum ratio is 0.85. For higher ratios such as 0.90, the remaining ductility is reduced to an extent insufficient for the majority of applications. However, for some specific applications a ratio exceeding 0.85, such as 0.90 may be applicable.

[0016] In an embodiment of the invention, the cold reduction is achieved by cold rolling. This ensures a homogeneous deformation over the entire product, and hence homogenous properties. The cold rolling reduction can be brought about in conventional cold rolling mills. The selection of the cold rolling reduction will, starting from the properties of the hot-rolled steel or cold-rolled and annealed steel, determine the level of the final cold deformed product.

[0017] In an embodiment of the invention the cold reduction is not higher than 35%. It was found that when cold deforming the hot-rolled steel or cold-rolled and annealed steel, to a degree substantially higher than 35%, that the residual formability becomes too low. More in particular, the yield strength attains the same level as the tensile strength, leading to immediate failure if the yield strength is exceeded. Preferably, the cold reduction is not higher than 20%.

[0018] In an embodiment of the invention the cold reduction is at least 2%, preferably at least 3%, more preferably at least 5%.

[0019] It is noted that the cold reduction may be applied before or after the TWIP steel is provided with a metallic and/or organic coating.

[0020] According to a second aspect a process to produce a steel product wherein the cold reduction is a step in the production of a tailor-rolled blank, and wherein the cold reduction of the TRB is chosen such that in the cold-reduced part or parts of the TRB the desired value of R_d is obtained. In this process a steel product, having an initial set of mechanical properties, is subjected to a rolling process allowing to change the degree of reduction over the length of the strip (laterally) and/or over the width of the strip (longitudinally). The degrees of reduction are chosen such so as to produce the TRB having the desired geometrical properties, but more importantly, to have the desired mechanical properties in each part of the TRB. Parts which have been subjected to a higher degree of cold reduction will possess a higher yield strength than the parts which have not been cold deformed to a smaller or not extent. The undeformed parts still have a large formability potential and can be used on the location where the TRB will be subjected to a large deformation during the production of the finished part for of the TRB, whereas the more heavily cold deformed parts can be located such that they coincide with the location of the finished part where a high yield strength is required. This tuning of the mechanical properties prior to the stamping or production of the final part allows a larger flexibility of designing the final part, whereas the cold-deformation process is a more accurate way of tuning the properties than the stamping or production process of the final part.

[0021] Traditionally, metal sheets of uniform thickness are used for stamping or forming vehicle structural parts. For a desired structure, a metal sheet with varying thickness is desirable. It not only saves material but also increases design flexibility. For example, some areas of a cross member require thicker thickness to support localized, larger loading, while for other areas, where there is no localized loading, thinner thickness can be used to save material. Currently, there are two kinds of tailor sheet metal blanks used to achieve the light-weight designed vehicle structures. One is Tailor Welded Blank (TWB), which requires welding two or more different gauge blanks together. The problem with TWB is that the heat input of the welding operation may adversely affect the mechanical properties of the parts welded together, thereby affecting the properties of the TWB as a whole. The other one is TRB. TRB is a manufacturing technology which allows engineers to change blank thickness continuously within a sheet metal, virtually eliminating the need for welding local reinforcements in the part. TRB also provides simpler structural design due to smooth, rolled transitions, which prevent stress concentrations in the finished part. In addition, there is little cost penalty for multiple thickness transitions, due to the nature of the rolling process. The use of TWIP steel for producing this TRB has the added advantage that for a different thickness different properties are obtained without an annealing treatment after the production of the TRB. A TRB made from a low carbon steel always needs to be annealed after the rolling step.

[0022] In a preferable embodiment of the invention a process is provided wherein the cold reduction is a step in the production of a tailor-rolled blank, and wherein the cold reduction of the TRB is chosen such that in the cold-reduced part or parts of the TRB the desired value of R or yield strength is obtained.

[0023] According to a third aspect a TWIP-steel tailor rolled blank is produced by the method according to the invention having a desired value of R_d in the, or in each cold-reduced part. This not only allows to tailor the thickness of the blank, but also the mechanical properties.

[0024] In Table 1, the chemical composition of three TWIP-steels in accordance with the invention are given.

[0025]

Table 1

	C	Si	Mn	Al	Cr	P	S
SiAl-TWIP	0.70	2.00	15	2.5	0.2	0.02	0.001
Al-TWIP	0.70	0.20	14	2.5	0.3	0.009	0.01
Cr-TWIP	0.30	0.20	20	0.05	4.5	0.02	0.005

[0026] These steels were provided in a continuously annealed form after cold rolling to a thickness of 1.75 and 1.56 mm respectively. Table 2 gives some of the mechanical properties after cold reducing rolling the annealed strips in accordance with the invention by cold rolling.

[0027]

Table 2

TR (%)	t (mm)	Steel	Rm (MPa)	Rp (MPa)	A50 (%)	Ri	Rd
0	1.75	SiAl-TWIP	970	560	52	0.57	
5		SiAl-TWIP	1055	750	39		0.71
10		SiAl-TWIP	1110	830	36		0.74
15		SiAl-TWIP	1170	960	29		0.82
20		SiAl-TWIP	1260	1050	19		0.83
0	1.56	Al-TWIP	830	400	58	0.48	
5		Al-TWIP	890	560	54		0.62
10		Al-TWIP	920	710	44		0.77

[0028] Table 1 shows that up to cold reductions of 15%, the level of ductility in the deformed product is still very high, resulting in a deformed material with a significant deformation potential. At higher levels of cold reduction such as 20%, the remaining ductility is reduced, but still at a very high level when compared to conventional steels of similar strength.

Claims

1. Process for producing a high strength steel product, wherein the product is produced from a hot-rolled and/or cold-rolled and annealed TWIP steel and having an initial ratio of yield strength and tensile strength, R_i, and wherein at least part of the TWIP steel is subsequently subjected to a cold reduction which is chosen such that the desired ratio of yield strength and tensile strength, R_d, in the part is obtained.

2. Process according to claim 1 wherein the TWIP-steel comprises 0.05-0.78% C, 11 to 23% Mn, at most 5% Al, at most 5% Cr, at most 2.5% Ni, at most 5% Si, up to 0.5% V, remainder iron and unavoidable impurities.

3. Process according to claim 1 or 2 wherein the TWIP-steel comprises up to 16.5% of Mn.

4. Process according to any one of claims 1 to 3 wherein the cold reduction is achieved by cold rolling.

5. Process according to any one of the preceding claims wherein the cold reduction is not higher than 35%.

6. Process according to any one of the preceding claims wherein the cold reduction is at least 2%, preferably at least 3%, more preferably at least 5%.

7. Process according to any one of the preceding claims, wherein the cold reduction is a step in the production of a tailor-rolled blank (TRB), and wherein the cold reduction of the TRB is chosen such that in the cold-reduced part or in each of the cold-reduced parts of the TRB the desired value of R_d is obtained.

8. TWIP-steel tailor rolled blank produced by the method of claim 7 having a desired value of R_d in the or each cold-reduced part.

9. TWIP-steel according to claim 8 wherein R_d is at least 0.60.

Amended claims in accordance with Rule 137(2) EPC.

1. Process for producing a high strength steel product, wherein the product is produced from a hot-rolled and/or cold-rolled and annealed TWIP steel and having an initial ratio of yield strength and tensile strength, R_I, and wherein at least part of the TWIP steel is subsequently subjected to a cold reduction which is chosen such that the desired ratio of yield strength and tensile strength, R_d, in the part is obtained, and wherein the TWIP-steel comprises 0.05-0.78% C, 11 to 23% Mn, at most 5% Al, at most 5% Cr, at most 2.5% Ni, at most 5% Si, up to 0.5% V, remainder iron and unavoidable impurities, and wherein the cold reduction is a step in the production of a tailor-rolled blank (TRB), and wherein the cold reduction of the TRB is chosen such that in the cold-reduced part or in each of the cold-reduced parts of the TRB the desired value of R_d is at least 0.70.

2. Process according to claim 1 or 2 wherein the TWIP-steel comprises up to 16.5% of Mn.

3. Process according to any one of claims 1 to 2 wherein the cold reduction is achieved by cold rolling.

4. Process according to any one of the preceding claims wherein the cold reduction is not higher than 35%.

5. Process according to any one of the preceding claims wherein the cold reduction is at least 2%, preferably at least 3%, more preferably at least 5%.

6. TWIP-steel tailor rolled blank produced by the method of claim 7 having a desired value of R_d in the or each cold-reduced part.

7. TWIP-steel according to claim 6 wherein R_d is at most 0.98.

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EUROPEAN SEARCH REPORT

Application Number
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The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
Munich	1 July 2008	Catana, Cosmin

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1

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