(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 375 694 B2

(12) # NEW EUROPEAN PATENT SPECIFICATION

After opposition procedure

(45) Date of publication and mention of the opposition decision:
17.11.2010 Bulletin 2010/46

(45) Mention of the grant of the patent:
27.04.2005 Bulletin 2005/17

(21) Application number: **03396059.2**

(22) Date of filing: **18.06.2003**

(51) Int Cl.:
C22C 38/18 (2006.01) ***C22C 38/12*** (2006.01)
C21D 8/02 (2006.01) ***C21D 1/18*** (2006.01)

(54) **Hot-rolled steel strip and method for manufacturing the same**

Verfahren zur Herstellung eines warmgewalzten Stahlbandes

Procédé de la fabrication d'une bande d'acier laminée à chaud

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IT LI LU MC NL PT RO SE SI SK TR

(30) Priority: **19.06.2002 FI 20021188**

(43) Date of publication of application:
02.01.2004 Bulletin 2004/01

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(56) References cited:
WO-A1-98/02589 GB-A- 2 076 425
GB-A- 2 195 658 JP-A- 06 248 341
US-A- 4 790 889 US-A1- 2001 049 956
US-B1- 6 284 063

- **PATENT ABSTRACTS OF JAPAN vol. 018, no. 668 (C-1289), 16 December 1994 (1994-12-16) & JP 06 264139 A (NISSHIN STEEL CO LTD), 20 September 1994 (1994-09-20)**
- **PATENT ABSTRACTS OF JAPAN vol. 012, no. 028 (C-471), 27 January 1988 (1988-01-27) & JP 62 180021 A (NISSHIN STEEL CO LTD), 7 August 1987 (1987-08-07)**
- **VAN DER VOORT G.F.: 'Atlas of Time-Temperature Diagrams for Irons and Steels', 1991, ASM INTERNATIONAL, ISBN 0-87170-415-3 page 267**
- **IRVINE K.J.; PICKERING F.B.: 'Low-carbon Bainitic Steels' JOURNAL OF THE IRON AND STEEL INSTITUTE December 1957, pages 292 - 309**
- **IRVINE K.J.; PICKERING F.B.: 'The impact properties of low carbon bainitic steels' JOURNAL OF THE IRON AND STEEL INSTITUTE June 1963, pages 518 - 531**
- **MAJKA T.F.; MATLOCK D.K.; KRAUSS G.: 'Development of Microstructural Banding in Low-Alloy Steel with simulated Mn Segregation' METALLURGICAL AND MATERIALS TRANSACTIONS A vol. 33A, June 2002, SE, page 1627**

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Description

[0001] The invention relates to a steel strip that is hot-rolled to a final thickness of at least 2 mm but no more than 12 mm, where the microstructure of said steel strip comprises at least 95% martensite and/or bainite and where the steel contains, in percentages by weight: 0.08 % - 0.16 % C, 0.5 % - 1.5 % Cr and/or 0.1 % - 0.5 % Mo, ≤ 0.015 % S and ≤ 0.03% P, 0.01%- 0.08% Al, and the rest is Fe and unavoidable impurities. The invention also relates to a method for manufacturing said hot-rolled steel strip.

[0002] Traditionally hard steels have been made by annealing and quenching, but by this technique, for instance optimal surface quality and impact toughness have not been achieved. Manufacturing expenses have also been high.

[0003] In the publication GB-2 195 658, there is described a steel meant for forgings, containing in a preferred embodiment 0.05% - 0.08% carbon, 0.1% - 0.5% silicon, 0.5% - 1.6% manganese, 0.5% - 1.5% chromium, up to 0.05% titanium, up to 0.1% niobium, 0.005% - 0.012% nitrogen, up to 0.06% aluminum and 0.002% - 0.005% boron. Further, according to said publication, forging is begun at the temperature 1,200° C - 1,275° C, and the forged object is quenched in a bath, so that the temperature of the object is continuously measured, and the quenching is interrupted before the transformation into martensite is finished. Thus there is obtained the tensile strength 700 - 1,100 N/mm^2, and at the same time there is obtained a satisfactory impact toughness as well as a PS/TS ratio of about 0.75 without separate tempering or other thermal treatment.

[0004] Differing from said steels used for forging, known strong steel strips, i.e. steels used in rolling, have a high manganese content and often also a fairly high carbon content, such as for example the hot-rolled steel strip described in the publication US-6 284 063 that has a thickness no more than 5 mm. The steel described in said publication contains, in percentages by weight, 0.08% - 0.25% carbon, 1.2% - 2.0% manganese, 0.02% - 0.05% aluminum and less than 0.07% silicon, as well as up to 0.015% phosphorus and up to 0.003% sulfur, while the hot strip contains over 95% martensite. The steel may also contain up to 1.0% chromium, up to 0.1% copper, up to 0.5% molybdenum, up to 0.1% nickel, up to 0.009% nitrogen, up to 0.0025% boron and possibly titanium in a stoichiometric proportion, Ti = 3.4×%N, with respect to the amount of nitrogen. First the slab is heated up to a temperature 1000° C - 1300° C, pre-rolled within the temperature range 950° C - 1150° C and finished at a final rolling temperature above Ar3. The hot strip produced in this way is cooled down to a coiling temperature in the range of 20° C below the martensite start temperature M_S, so that the content of other phase forms except for the martensite were less than 5%. According to said publication, the cooling down to the coiling temperature is preferably realized so that the cooling time in the range 800° C → 500° C is less than 10 seconds. Thus there is obtained for the end product a tensile strength that is in the range 800 N/mm^2 - 1400 N/mm^2.

[0005] The publication US-4 406 713 depicts a method of making high-strength, high-toughness steel with good workability and weldability, said steel containing

0.005% - 0.3% carbon, 0.3% - 2.5% manganese, up to 1.5% silicon, up to 0.1% niobium, up to 0.15% vanadium, up to 0.3% titanium and up to 0.3% zirconium. According to the method, austenitizing is effected at the temperature 1000° C - 1300° C, and thereafter there is performed first for instance hot-rolling in the temperature range Ar3 - 930° C, when the recrystallization of austenite has significantly retarded, at an area reduction of at least 30%. This kind of working introduces a lot of strain into the austenite, which shifts the ferrite phase precipitation temperature range in a usual CCT diagram to higher temperatures and shorter times. In the course of cooling after the working, carbon is concentrated in the untransformed austenite phase as the precipitation of the ferrite phase proceeds. After the ferrite has occupied 5 - 65% of the steel, the steel is rapidly quenched below the M_S temperature, and there can be obtained a two-phase structure in the steel, comprising fine grains of ferrite and martensite with a high carbon concentration.

[0006] Publication GB-2 076 425 discloses a process for producing dual-phase steel in which process the steel strip is hot rolled, the hot rolling is finished at about 900°C, and coiled at a temperature of between about 350°C to about 580°C, and in which the strip is subsequently continuously annealed in the two-phase ferrite austenite field in temperatures between 760°C and 830°C with holding time between 1.5 and 3 minutes followed by cooling with a rate of 3.5 to 6 ° C/s to transform at least the bulk of the austenite to martensite. The composition of the steel comprising, by weight, 0.03% to 0.25%carbon, 0.3% to 2.5% manganese, up to 1.5% silicon, up to 0.25% molybdenum and up to 2% chromium the remainder being iron except for incidental impurities and residuals in amounts depending on the steelmaking practice. The hot rolled strip is subsequently cold rolled before the mentioned annealing at temperatures between 760°C and 830°C. This latter annealing is terminated by forced or natural air cooling.

[0007] The patent publication US 6,554,919 (published application was US 2001/0049956) discloses according to its claim 1 a hot-rolled steel with very high maximum elasticity and mechanical resistance usable in particular for producing auto parts, said steel comprising an entirely bainitic structure, and the following composition by weight: 0.08% < carbon < 0.2%, 1% < manganese < 2%, 0.02% < aluminum, < 0.1%, silicon < 0.5%, phosphorus < 0.03%, sulfur < 0.01%, 0.1% < vanadium < 0.3%, chromium < 1%, nitrogen < 0.015%, molybdenum < 0.6%, the rest being of steel and impurities inherent in processing, wherein said steel does not comprise niobium. The patent publication also discloses a process for producing a hot-rolled steel sheet strip wherein said alloy is subjected to: rolling at a temperature below 950°C, cooling carried out at a rate of more than 20°C per second up to a temperature ranging from 400°C to 600°C. US 6,554,919 utilizes pure bainitic structure teaching that martensite steels indeed have the highest resistance levels, but that it is difficult to produce such structure on a wide-strip train because of the fragility of martensite, which causes the strip to break after rolling, and accordingly, martensite steels make it possible to achieve resistance levels above 1,000 MPa but with very low ductility levels and expansions of less than 8%. US 6,554,919 further describes that an additional heat treatment must be carried out after rolling, because martensite structure is to be obtained by heat treatment after rolling. US 6,554,919 also teach that: "The vanadium increases mechanical resistance and reduces expansion. Vanadium is the necessary element in steel with a bainite structure in order to produce a hardening effect, something that was not expected since the micro-alloying elements have a hardening effect by precipitation but this precipitation ends at a higher temperature and must be carried out in the ferrite domicile in order to be hardening. This effect cannot be obtained by other micro-alloying elements such as titanium or niobium because these elements cause an increase in hardness when hot, thus limiting the hot-rolling reduction rates and thus the minimum thickness achievable for this kind of sheet metal. It turns out that vanadium has no effect on hardness when hot. Other residual elements may be present and used according to their known properties such as Cu and Ni. Added alloying elements such as titanium or boron can be used to promote the precipitation of vanadium carbides at the expense of vanadium nitrides. Titanium and boron form nitrides at high temperature, which remain stable during the subsequent heat treatment."

[0008] The object of the present invention is to achieve such a hot-rolled steel strip and its manufacturing method that the steel would not be critical as for the local coiling temperature fluctuations in the strip, that it would be highly weldable, suitable for thermal cutting and bending and had a high strength and particularly a high impact toughness. Another object of the invention is to realize this kind of hot-rolled steel strip and its manufacturing method that would enable economical production costs.

[0009] The invention is given in the claims.

[0010] According to a first principle of the invention, the first defined hot-rolled steel strip also contains 0.6% - 1.1% Mn and 0.1% - 0.3% Si; the tensile strength of the steel strip is 700 Mpa - 1500 Mpa with a tensile elongation having an A5 value that is at least 6%, and the yield strength is 600 Mpa - 1400 Mpa. According to another principle of the invention, this kind of steel strip is manufactured by a method comprising the following steps: the hot rolling of the steel strip in the temperature range 860° C - 960° C to said final thickness; the direct quenching of said hot-rolled steel strip at a delay no more than 15 seconds from the last rolling pass to the coiling temperature within the range 100° C - 520° C, so that the cooling rate in the direct quenching is at least 30° C/s. There is not performed any tempering annealing.

[0011] The inventive idea is based on the fact that by reducing the amount of manganese and carbon, as well as by alloying chromium and/or molybdenum, as well as boron when necessary, there can be maintained a good hardening and the following advantages can be achieved. The steel structure is not critical for the segregation of manganese and carbon during the casting process owing to the low manganese and carbon content. The steel properties are not critical for local fluctuations of the coiling temperature in the strip, which facilitates the steel production and has an advantageous effect in the homogeneity of its mechanical properties, which again has a positive influence both in the flatness of the end product and in the residual stress. The steel sheet is highly suitable for welding and laser cutting, and at the same time it has a good fatigue strength irrespective of said thermal treatments. Further, the steel sheet has excellent bending properties, a good impact toughness as well as a good resistance to softening in tempering.

[0012] By manufacturing this type of steel instead of the traditional furnace annealing and quenching, by quenching directly after hot rolling, there is achieved an excellent impact toughness, because the phase transformation into martensite and/or bainite takes place from a fine-grained, worked austenite. Likewise the surface quality is improved, because the primary scale is removed in a descaler prior to the rolling. Manufacturing expenses are also reduced along with the streamlining of the process. In a strip rolling line, there is typically applied a high heating temperature in the furnace, for instance in the range 1000° C - 1300° C, and a long holding time, for instance 2 h - 10 h. In that case the dissolution of special carbides, such as Cr and Mo carbides, and the homogenization of the structure are as complete as possible. On the other hand, the growing of the austenite grain at the high heating temperature does not make the end product more brittle, because austenite is fine-grained during the hot rolling. There is thus achieved an excellent hardness, combined with an excellent impact toughness.

[0013] The hot-rolled steel strip according to the invention that is directly hot-rolled to the thickness 2 mm - 12 mm can be manufactured as wear-resistant and with different hardnesses, typically in the hardness range 300 HB - 400 HB, as so-called wear-resistant steel plate in the same production method as the structural steel plates, only by changing the analysis and/or the post-rolling cooling rate of the strip, and/or temperature before the coiling, within the scope of the invention. This kind of wear-resistant steel can also be used in targets where the structures require properties typically demanded of structural steel, such as good workability, weldability and impact toughness, which means that the hot-rolled steel strip according to the invention is feasible also as structural steel. In the steel analysis to be explained in the specification below, all content percentages are percentages by weight, and the rest of the steel that is otherwise not defined is iron, Fe, and unavoidable impurities.

[0014] First of all, the steel according to the invention has a relatively low carbon content, i.e. at least 0.08% C but no more than 0.16 % C for good impact toughness, bendability and weldability. Phosphorus P contained as an impurity may rise up to 0.03%, and respectively sulfur S may rise up to 0.015%, which means that these contents are restricted in order to achieve good impact toughness and bendability. When necessary, further properties can be improved by treating the melt with Ca or CaSi. The employed killing agent is aluminum, which in the end product can be at least 0.01% Al but no more than 0.08 % Al. Chromium, at least 0.5% Cr but no more than 1.5% Cr, and/or molybdenum is at least 0.1% Mo but no more than 0.5% Mo, are alloyed in order to increase hardening and tempering resistance. This enables precipitation at higher coiling temperatures, which can be used for decreasing and even preventing the softening of the steel, as well as for alleviating strength fluctuations caused by local temperature differences during the cooling of the coil.

[0015] Deviating from other high-strength steel strips of the same type, the manganese content is at least only 0.6% Mn but no more than only 1.1 % Mn. Thus the steel is not as susceptible to the segregation of manganese and carbon, which improves the homogeneity of the microstructure. In tests that were carried out it was observed that this is the way to achieve good bending properties and even mechanical properties in different directions, as well as a high-quality surface as thermally cut. As for silicon, it serves as a killing agent in the steel of the present invention, and it also works as a solid solution hardener in contents that area at least 0.10% Si and up to 0.30 % Si, which has an advantageous effect on the impact toughness and workability.

[0016] The steel according to the invention can be thermally cut, for instance by laser, into precisely defined shapes. It has been observed that a remarkably smooth cutting surface is achieved in a laser cut object. On the other hand, it has been found out that the strength difference between the basic material and the soft zone created in the technical cutting process, which zone is located in the immediate vicinity of the hardened zone, is relatively small. These together have an advantageous affect in the fatigue strength. In addition, a low carbon content reduces the peak hardness of the hardened zone, so that the cutting surface is not sensitive to embrittlement and cracking, neither in the working of the object nor in practical use.

[0017] In the test analyses given here, there were no remarkable contents of copper, but on the basis of other tests not illustrated here, it can still be maintained that the copper content must be limited to less than 0.3% Cu in order to ensure an excellent surface quality of the hot-rolled strip. If the copper content surpasses 0.3%, it is recommendable also to alloy nickel, at least 0.25 times the copper content. Even if there is no copper in the alloy, the amount of nickel in is restricted to ≤ 1.5% Ni.

[0018] The amount of alloyed boron is typically at least 0.0005% B but no more than 0.005% B in order to reduce grain size and to increase the hardenability. The amount of alloyed titanium is typically at least 0.01% Ti but no more than 0. 1% in order to bind the nitrogen N and to prevent the creation of boron nitrides BN, because boron nitride reduces the efficiency of boron as a booster of hardening and a reducer of grain size.

[0019] The steel according to the invention can, particularly at the lower limit of the carbon content, be well bent with respect to its strength, i.e. welded for instance in an filler-metal-free high-frequency welding, so-called HF welding, into a tube. In test production it was .also found out that the material suits extremely well in the production of both open profiles and HF-welded hollow sections.

[0020] According to the invention, steel is manufactured at a final rolling temperature that remains within the range 860° C - 960° C, to a final thickness of 2 mm -12 mm. The cooling of the strip is begun no later than 15 seconds after the last rolling pass, and it is cooled rapidly, the cooling rate being at least 30°C/s, down to a low coiling temperature in the range 100° C - 520° C. The obtained result is typically a nearly completely bainitic and/or martensitic microstructure, so that the bainite and/or martensite content is at least 95 % by volume. In the coiling temperature range 20° C - 100° C, martensite would not be tempered, whereas when the coiling temperature is at least 100° C, the martensite is tempered, so that for instance in the range 100° C - 200° C, the martensite is mildly tempered, and in the coiling temperature range of about 200° C - 520° C, the martensite is tempered and the carbon precipitated. Although the coiling was carried out at a lower temper brittleness range, 200° C - 400° C, or the cooling was carried out through said range, temper brittleness was not observed with the combination of this production method and composition. The obtained tensile strength Rm is about 700 Mpa - 1500 Mpa, and the obtained yield strength Rp0.2, i.e. strength at a elongation of 0.2%, is about 600 MPa - 1,400 Mpa. The tensile elongation A5 is correspondingly about 18% - 6%. The yield ratio Y/T is typically in the range 0.8 - 0.96.

[0021] When there are desired particularly wear resistant, surface-hard sheets, the carbon content of the steel can be arranged in the range 0.12% - 0.16% C, and the hot-rolled steel strip can in that case be directly quenched to the coiling temperature, which is over 100° C, but still under 400° C, in which case the residue stress is reduced or disappeared without, however, affecting the hardness of the wear plate. Thus a relatively low coiling temperature, in the range 100° C - 200° C, can be applied for example for thinner strips, or a slightly higher coiling temperature, in the range 200° C - 400° C, for example for thicker strips. If, on the other hand, there are desired more properties of the structural steel type, the carbon content of the steel is arranged in the range 0.08% - 0.12% C, and the hot-rolled steel strip is directly quenched to the coiling temperature, which is over 100° C, but still under 520° C. For instance a relatively low coiling temperature, in the range of 100° C - 200° C, can be applied for thinner strips, and for instance a slightly higher coiling temperature, in the range of 200° C - 520° C, can be applied to thicker strips. In this case of "structural steel", i.e. with a carbon content in the range 0.08% - 0.12%, the coiling temperature fluctuations of the above-described order have, however, a fairly restricted effect on the properties of the steel strip, as they remain good irrespective of the coiling temperature.

Examples

[0022] Example 1. Traditional tempering tests were carried out in a laboratory with composition **a1**, see table 1, by heating samples with measures 8×100×250 mm, in a furnace for 20 minutes and at the temperature 900° C. The samples were quenched into water and tempered for 2 h at different temperatures. The results are presented in table 2. From the results it is apparent that the material has a low toughness area in the temperature range 250° C - 350° C. On the other hand, the elongation is clearly increased at temper temperatures over 400° C, in which case also the strength starts to drop.

Table 1.

Test compositions										
	C	**Si**	**Mn**	**P**	**S**	**Al**	**N**	**Cr**	**Mo**	**Ti**	**B**
steel A											
a1	0.098	0.22	0.71	0.008	0.004	0.030	0.005	0.94	0.20	0.032	0.002
a2	0.086	0.28	0.77	0.008	0.003	0.024	0.005	0.82	0.27	0.032	0.002
a3	0.083	0.21	0.77	0.010	0.003	0.033	0.005	1.04	0.27	0.036	0.002
steel B											
b1	0.140	0.26	0.81	0.110	0.003	0.027	0.006	0.65	0.21	0.038	0.002
b2	0.146	0.23	0.82	0.006	0.003	0.032	0.007	0.88	0.27	0.036	0.002
b3	0.135	0.23	0.90	0.009	0.004	0.035	0.006	0.88	0.27	0.038	0.002
b4	0.130	0.25	0.84	0.008	0.002	0.032	0.005	1.06	0.28	0.037	0.002

Table 2.

Tempering test results with the composition **a**1.								
T_{temper} °C	**Time h**	**Rp0.2 N/mm²**	**Rm N/mm²**	**A5 %**	**Charpy-V, J/cm²**		**toughness, %**	
					(-20° C)	**(-40° C)**	**(-20° C)**	**(-40° C)**
*)		972	1072	12.6		20		5
100	2	897	1123	11.7	133	85	40	15
150	2	913	1125	12.0	172	72	65	10
200	2	922	1113	12.4	122	50	40	10
250	2	938	1112	12.2	36	26	10	10
300	2	928	1086	11.7	55	28	10	5
350	2	963	1064	11.8	115	27	40	10
400	2	971	1049	12.6	93	58	20	15
450	2	911	960	14.2	218	85	80	15
500	2	822	901	15.1	251	216	98	80
600	2	741	773	17.3	334	329	100	98
700	2	430	528	21.2	430	451	100	100
*) only quenched								

Production-scale direct quenching tests with a low carbon level

[0023] Example 2. In the strip rolling line, there was hot-rolled a 6 mm thick strip with a composition a2 by direct quenching at the coiling temperature T_{COIL}. The results are presented in table 3.

[0024] From the results it is apparent that also when coiling in the temper brittleness temperature range 300° C, as is shown in example 1, there still is achieved excellent toughness. Strength and elongation do not largely differ from example 1. The bending test results of the material are illustrated in table 4.

[0025] Example 3. In the strip rolling line, there was hot-rolled a 3 mm thick strip with the composition **a2** by direct quenching to the coiling temperature T_{COIL}. The results are presented in table 3.
From the results it is apparent that also when coiling at a clearly higher temperature 450° C, there were still achieved the same mechanical properties as in example 2.

[0026] Example 4. In the strip rolling line, there was hot-rolled a 4 mm thick strip with the composition **a2** by directly quenching into the coiling temperature T_{COIL}. The results are presented in table 3.
From the results it is apparent that also when coiling at a clearly lower temperature, i.e. at 100° C, there were still achieved the same mechanical properties as in examples 2 and 3.

[0027] It can be concluded that by means of this composition and manufacturing method of steel, there is achieved a homogeneous material that is not sensitive to the fluctuations of the coiling temperature.

[0028] Example 5. In the strip rolling line, there was hot-rolled a 10 mm thick strip with the composition **a3** by direct quenching to the coiling temperature T_{COIL}. The results are presented in table 3.
From the results it is apparent that strength and impact toughness are somewhat reduced, but the properties are still excellent, as long as the coiling temperature does not surpass about 500 ° C.

Table 3.

Mechanical properties of he strip as results from rolling tests

						Lengthwise				Transversal		
steel	**thickness mm**	**width mm**	**T $_{COIL}$ °C**	**Rp0.2 N/mm ^{2}**	**Rm N/mm ^{2}**	**Y/T**	**A5 %**	**HB**	**ChV -40 °C, J/cm ^{2}**	**Rp0.2 N/mm ^{2}**	**Rm N/mm ^{2}**	**A5 %**
a1	8		a*	971	1049	0.93	12.6		57			
a1	8		b*	897	1123	0.80	11.7		25			
a2	3	1000	460	958	1030	0.93	10.9	304		925	1016	10.5
a2	3	1000	450	971	1014	0.96	11.8	299		977	1056	9.9
a2	4	1000	100	977	1117	0.87	13.3	329		987	1130	11.6
a2	6	1000	200	934	1078	0.87	12.8		240	920	1070	9.9
a3	10	1250	520	748	874	0.86	13.0		71	819	899	11.8
a3	10	1250	510	836	901	0.93	13.0		133	896	957	11.0
a3	10	1250	370	853	965	0.88	11.5		171	898	975	9.5
a3	10	1250	320	858	979	0.88	11.1		165	914	1005	10.8
b1	4	1300	470	980	1031	0.95	10.0	304		1051	1071	8.4
b2	4	1500	515	860	1000	0.86	12.4	295		974	1006	9.9
b2	4	1500	530	702	853	0.82	17.4	252		747	847	13.8
b2	4	1500	100	1179	1347	0.88	8.9	396		1189	1308	6.9
b3	4	1250	380	1163	1275	0.91	9.6	375		1162	1294	6.8
b3	4	1250	200	1125	1317	0.85	11.5	387		1130	1333	8.9
b4	6	1250	200	1125	1295	0.87	9.5	384				

a* Traditional laboratory test: austenization, quenching into water, tempering 400° C, 2h

b* Traditional laboratory test: austenization, quenching into water, tempering 100° C, 2h

Production-scale direct quenching tests with a high carbon level

[0029] Example 6. In the strip rolling line there was hot-rolled, with a higher carbon level, a 4 mm thick strip with the compositions **b2** and **b3** by direct quenching to the coiling temperature T_{COIL}. The coiling temperatures applied in the tests were 100° C, 200° C and 380° C. The results are presented in table 3.
From the results it is apparent that strength and hardness are somewhat lowered as the coiling temperature increases, but the properties are still of the same class, as long as the coiling temperature does not surpass about 400° C.
[0030] It can be concluded that with this steel composition and manufacturing method, there is achieved a homogeneous material that is not sensitive to the fluctuations of the coiling temperature.
[0031] Example 7. In the strip rolling line there was hot-rolled, with a higher carbon level, 4 mm thick strip with a composition **b**1 and **b**2, by directly quenching to the coiling temperature T_{COIL}. The coiling temperatures applied in the tests were 470° C, 515° C and 530° C. The results are presented in table 3.
From the results it is apparent that strength and hardness decrease, whereas the elongation is clearly increased as the coiling temperature rises.

Table 4.

Bending tests with composition **a**2, coiling temperature 300° C		
R =	**Lengthwise in the rolling direction**	**Transversally in the rolling direction**
3t	ok	ok
2.5t	ok	ok
2t	ok	(ok), shallow surface cracks
1.5t	ok	deep cracks
1t	(ok), shallow surface cracks	deep cracks
0.7t	(ok), shallow surface cracks	
Bending radius = R, sheet thickness = t		

Claims

1. A steel strip having a microstructure comprising martensite and/or bainite, and where the steel contains, in percentages by weight: 0.08% - 0.16% C, 0.5% - 1.5% Cr and/or 0.1 % - 0.5% Mo, 0.6% - 1.1% Mn, ≤ 0.015% S and ≤ 0.03% P, 0.01% - 0.08% Al, 0.1% - 0.3% Si, 0.0005% - 0.005% B and 0.01% - 0.1% Ti, the rest being Fe and unavoidable impurities; the tensile strength of the steel strip being 700 Mpa - 1500 Mpa with a tensile elongation, the value A5 of which is at least 6%; wherein the steel strip is a hot rolled steel strip rolled to a final thickness of at least 2 mm but no more than 12 mm; the microtructure comprises at least 95% martensite and/or bainite; the yield strength is 600 Mpa - 1400 Mpa; and said hot-rolled steel strip has yield ratio within the range 0.8 - 0.96.

2. A method for manufacturing a steel strip having a microstructure comprising at least 95% martensite and/or bainite, said steel containing in percentages by weight: 0.08% - 0.16% C; 0.5% - 1.5% Cr and/or 0.1% - 0.5% Mo; 0.01% - 0.08% Al; 0.6% - 1.1% Mn; 0.1% - 0.3% Si, 0.0005% - 0.005% B, and 0.01% - 0.1 % Ti, as well as the rest Fe and unavoidable impurities, the steel strip being hot-rolled in the temperature range 860 °C - 960 °C, wherein the method includes the following steps:

   - said hot-rolling in said temperature range provides a final thickness of at least 2 mm but no more than 12 mm for said steel strip;
   - this hot-rolled steel strip is directly quenched with a delay no longer than 15 seconds from the last rolling pass to a coiling temperature in the range 100°C - 520°C, so that the cooling rate in this direct quenching is at least 30 °C/s.

3. A method according to claim 2, **characterized in that** the carbon content of the steel is arranged in the range 0.12% - 0.16% C, and said hot-rolled steel strip is directly quenched to the coiling temperature in the range 100° C - 200° C, or in the range 200° - 400° C.

4. A method according to claim 2, **characterized in that** the carbon content of the steel is arranged in the range 0.08% - 0.12% C, and said hot-rolled steel strip is directly quenched to the coiling temperature in the range 100° C - 200° C, or in the range 200° C - 520° C.

5. A method according to claim 2, **characterized in that** there is not performed any tempering annealing and further quenching in the method.

Patentansprüche

1. Ein Stahlband, welches ein Kleinstgefüge aufweist, umfassend Martensit und/oder Bainit, und wobei der Stahl in Gewichtsprozent beinhaltet: 0,08% - 0,16% C, 0,5% - 1,5% Cr und/oder 0,l% - 0,5% Mo, 0,6% - 1,l% Mn, ≤ 0,015% S und ≤ 0,03% P, 0,01% - 0,08% Al, 0,1% - 0,3% Si, 0,0005% - 0,005% B und 0,01% - 0,l% Ti; wobei der Rest aus Fe und unvermeidbaren Verunreinigungen besteht, die Zugfestigkeit des Stahlbandes 700 Mpa - 1500 Mpa beträgt, mit einer Zugdehnung, deren A5-Wert wenigstens 6% beträgt, wobei das Stahlband ein warmgewalztes Stahlband ist, das auf eine Enddicke von wenigstens 2 mm aber nicht mehr als 12 mm gewalzt ist; das Kleinstgefüge wenigstens 95% Martensit und/oder Bainit umfasst; und die Streckgrenze 600 Mpa - 1400 Mpa beträgt; und das gesagte warmgewalzte Stahlband ein Streckgrenzenverhältnis aufweist, welches innerhalb des Bereichs von 0,8 bis 0,96 liegt.

2. Ein Verfahren zum Herstellen eines Stahlbandes, welches ein Kleinstgefüge aufweist, das wenigstens 95% Martensit und/oder Bainit umfasst, wobei der gesagte Stahl in Gewichtsprozent umfasst: 0,08% - 0,16% C; 0,5% - 1,5% Cr und/oder 0,l% - 0,5% Mo; 0,01% - 0,08% Al, 0,6% - 1,1% Mn; 0,1% - 0,3% Si, 0,0005% - 0,005% B und 0,01% - 0,l% Ti, sowie als den Rest Fe und unvermeidbare Verunreinigungen, das Stahlband im Temperaturbereich 860°C - 960°C warmgewalzt wird, wobei das Verfahren die folgenden Schritte umfasst:

   - das gesagte Warmwalzen in dem gesagten Temperaturbereich führt zu einer Enddicke von wenigstens 2 mm aber nicht mehr als 12 mm für das gesagte Stahlband;
   - dieses warmgewalzte Stahlband wird direkt abgeschreckt, mit einer Verzögerung von nicht mehr als 15 Sekunden, beginnend mit dem letzten Walzdurchgang, auf eine Wickeltemperatur in dem Bereich 100°C - 520°C, so dass die Abkühlgeschwindigkeit in diesem direkten Abschrecken wenigstens 30°C/s beträgt.

3. Ein Verfahren gemäß Anspruch 2, **dadurch gekennzeichnet, dass** der Kohlenstoffgehalt des Stahls in dem Bereich von 0,12% - 0,16% C gelegen ist, und das gesagte warmgewalzte Stahlband direkt auf die Wickeltemperatur in dem Bereich 100°C - 200°C oder in dem Bereich 200°C - 400°C abgeschreckt wird.

4. Ein Verfahren gemäß Anspruch 2, **dadurch gekennzeichnet, dass** der Kohlenstoffgehalt des Stahls in dem Bereich von 0,08 % - 0,12% C gelegen ist, und das gesagte warmgewalzte Stahlband direkt auf die Wickeltemperatur in dem Bereich 100°C - 200°C oder in dem Bereich 200°C - 520°C abgeschreckt wird.

5. Ein Verfahren gemäß Anspruch 2, **dadurch gekennzeichnet, dass** in diesem Verfahren kein Anlassglühen und weiteres Abschrecken ausgeführt wird.

Revendications

1. Bande d'acier ayant une microstructure comprenant de la martensite et/ou de la bainite, et dans laquelle l'acier contient, en pourcentages en poids: 0,08% - 0,16% de C, 0,5% - 1,5% de Cr et/ou 0,l% - 0,5% de Mo, 0,6% - 1,l% de Mn, ≤ 0,015% de S et ≤ 0,03% de P, 0,01% - 0,08% d'Al, 0,l% - 0,3% de Si, 0,0005% - 0,005% de B et 0,01% - 0,1% de Ti le reste étant composé de Fe et impuretés inévitables, la résistance à la traction de la bande d'acier étant 700 Mpa - 1500 Mpa avec un allongement de tension dont la valeur A5 est au moins de 6%, dans laquelle la bande d'acier est une bande d'acier laminée à chaud à une épaisseur finale d'au moins 2 mm mais n'excédant pas 12 mm; la microstructure comprend au moins 95% de martensite et/ou de bainite; et la limite d'élasticité est 600 Mpa - 1400 Mpa; et la bande d'acier laminée à chaud a un taux d'élasticité dans la gamme 0,8 - 0,96.

2. Procédé pour fabriquer une bande d'acier ayant une microstructure comprenant au moins 95% de martensite et/ou de bainite, ledit acier contenant en pourcentages en poids: 0,08% - 0,16% de C, 0,5% - 1,5% de Cr et/ou 0,1% - 0,5% de Mo, 0,01% - 0,08% d'Al, 0,6% - 1,1% de Mn, 0,1% - 0,3% de Si, 0,0005% - 0,005% de B et 0,01% - 0, 1

% de Ti, et également du Fe et impuretés inhérentes, la bande d'acier étant laminée à chaud dans la gamme de températures 860°C - 960°C, dans lequel le procédé comprend les étapes suivantes:

- ladite bande d'acier laminée à chaud dans la gamme de température fournit une épaisseur finale d'au moins 2 mm mais inférieure à 12 mm pour ladite bande d'acier;
- cette bande d'acier laminée à chaud est directement trempée dans un délai n'excédant pas 15 secondes depuis la dernière passe de laminage à une température de bobinage dans la gamme 100°C - 520°C, de sorte que le taux de refroidissement dans ce traitement direct soit d'au moins 30 °C/s.

3. Procédé selon la revendication 2, **caractérisé en ce que** la teneur en carbone de l'acier est comprise dans la gamme 0,12% - 0,16% de C, et ladite bande d'acier laminée à chaud est directement trempée à la température de bobinage dans la gamme 100 °C - 200 °C ou dans la gamme 200 °C - 400 °C.

4. Procédé selon la revendication 2, **caractérisé en ce que** la teneur en carbone est comprise dans la gamme 0,08% - 0,12% de C et ladite bande d'acier laminée à chaud est directement traitée à la température de bobinage dans la gamme 100 °C - 200 °C, ou dans la gamme 200 °C - 520 °C.

5. Procédé selon la revendication 2, **caractérisé en ce qu'**aucun recuit de durcissement ni trempe ultérieure ne sont effectués dans le procédé.

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- GB 2195658 A **[0003]**
- US 6284063 B **[0004]**
- US 4406713 A **[0005]**
- GB 2076425 A **[0006]**
- US 6554919 B **[0007]**
- US 20010049956 A **[0007]**