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

(11) EP 2 562 272 A2

(12) # EUROPEAN PATENT APPLICATION

(43) Date of publication:
27.02.2013 Bulletin 2013/09

(21) Application number: **12181887.6**

(22) Date of filing: **27.08.2012**

(51) Int Cl.:
C21D 8/10 (2006.01) ***C22C 38/02*** (2006.01)
C22C 38/04 (2006.01) ***C22C 38/06*** (2006.01)
C22C 38/12 (2006.01) ***C22C 38/14*** (2006.01)
C22C 38/16 (2006.01) ***C22C 38/18*** (2006.01)
C21D 9/08 (2006.01)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

(30) Priority: **26.08.2011 FI 20115832**

(71) Applicant: **Rautaruukki OYJ**
00810 Helsinki (FI)

(72) Inventors:
- **Saarinen, Tuomo**
00810 Helsinki (FI)
- **Peura, Pasi**
00810 Helsinki (FI)
- **Steen, Petteri**
00810 Helsinki (FI)
- **Rajala, Juha**
00810 Helsinki (FI)
- **Minkkinen, Jussi**
00810 Helsinki (FI)

(74) Representative: **Parta, Ari Petri**
Kolster Oy Ab
Iso Roobertinkatu 23
P.O. Box 148
00121 Helsinki (FI)

(54) **Method for producing steel product having excellent mechanical properties, steel product produced with the method and its use**

(57) The invention relates to a method for producing a steel product having excellent mechanical properties and to a steel product produced by the method and used, in particular, for manufacturing components for automotive industry, inter alia. In addition, the invention relates to the use of a strain hardened steel pipe and to the manufacturing of said component. The invention is based on the idea that in the micro structure of a steel pipe to be heated very rapidly there is provided a strain hardened structure that is not soft annealed prior to the very rapid heating. Further, it is essential for the invention that the very rapid heating is followed by immediate cooling such that the micro structure formed in the steel product comprises at least 30% by volume martensite and/or bainite. The invention has significant advantages as to both a production chain and mechanical properties of the product.

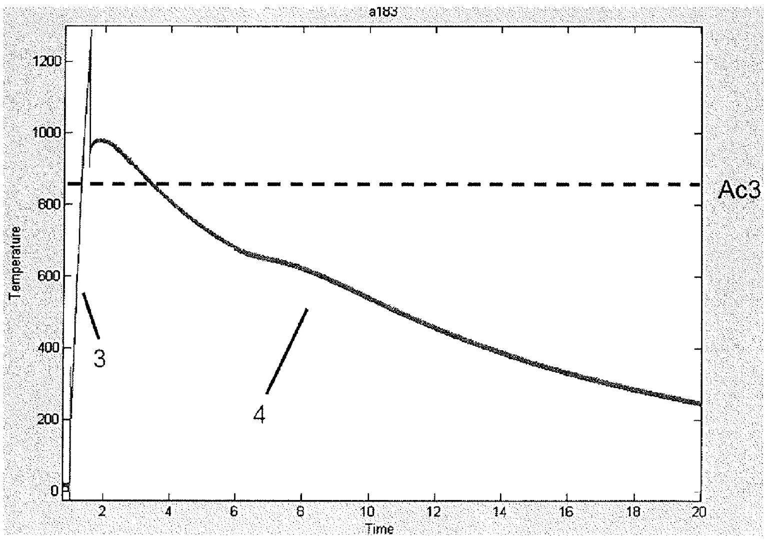

Figure 3

Printed by Jouve, 75001 PARIS (FR)

Description

Background of the invention

[0001] The invention relates to a method for producing a steel product having excellent mechanical properties and to a steel product produced by the method and used, in particular, for manufacturing components, more precisely steel components, for automotive industry, inter alia. In addition, the invention relates to the use of a strain hardened steel pipe and to the manufacture of said component.

[0002] It is known that in steel applications higher strengths are sought, which allows lighter structures to be made, the importance of which lighter structures is emphasized particularly in vehicle applications. However, as the strength of steel increases, the properties typically relating to formability of steel, such as strain, are known to deteriorate. This poses restrictions for applications of high-strength steels. A combination of high strength and high ductility increases usability of steels in many applications. Heat treatments may not, however, be a delaying factor in production, therefore it is also advantageous to render the heat treatment methods faster.

[0003] It is commonly known that steel can be provided to have high strength combined with high ductility, for instance, by Q&T treatments. A problem with this method is, however, that the heat treatment involves two phases and requires a considerable amount of time. In recent years, quick heat treatments have been developed, which make it possible to provide strong and yet more tensile steel in comparison to conventional quenching and tempering treatments. A problem with these known, quick methods is, however, that the methods employ, after cold forming, soft annealed steel, in other words, the method employs a quick heat treatment prior to soft annealing, and again the heat treatment part of the method involves two phases. In addition, due to the starting material used previously in the method, the known methods including quick heat treatments have a difficulty of achieving superior mechanical properties according to the invention which will be described later on.

[0004] The object of the present invention is to provide such an improvement in the known heat treatment and/or forming processes that gives a steel product better mechanical properties than before, or enables simplification of the process over the known techniques.

Brief description of the invention

[0005] The objects of the invention are achieved by a method according to the preamble of claim 1, which is characterized in that in the method

- steel having a strain hardened structure is *heated* very rapidly, preferably at least at a rate of HR $\geq$ 100 °C/s to a temperature of $A_{c3} \pm 100$ °C,
- the heated steel is cooled such that the micro structure formed in the steel product will comprise at least 30% martensite and/or bainite in percentages by volume.

[0006] Preferred embodiments of the method according to the invention are disclosed in the dependent claims.

[0007] Preferred embodiments of the steel product produced by the method are disclosed in claims 11 to 15.

[0008] Further, the objects of the invention are achieved by the use of a strain hardened steel pipe of independent claim 16, which is characterized by using the strain hardened steel pipe in an extremely rapid heat treatment method which comprises:

- extremely rapid heating, at least at a rate of HR $\geq$ 100 °C/s to a temperature of $A_{c3} \pm 100$ °C
- cooling in such a manner that the micro structure formed in the steel product comprises at least 30% martensite and/or bainite in percentages by volume.

[0009] Further, the objects of the invention are achieved by a method according to the preamble of independent claim 18, which is characterized in that

- a cold rolled steel strip having a highly strain hardened structure is moulded into a steel pipe through cold moulding
- the steel pipe having a strain hardened structure is rapidly *heated* (3) to a temperature of $A_{c3} \pm 100$ °C,
- the heated steel pipe is moulded and cooled in a mould, preferably moulded and hardened in the mould, for providing a component.

[0010] The invention is based on the idea that in the micro structure of the steel pipe to be heated very rapidly there is provided a strain hardened structure that is not soft annealed prior to the rapid heating. In other words, the strain hardened structure may refer to a structure that is not recrystallized after moulding, i.e. it may refer to a non-recrystallized structure. The strain hardened structure, such as full hard structure, is provided by cold forming, such as cold rolling a steel strip, for instance. Further, the invention is characterized in that the rapid heating is followed by immediate cooling. The micro structure provided in the steel product comprises at least 30 percent martensite and/or bainite by volume. In other words, the steel is heated in an accelerated manner after obtaining a strain hardened structure and hardened immediately after the rapid heating. Hardening may also be performed by air cooling, in case the composition of the steel is suitable therefor. According to an embodiment, cooling or hardening is provided in a mould, in which moulding into a component is also carried out. The method of the invention provides an extremely fine micro structure in steel, and as a consequence the steel will have progressive mechanical properties.

[0011] The invention has significant advantages regarding as well a production chain as mechanical properties of the product. In the method of the invention the heat treatment may be implemented very quickly, and consequently, when needed, it may be applied on some continuously-operating production lines, arranged in immediate connection with the forming of a steel product. The duration of the heat treatment step of the method may be less than one minute, even less than 30 seconds.

[0012] Particularly shaped products, such as steel pipes are produced by the method. Steel components may also be provided by the method. When needed, the method allows higher R_m*A values to be provided as compared to steel products manufactured by a conventional slow method. Further, the production of a steel product does not require annealing after cold forming, and therefore this step need not restrict the throughput of production.

[0013] Under certain conditions, by the method of the invention it is possible to provide even progressive properties typical of TRIP (transformation induced plasticity) steel as regards strength and ductility without slow heat treatments typical of TRIP steel manufacturing, or advantageously even without costly and high alloying that deteriorates weldability.

[0014] According to an embodiment, by the method it is possible to provide strong and formable steel products, such as steel pipes, whereby the use of a ready-tempered, yet well cold-mouldable, steel pipe is cost effective in the manufacture of cold-mouldable components, because the final component made of steel pipe need not be hardened separately as pipe material is already hardened, at least partly.

Brief description of the figures

[0015] In the following, the present invention is described in greater detail with reference to the attached drawings, in which

Figure 1 shows the main steps of the method according to an embodiment of the invention;
Figure 2 shows the main steps of the method according to a second embodiment of the invention;
Figure 3 shows, in principle, a temperature/time graph on partial steps of a method according to the invention;
Figure 4 shows stress-strain curves obtained from laboratory tests.

Descriptions of reference numerals

[0016]

1 Cold forming
2 Cold forming of a shaped product
3 Rapid heating
4 Cooling

Detailed description of the invention

[0017] Figure 1 shows the main steps of the method according to the invention, wherein in the first step a steel strip is cold formed 1, such as cold rolled, in such a manner that a strain hardened structure will be formed in the steel of the steel strip. Cold forming 1 is performed on a suitable steel preform, such as a hot-rolled or moulded steel strip/plate/shaped product. In cold forming 1 the steel typically becomes thinner, at least partly.

[0018] The effectiveness of cold forming may be assessed roughly, for instance, through reduction, which refers to a change in the thickness of steel after cold forming in relation to the original thickness.

[0019] In the context of the present patent application, a strain hardened structure refers to a steel structure whose reduction used in cold forming exceeds 15%. Preferably the reduction used in cold forming is more than 30%, most preferably more than 40%. According to an embodiment, the strain hardened structure refers to a full hard structure, in which the reduction used is at least 50%, such as 60%.

[0020] Preferably the cold forming means that the steel is cold rolled to a thin sheet having a thickness of 0.4 to 5 mm, for instance. Advantageously, cold rolling is performed to a thickness of 0.8 to 3 mm.

[0021] In accordance with the embodiment of Figure 1, the steel having strain hardened structure is cold formed into a shaped product 2. The cold forming step 2 of the shaped product may comprise cold forming of a pipe and longitudinal seam welding to obtain a closed pipe profile. In the cold forming of the pipe the degree of strain hardening of the steel further increases. Thus, in accordance with this embodiment, after step 2 is obtained a highly strain hardened steel pipe, which is still unusable as such. In accordance with the embodiment of Figure 1, in a next process step the shaped steel product, such as steel pipe, having a strain hardened structure is *heated* 2 very quickly, preferably at least at a rate of HR $\geq$ 100 °C/s to a temperature of $A_{c3} \pm 100$ °C.

[0022] Thanks to the very quick heating and the strain hardened structure as shown in Figures 1 and 2, the grain structure of austenite is very fine due to heating 3. Figure 3 further illustrates steps "rapid heating 3" and "cooling 4" of the method according to the invention. According to the invention, the rapid heating 3 is preferably carried out at least at a mean heating rate of 100 °C/s. In this manner it is possible to make sure that during heating the grain size will not have time to grow excessively. On the other hand, high heating rates require a considerable amount of energy and they may deteriorate the uniform quality of mechanical properties of a steel product. According to an embodiment, heating 3 is performed at a rate of HR $\geq$ 160 °C/s and, according to a second embodiment, heating 3 is performed at a rate of HR = 160-500 °C/s. Preferably, but not necessarily, heating is implemented as induction heating, which may be readily performed on closed steel pipes, for instance. Other heating methods of high heating rate are also possible.

[0023] The abbreviation HR stands for heating rate.

[0024] Rapid heating 3 of the steel having strain hardened structure is carried out to a temperature of $A_{c3} \pm 100$ °C. Preferably heating is carried out rapidly 3 above the temperature A_{c3}. Preferably, but not necessarily, heating 3 starts substantially at room temperature.

[0025] It is important that due to heating the steel is not maintained excessively long above the temperature A_{c3} or in the vicinity thereof. In other words, the dwelling time Δt above the temperature A_{c3}, or in the vicinity thereof, is as short as possible, because in that case the grain size of austenite remains small. Preferably cooling 4 *is started* in at least 10 seconds from the termination of heating 3, most preferably the cooling *is started* in at least 2 seconds from the termination of heating. In other words, the time spent in the austenite range, or in proximity thereto, is as short as possible.

[0026] According to the embodiment of Figure 2, a rapidly heated steel pipe is hot-formed, such as hot-stamped, immediately after the rapid heating 3, whereby there will be no longer need to form the cooled steel product. After hot-stamping it is possible to perform cooling in a mould, preferably tempering in a mould. The embodiment may provide an improvement in the mechanical properties of a hot-stamped steel component, when the steel pipe to be heated and tempered is made of strain hardened steel strip. The steel pipe of the invention may also be more robust to some hot-stamping process parameters because of the strongly strain hardened initial structure.

[0027] According to an embodiment, upon the termination of heating 3 there is started immediate cooling without a substantial, constant temperature in the austenitic range. This allows minimization of the time the steel dwells in the austenitic range or in the vicinity thereof.

[0028] Thanks to the very high heating rate and the strain hardened structure of the steel pipe to be heated, the density of occurrence of small austenite grains formed in the rapi heating 3 is high, which results in a very fine micro structure in a steel product of the invention having excellent mechanical properties. Thanks to the rapid heating 3 the austenite grain size will have no time to grow large, whereby, as a result of heating 3, the micro structure comprises very densely formed, small-sized austenite grains. The end result, after cooling, will be a stronger steel product the tensile strain of which is still substantially at the same or higher level than that of a steel product in rapid heating of which soft annealed steel is employed.

[0029] In connection with the invention, it was found that the A_{c3} temperature is higher at high heating rates in comparison to the A_{c3} temperature at low heating rates. Thus, it is to be noted that in this connection the A_{c3} temperature is understood to be a possibly elevated A_{c3} temperature as a consequence of a higher heating rate.

[0030] Cooling 5 from the austenitic range, or from the vicinity thereof, may be implemented in a variety of ways so as to obtain a desired end result. It is essential, however, that the cooling 5 is provided in a manner known per se such that the micro structure formed in the steel structure comprises 30% by volume martensite and/or bainite. In other words, in cooling 4, the steel is tempered in a manner fully known per se. The rest of the micro structure may consist of ferrite and possibly residual austenite.

[0031] The desired micro structure may be obtained in a manner known per se, for instance, such that cooling 4 is performed at a mean cooling rate of at least 5 °C/s. Further, in a manner known per se there is used steel the hardenability of which is sufficient to provide 30 % by volume martensite and/or bainite in the cooling.

[0032] The hardenability of steel may be determined in various ways, such as by using a hardenability index DI, which is based on a modification of ASTM standard A255-89. The hardening index DI is determined on the basis of the composition of steel in accordance with the following formula:

$$DI = 13.0C \times (1.15+2.48Mn+0.74Mn2) \times (1+2.16Cr) \times (1+3.00Mo) \times (1+1.73V) \times (1+0.36Ni) \times (1+0.70Si) \times (1+0.37Cu)$$

In the formula the composition is expressed in percentages by weight (%) and DI is millimetres (mm).

[0033] Preferably the hardenability index DI of the steel product is at least 3mm.

[0034] Most preferably the hardenability index DI of the steel product is at least 15mm.

[0035] Cooling may be implemented in a manner known per se, for instance as water vapour or water cooling, depending particularly on the steel composition used and the thickness of the steel. An element providing cooling may also be a mould.

[0036] Preferably the cooling 4 is provided in such a manner that the formed micro structure comprises at least 70 % by volume martensite and/or bainite, the rest being ferrite and possibly residual austenite.

[0037] Preferably the cooling is implemented as water vapour or water cooling or as cooling in a mould in such a manner that a mean cooling rate is at least 20 °C/s, preferably at least 35 °C/s. The final temperature of accelerated cooling is preferably below a bainite start temperature (B_s temperature), most preferably below a martensite start temperature (M_s temperature), i.e. the temperature at which a bainite transformation, and correspondingly, a martensite transformation start. In this manner it is made sure that the micro structure of the steel will be as desired.

[0038] After cooling 5, the steel product may be cut to desired dimensions, when the steel product is a steel pipe.

[0039] The invention also relates to a steel product produced by the method and described in the following.

[0040] The steel product obtained by the method possesses high strength and ductility. Thus, the steel product has excellent mechanical properties. Preferably, the steel product is also well formable, and thanks to low alloyage, its weldability is good.

[0041] In the steel product obtained by the method, the product of breaking strength and breaking elongation is at least 12000, i.e. $R_m * A \geq 12000$. Preferably $R_m * A \geq 15000$, and most preferably $R_m * A \geq 18000$. In addition, the breaking strength of the steel product obtained by the method is at least 800 MPa.

[0042] An advantage of the method is also that by using the method, with the same steel composition, it is possible to provide 1) high-strength steel of excellent ductility (Rm≥1500 MPa and A≥10%) or 2) strong and particularly ductile steel (Rm ≥800 MPa and A≥18%).

[0043] The products to be produced by the method may be roughly divided into two categories:

<u>Category 1.</u>

[0044] Steels in this category possess very high breaking strength and well retained breaking elongation A as follows: $R_m \geq 1500$ MPa and A≥10%. These steels are thus very strong, yet the ductility is of good level thanks to the method of the invention. This is indicated by exemplary steels 1, 4, 5, 10 and 11 of Table 2.

[0045] Surprisingly, the steel product produced by the method advantageously also possesses relatively high uniform elongation Ag≥3%, despite the substantially hardened micro structure and high breaking strength of the steel produced by the method.

<u>Category 2.</u>

[0046] Steels in this category possess relatively high breaking strength (Rm≥800 MPa) and very high elongation (A≥18%, preferably up to A≥18% and Ag>8%). These steels are thus relatively strong and the elongation has become very high, thanks to the method of the invention.

[0047] Next is described the chemical composition of the steel product produced by the method of the invention.

[0048] The steel product produced by the method contains iron Fe and unavoidable residuals and comprises in percentages by weight
C: 0.04-0.32 %,
Si: 0.00-2.5%
Mn: 0.2-2.5%
Al: 0.00-2.5%
such that the hardenability index DI of the steel product is at least 3mm, preferably at least 15mm.

[0049] According to a preferred embodiment, the steel product produced by the method contains iron Fe and unavoidable residuals and comprises in percentages by weight
C: 0.04-0.32 %,
Si: 0.00-2.5%
Mn: 0.2-2.5%
Al: 0.00-0.5%

Ti: <0.15%
Nb: <0.1 %
V: <0.17%
Nb+Ti+V<0.22 % such that the hardenability index DI of the steel product is at least 3mm, preferably at least 15mm.

[0050] According to a second preferred embodiment, the steel product produced by the method contains iron Fe and unavoidable residuals and comprises in percentages by weight
C: 0.05-0.25 %
Si: 0 - 2.5 %
Mn: 0.8 - 3.0 %
Al: 0 - 2.5 %
Mo: <1.5 %, preferably 0.1-0.8%
Cr: <1.5 %, preferably 0.2 - 1.5%
Cu <1.00 %
Ti: < 0.15 %
Nb: < 0.09 %
V: < 0.17 %
preferably 0.015 % < Ti+Nb+V < 0.22 %
such that the hardenability index DI of the steel product is at least 3mm, preferably at least 15mm.

[0051] According to a third preferred embodiment, the steel product produced by the method contains iron Fe and unavoidable residuals and comprises in percentages by weight
C: 0.10-0.40 %,
Si: 0 - 2.5 %
Mn: 0.2 - 3.0 %
Al: 0 - 2.5 %
Cu 0 - 1.0%
B: 0.0005 - 0.009 %
Cr 0-1.5%
Mo 0 - 1.5 %
Ti: < 0.15 %
Nb: < 0.09 %
V: < 0.17 %
such that the hardenability index DI of the steel product is at least 3mm, preferably at least 15mm.

[0052] Prior austenite grain size formed in the heating 3 of the steel product produced by the method of the invention is very small, preferably less than 10 micrometres and most preferably less than 3 micrometres. Further the grain size of ferrite and/or bainite possibly formed in the steel product in the cooling 4 is also very small, preferably less than 5 micrometres and most preferably less than 3 micrometres. Also martensite formed in hardening will be fine and tough thanks to the invention.

[0053] Material thickness in the steel product may be 0.4 to 5mm, preferably 1 to 3mm. The steel product may be a cold-formed shaped product. Most preferably the steel product is a steel pipe used, for instance, for manufacture of components in automotive industry. The steel product may thus be a hollow section, such as a circular or rectangular steel pipe. The steel product may also be a stamped steel component.

Examples

[0054] Table 1 shows the mechanical properties and process parameters of steel samples 10a and 8a produced in laboratory conditions by the method of the invention. Additionally, Table 1 shows as reference the mechanical properties and process parameters of steel samples ref8a and ref10a whose heating rate is low, 4 °C/s, i.e. the heating rate is clearly lower than the heating rate used in the method of the invention. Further, Table 1 shows as reference the mechanical properties of a test sample ref that is not heat treated in accordance with the method of the invention. For the sake of clarity, the references are depicted in grey in Table 1. Correspondingly, Figure 4 shows the corresponding stress-strain curves 10a, 8a, ref8a, ref10a and ref. All the results in the table and the graph concern strain hardened steel CP800 the composition of which is shown in Table 3. The results shown in Table 1 and Figure 4 are not comparable with those in Table 2, but they are mutually comparable.

[0055] In the laboratory test of Table 1 small test rods were heated rapidly to a temperature above A_{c3}, or in the vicinity thereof, using a DC source whose current and/or voltage was modified depending on the sample and the desired heating rate. The temperature of the sample and its rising rate were measured with a type K thermocouple wire spot-welded in the middle of the sample. Immediately after heating the samples were quench cooled with water spray or in free air. Figure 3 shows a temperature-time graph of a laboratory test, in which cooling is implemented as free air cooling. In this example the heating rate is about 1500 °C/s and a mean cooling rate about 50 °C/s. A peak appearing in Figure 3 above the A_{c3} temperature is caused by a measuring error due to a high heating rate. In other words, the temperature peak appearing in Figure 3 is not part of the invention. After the heat treatment the test rods were machined and a tensile test was performed on their even portions (4mm length, 2mm width, 2.5mm thickness).

[0056] The results of the laboratory test show that the uniform elongation Ag in the steel samples 10a and 8a produced by the method of the invention is substantially improved as compared to the untreated steel sample ref. In addition, breaking strength R_m increased substantially at the same time.

[0057] The results of the laboratory tests also show that because of the high heating rate the breaking elongation A of the water-cooled steel sample 10a increases as compared to the steel sample ref10a produced at a low heating rate. In addition, yield strength and breaking strength ($Rp_{0.2}$ and R_m) increased at the same time.

[0058] Correspondingly, yield strength and breaking strength ($Rp_{0.2}$ and R_m) of the air-cooled steel sample 8a increased significantly thanks to the high heating rate as compared to the steel sample ref8a produced at a low heating rate. At the same time, the uniform elongation Ag surprisingly remained the same and the breaking elongation A weakened only slightly.

Table 1. Results of laboratory tests

	Steel	RR (%)	HR (°C/s)	CT (water/air)	HT (°C)	Rp0.2 (Mpa)	Rm (Mpa)	Rp0,2/Rm	A (%)	A*Rm	Ag (%)
10a	CP800FH	50	192	water	935	1290	1660	0,78	30	49800	5
8a	CP800FH	50	197	air	963	660	1100	0,60	29	31900	13
ref8a	CP800FH	50	4	air	950	585	920	0,64	32	29440	13
ref10a	CP800FH	50	4	water	950	1160	1600	0,73	27	43200	5
ref	CP800FH	50	-	-	-	820	950	0,86	34	32300	2

[0059] Table 2 presents the mechanical properties and dimensions of steel products obtained in full-scale tests 1 - 15 as well as process parameters used. The table gives as reference values the tests 3, 6, 9, 12 and 15, in the heat treatment of which there was not used steel having strain hardened structure, i.e. after cold forming the steel was soft annealed in a known manner. X in column FH indicates that in said test there was used steel that is not soft annealed. In addition, Table 2 presents as reference the tests 16 to 21, in which there was used a heating rate significantly lower than that in the method of the invention. For the sake of clarity, the references are depicted in grey in Table 2. In the tests, the pipe diameter (D) was 48 - 49mm and the thickness of material (T) 1.7 - 2.1 mm.

[0060] All the results in Table 2 concern strain hardened steel B24 the composition of which is shown in Table 3. Tensile tests were performed in accordance with tensile test standard EN10002 and the employed measurements of the tensile test rod were 50mm in gauge length and 10mm in width. Percentage of the breaking elongation A is determined computationally to correspond to a strain measured with a ratio rod 5.65x(square root)S0.

Table 2. Test results

	RR (%)	HR (°C/s)	CR (water/air)	HT (°C)	FH	T (mm)	D (mm)	Rp0.2 (Mpa)	Rm (Mpa)	Rp0,2/Rm	A (%)	A5*Rm	Ag (%)
1	50	500	water vapour	940	x	1,95	49	1350	1770	0,76	11,8	20886	3,3
2	20	500	water vapour	940	x	1,8	49	1126	1438	0,78	7,9	11360	2,5
3	50	500	water vapour	940		1,77	49	1249	1644	0,76	10	16440	3,6
4	50	1000	water	880	x	2	49	1303	1784	0,73	10,9	19446	4,9
5	20	1000	water	880	x	1,78	49	1219	1588	0,77	11,4	18103	3,4
6	50	1000	water	880		1,77	49	1413	1805	0,78	9,3	16787	4,1
7	50	1000	water vapour	880	x	1,97	49	1373	1794	0,77	9,2	16505	3,1
8	20	1000	water vapour	880	x	1,72	49	1136	1423	0,80	8,4	11953	1,9
9	50	1000	water vapour	880		1,86	49	1232	1577	0,78	9	14193	2,9
10	50	1000	water	940	x	1,97	49	1347	1835	0,73	10	18350	5,1
11	20	1000	water	940	x	1,69	49	1291	1687	0,77	11,8	19907	4,1
12	50	1000	water	940		1,81	49	1291	1599	0,81	5,3	8475	2
13	50	300	water vapour	940	x	1,88	49	1359	1764	0,77	8	14112	2,6
14	20	300	water vapour	940	x	1,8	49	1129	1409	0,80	10,6	14935	1,8
15	50	300	water vapour	940		1,8	49	1217	1609	0,76	6,8	10941	2,6
16	50	slow	water	880	x	2,00	48	1312	1655	0,79	8,7	14394	2,5
17	20	slow	water	880	x	1,83	48	1338	1690	0,79	8,5	14276	2,4
18	50	slow	water	880		1,78	48	1342	1702	0,79	10,3	17525	2,8
19	50	slow	water	940	x	2,06	48	1253	1549	0,81	9,7	15020	2,2
20	20	slow	water	940	x	1,73	48	1304	1644	0,79	7,9	12905	2,3
21	50	slow	water	940		1,84	48	1233	1547	0,80	9,4	14464	2,5

[0061] In the tests of Table 2, two different degrees of reduction, 50% and 20%, were used, the degree of reduction representing the effective amount of cold forming and affecting directly the level of rolling hardness. The magnitude of reduction is indicated in column RR (%).

[0062] It is seen in Table 2 that both the strengths $R_{p0.2}$ and R_m and the breaking elongation A of the steel products obtained in the tests (1, 7, 10 and 13) carried out by the method of the invention are substantially better than those of the steel products of reference tests (3, 9, 12 and 15).

[0063] It is seen in Table 2 that the product of the breaking elongation A and the breaking strength R_m of the steel product improved by 15.8 to 116.5 % in the exemplary tests (1, 4, 7, 10, 13) using the method of the invention as compared to tests (3, 6, 9, 12 and 15), i.e. the improvement obtained by the invention is very significant.

[0064] It is seen in Table 2 that with higher reduction (50%) a considerable increase both in strengths $R_{p0.2}$ and R_m and in uniform elongation Ag was obtained as compared to corresponding tests conducted with lower reduction (20%).

[0065] Therefore it is recommendable to use high reduction in the method, i.e. the steel to be heated rapidly comprises a strongly strain hardened structure.

[0066] In the tests of Table 2 there were used both water cooling of high cooling effect and water vapour cooling of lower cooling effect as the cooling method. This is indicated in column CR of Table 2. A larger product $A*R_m$ of the breaking elongation and the breaking strength than in the reference test (3, 6, 9, 12, 15) is also achieved with water vapour, when the reduction is 50%.

[0067] The heating rate used is given in column HR. It appears from the test results of Table 2 that the tests (4, 5, 10, 11) conducted at the heating rate of the invention result in a higher elongation and a higher R_m * A value than the reference tests (16, 17, 19, 20) conducted at a lower heating rate.

[0068] Heating rates 300, 500 and 1000 °C/s were used in the tests of the method according to the invention in Table 2. It is seen in the table that the objects of the invention are also achieved at the heating rate of 300 °C/s. A lower heating rate is advantageous because of a lower power requirement in the apparatus, and consequently it is advisable to use a lower heating rate when sufficient. In many cases the heating rate of at least 100 °C/s will suffice to achieve the objects of the invention.

[0069] Advantageously, however, heating rates of at least 160 °C/s are used, whereby it is made sure that the austenite grain size formed in the heating does not grow excessively and excellent mechanical properties will be achieved. Table

1 presents results which show that the invention works also at heating rates of 192 and 197 °C/s.

[0070] It should be noted, however, that, in appropriate conditions, heating rates used in hot stamping may be lower, even as low as 15 to 100 °C/s, because the strain hardened steel pipe in itself improves the component's mechanical properties to be achieved in said hot stamping process, or it is more robust to use in said process than the prior art solutions. Further, a higher heating rate may provide advantages in this process as well.

[0071] The heating and cooling rates are mean cooling rates.

[0072] It is advisable, however, that the method uses heating rates, such as 160 to 500 °C/s, because generation of a lower heating rate requires less energy and may contribute to controlling the uniformity of results.

[0073] The heating temperature used is indicated in column HT. An appropriate heating temperature depends on the composition of steel, yet it is selected such that the heating temperature is $A_{c3} \pm 100$ °C. Preferably, but not necessarily, the heating is performed to a temperature slightly above A_{c3}. Said temperature refers to a temperature at which the steel austenitizes completely. It is important, however, that due to heating the steel is not maintained excessively long above the temperature A_{c3} or in the vicinity thereof. It is preferable to *start* cooling 4 in at least 10 seconds from the termination of heating 3, most preferably in at least 2 seconds from the termination of heating.

[0074] Table 3 shows some steel compositions to which the method of the invention is applicable.

Table 3. Contents of test steels in percentages by weight

	C	Si	Mn	Al	Nb	V	Cu	Cr	Ni	Mo	Ti	B
steel	%	%	%	%	%	%	%	%	%	%	%	%
DP800	0,13	0,20	1,46	0,05	0,02	0,01	0,01	0,05	0,05	0,02	0,002	0,000
355	0,07	0,15	1,43	0,04	0,02	0,01	0,02	0,03	0,04	0,00	0,013	0,000
CP 800 full hard	0,17	0,18	1,74	0,03	0,01	0,01	0,04	0,33	0,06	0,15	0,002	0,000
HSF420	0,06	0,20	0,80	0,03	0,01	0,01	0,28	0,04	0,04	0,00	0,068	0,000
CP800	0,16	0,21	1,74	0,04	0,00	0,01	0,02	0,31	0,07	0,15	0,002	0,000
B24	0,24	0,26	1,21	0,04	0,00	0,01	0,03	0,32	0,05	0,01	0,040	0,002

[0075] In the above, the invention is described by means of preferred embodiments, and it is clear that the details of the invention may be implemented in a variety of ways within the scope of the accompanying claims.

Claims

1. A method for producing a steel product having excellent mechanical properties, such as a steel pipe, the method including *cold forming* (1, 2), whereby a strain hardened structure is formed in the steel, **characterized in that** the method also comprises the following steps:

   - steel having a strain hardened structure is cold formed into a shaped steel product (2) and
   - the shaped product, such as a steel pipe, having a strain hardened structure is rapidly *heated* (3) to a temperature of $A_{c3} \pm 100$ °C,
   - the heated, shaped steel product is *cooled* (4) such that the resulting micro structure formed in the steel product will comprise at least 30% martensite and/or bainite in percentages by volume.

2. The method of claim 1, **characterized in that** the cold forming (1) is implemented by cold rolling a steel strip.

3. The method of claim 1 or 2, **characterized by** *heating* (3) at a rate of HR ≥ 100 °C/s, preferably at a rate of HR ≥ 160 °C/s, most preferably at a rate of 160 to 500 °C/s.

4. The method of any one of the preceding claims 1 to 3, **characterized by** *cooling* at a rate of at least 5 °C/s.

5. The method of any one of the preceding claims 1 to 3, **characterized by** *cooling* (4) at a rate of at least 20 °C/s.

6. The method of any one of the preceding claims 1 to 3, **characterized in that** the cooling (4) is provided in such a manner that the micro structure formed in the steel product comprises at least 70 % by volume martensite and/or

bainite the rest being ferrite and possibly residual austenite.

7. The method of any one of the preceding claims, **characterized in that** the cooling (4) is *started* in at least 10 seconds, more preferably in at least 2 seconds from the termination of heating (3).

8. The method of any one of the preceding claims, **characterized in that** reduction used in the cold forming (1, 2) is more than 15%, preferably more than 30% and most preferably more than 40%.

9. The method of claim 8, **characterized in that** the strain hardened structure is a full hard structure whose reduction used in the cold forming is at least 50%, such as 80%.

10. The method of any one of the preceding claims, **characterized in that** the cooling or the hardening is provided in a mould, in which mould formation into a component is also carried out.

11. A steel product, such as steel pipe, produced by the method of any one of claims 1 to 10, **characterized in that** the product of breaking strength and breaking elongation R_m * A is at least 12000, preferably at least 15000 and most preferably at least 18000.

12. The steel product produced by the method of any one of claims 1 to 10, **characterized in that** uniform elongation of the steel product is $A_g \geq 3\%$.

13. The steel product produced by the method of any one of claims 1 to 10, **characterized in that** breaking strength of the steel product is Rm≥800MPa.

14. The steel product produced by the method of any one of claims 1 to 10, **characterized in that** the steel product contains iron Fe and unavoidable residuals and comprises in percentages by weight
C: 0.05-0.25 %
Si: 0 - 2.5 %
Mn: 0.8 - 3.0 %
Al: 0 - 2.5 %
Mo: <1.5 %, preferably 0.1-0.8%
Cr: <1.5 %, preferably 0.2 - 1.5%
Cu <1.00 %
Ti: < 0.15 %
Nb: < 0.09 %
V : <0.17%
preferably 0.015 % < Ti+Nb+V < 0.22 %
such that the hardenability index DI of the steel product is at least 3mm, preferably at least 15mm.

15. The steel product produced by the method of any one of claims 1 to 10, **characterized in that** the steel product contains iron Fe and unavoidable residuals and comprises in percentages by weight
C: 0.10-0.40 %,
Si: 0 - 2.5 %
Mn: 0.2 - 3.0 %
Al: 0 - 2.5 %
Cu 0 - 1.0%
B: 0.0005 - 0.009 %
Cr 0 - 1.5 %
Mo 0 - 1.5 %
Ti: < 0.15 %
Nb: < 0.09 %
V: < 0.17 %
such that the hardenability index DI of the steel product is at least 3mm, preferably at least 15mm.

16. Use of a steel pipe made of strain hardened steel in a rapid heat treatment process, which heat treatment process comprises:

- extremely rapid heating of the strain hardened steel pipe, at least at a rate of HR ≥ 100 °C/s to a temperature

of $A_{c3} \pm 100$ °C
- cooling of the heated steel pipe in such a manner that the micro structure formed in the steel product comprises at least 30% martensite and/or bainite in percentages by volume.

17. Use in accordance with claim 16, **characterized in that** the process comprises an extremely rapid heating, at least at a rate of HR ≥ 160 °C/s to a temperature of $A_{c3} \pm 100$ °C.

18. A method for manufacturing a steel component having excellent mechanical properties, the method comprising *cold rolling (1) a steel strip to provide a cold-rolled steel strip,* the cold-rolled steel strip thus having a highly strain hardened structure, **characterized in that** the method further comprises the following steps:

- a cold rolled steel strip having a highly strain hardened structure is moulded into a steel pipe through cold moulding (2)
- the steel pipe having a strain hardened structure is rapidly *heated* (3) to a temperature of $A_{c3} \pm 100$ °C,
- the heated steel pipe is moulded and cooled in a mould, preferably moulded and hardened in the mould, for providing a component.

19. The method of claim 18, **characterized by** heating (3) at a rate of HR ≥ 100 °C/s, preferably at a rate of HR ≥ 160 °C/s, most preferably at a rate of 160 to 500 °C/s.

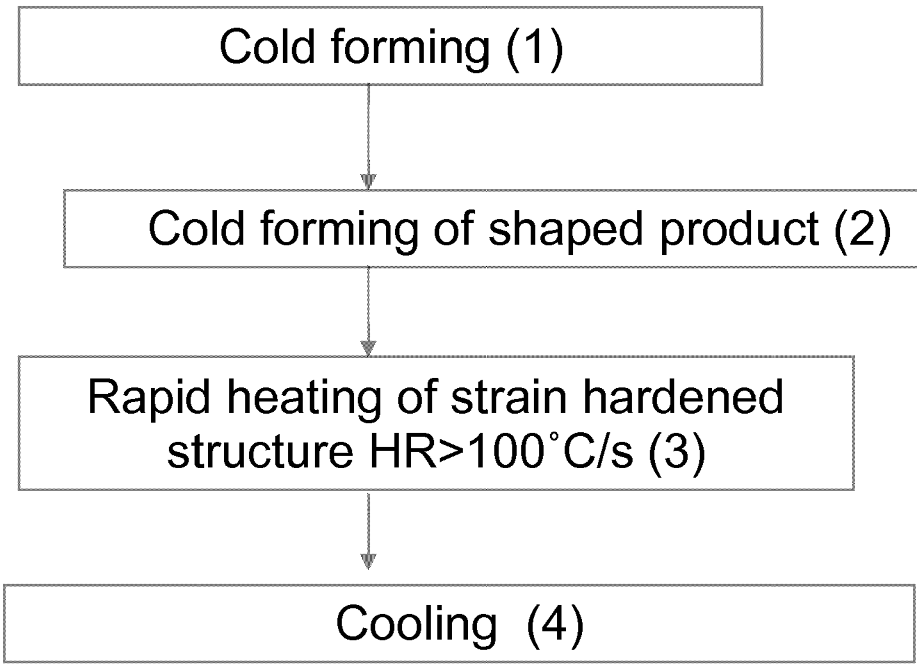
Cold forming (1)
Cold forming of shaped product (2)
Rapid heating of strain hardened structure HR>100˚C/s (3)
Cooling (4)

Figure 1

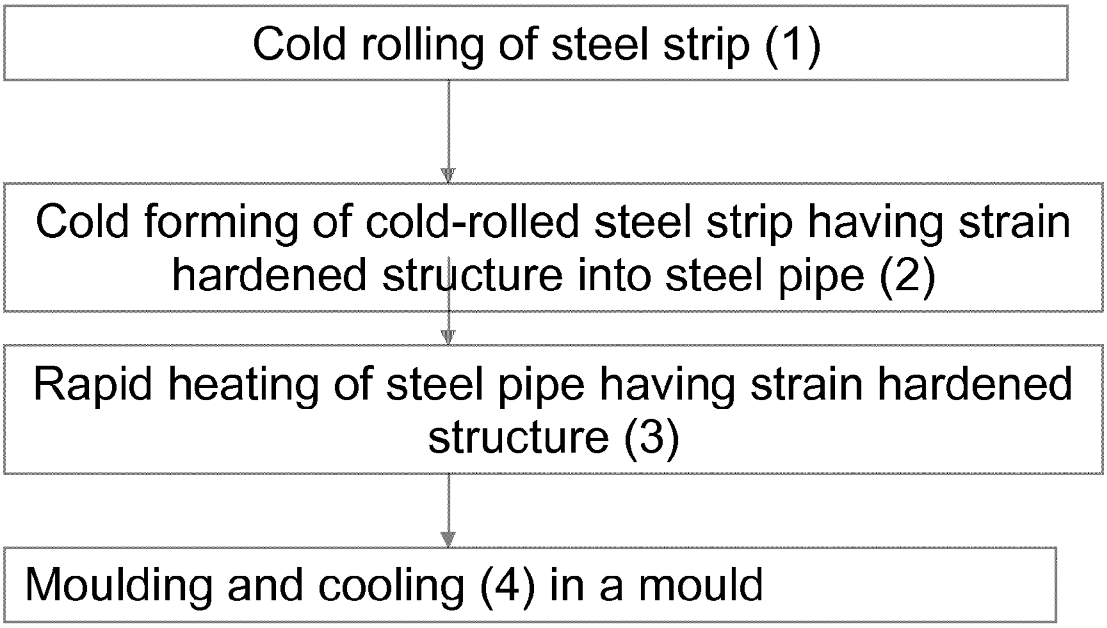
Cold rolling of steel strip (1)
Cold forming of cold-rolled steel strip having strain hardened structure into steel pipe (2)
Rapid heating of steel pipe having strain hardened structure (3)
Moulding and cooling (4) in a mould

Figure 2

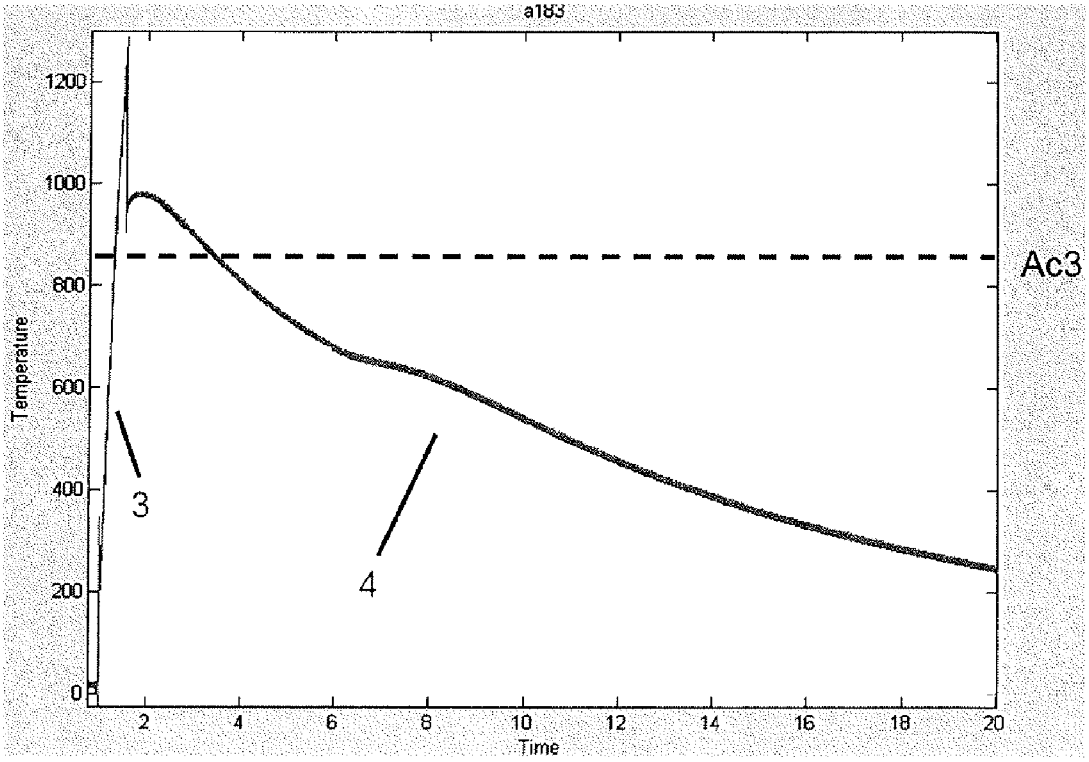

Figure 3

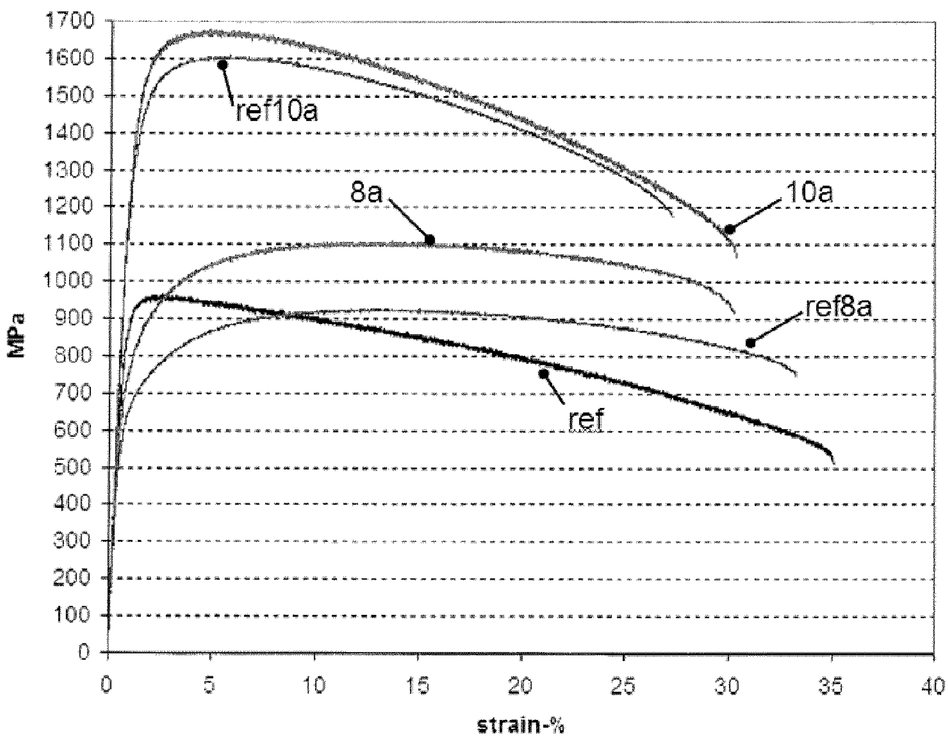

Figure 4