A martensitic stainless steel is provided, wherein its composition is:

- trace amount ≤ 0.030%;
- trace amount ≤ 0.25%;
- trace amount ≤ 0.25%;
- trace amount ≤ 0.02%;
- trace amount ≤ 0.40%;
- 8% ≤ Ni ≤ 14%;
- 8% ≤ Cr ≤ 14%;
- 1.5% ≤ Mo + W ≤ 3.0%;
- 1.0% ≤ Al ≤ 2.0%;
- 0.5% ≤ Ti ≤ 2.0%;
- 2% ≤ Co ≤ 9%;
- trace amount ≤ 0.30%;
- trace amount ≤ 0.20%;
- the remainder being iron and impurities resulting from the steelmaking;

and its martensitic transformation beginning temperature \( M_s \) is calculated by the formula

\[
M_s (°C) = 1302 - 28Si - 50Mo - 63Ni - 42Cr - 30Mo + 20Al - 12Co + 25Cu + 10(2\%Cr-N)
\]  

(1)

wherein the contents of the various elements are expressed in weight percentages, is greater than or equal to 50°C, preferably greater than or equal to 75°C. A part made in this steel and its manufacturing method are also provided.
MARTENSITIC STAINLESS STEEL, PART MADE IN SAID STEEL AND METHOD FOR MANUFACTURING SAME

[0001] The present invention relates to stainless steels with high tensile strength and toughness, notably intended for manufacturing aeronautical structural parts, notably for landing gears.

BACKGROUND

[0002] Martensitic stainless steels with structural hardening have been developed with the purpose of meeting needs in particular related to this application. Traditionally, non-stainless steels are used of the 40Ni5CrMo7 type, more usually designated as 300M, and notably containing 0.40% of C, 1.80% of Ni, 0.85% of Cr and 0.40% of Mo. These are weight percentages, as will be all the contents mentioned in the text. After adequate heat treatments, this steel may have a tensile strength Rm of more than 1,930 MPa and a toughness Klc of more than 55 MPa m²/2. It would be advantageous to have the possibility of having steels having, in addition to these mechanical properties, high corrosion resistance properties. For this purpose, different grades have been developed, but without any of them giving entire satisfaction.

[0003] The grade described in document U.S. Pat. No. 3,556,776 and for which typically, C=0.050%, Si=0.6%, Mn=0.5%, S=0.015%, Cr=11.5-13.5%, Ni=7-10%, Mo=1-1.75-2.5%, Al=0.5-1.5%, Ti=0.5-1.5%, Nb=0.75%, N=0.050%, has a too low mechanical strength, of less than 1,800 MPa.

[0004] The grade described in document U.S. Pat. No. 7,901,519, for which, typically, C=0.020%, Cr=11-12.5%, Ni=9.91%, Mo=1-1.25%, Al=0.7-1.5%, Ti=0.15-0.5%, Cu=0.5-2.5%, W=0.5-1.5%, B=0.0010%, also itself has insufficient Rm.

[0005] The grade described in document U.S. Pat. No. 5,855,844, for which, typically, C=0.030%, Si=0.75%, Mn=1.5%, S=0.020%, P=0.040%, Cr=9-13%, Ni=10.5-11.5%, Mo=0.25-1.5%, Al=0.25%, Ti=1.5-1.8%, Cu=0.95%, Nb=0.3%, N=0.030%, B=0.010% also itself has insufficient Rm.

[0006] The grade described in document U.S.-2003/ 0049153, for which, typically, C=0.030%, Si=0.5%, Mn=0.5%, S=0.0025%, P=0.0004%, Cr=9-13%, Ni=7-9%, Mo=3-6%, Al=1-1.5%, Ti=1%, Co=5-11%, Cu=0.75%, Nb=1%, N=0.030%, O=0.020%, B=0.0100%, may have desired levels of mechanical properties, but would have an insufficient corrosion resistance. It may also not be sufficiently capable of being applied as massive parts, since it was developed for the manufacturing of thin products. During heat treatments, it has to be subject to solution heat treatment at a generally high temperature, from 930 to 980° C.

[0007] Document WO-A-2012/002208 describes a steel of a typical composition C=0.200%, Si=0.1%, Mn=0.1%, S=0.008%, P=0.030%, Cr=9-15.4%, Ni=7-14%, Mo=0.5-3.3%, Al=0.25-1%, Ti=0.75-2.5%, Co=3.5%, Cu=0.1%, N=0.010%, O=0.005%, which would have good mechanical properties as regards the main properties of which have been mentioned. But its ductility would be insufficient if more than 1% of Al were added to it. The solution heat treatment is always carried out at a very high temperature, from 940 to 1,050° C., for ½ hr to 3 hrs, so as to be sufficiently complete without causing excessive enlargement of the grain.

[0008] Document EP-A-1 896 624 describes a steel of typical composition C=0.025%, Si=0.25%, Mn=3%, S=0.005%, P=0.020%, Cr=9-13%, Ni=8-14%, Mo=1.5-3%, Al=1-2%, Ti=0.5-1.5%, Co=2%, Cu=0.5%, W=1%, N=0.006%, O=0.005%. It has the advantage of containing little or no Co which is an expensive element, and of tolerating solution heat treatments at not very high temperatures (850-950° C.), therefore with less expenditure of energy and a lesser risk of grain enlargement. But its tensile strength-toughness compromise is not as favorable as this would be desired.

SUMMARY OF THE INVENTION

[0009] An object of the invention is to propose a martensitic stainless steel with structural hardening simultaneously having high mechanical strength properties Rm and toughness properties Klc, high corrosion resistance and excellent capability of being shaped as massive parts.

[0010] For this purpose, a martensitic stainless steel is provided, characterized in that its composition is, in weight percentages:

[0011] trace amounts C≤0.030%, preferably ≤0.010%;
[0012] trace amounts Si≤0.25%, preferably ≤0.10%;
[0013] trace amounts Mn≤0.25%, preferably ≤0.10%;
[0014] trace amounts P≤0.020%, preferably ≤0.010%;
[0015] trace amounts S≤0.040%, preferably ≤0.020%;
[0016] 0.8%≤Ni≤14, preferably 11.3%≤Ni≤12.5%;
[0017] 0.8%≤Cr≤14, preferably 8.5%≤Cr≤15.4%;
[0018] 1.5%≤Mo+W≤3.3%, preferably 1.5%≤Mo+W≤2.5%;
[0019] 1.0%≤Al≤2.0%, preferably 1.0%≤Al≤1.5%;
[0020] 0.5%≤Ti≤2.0%, preferably 1.1%≤Ti≤1.55%;
[0021] 2%≤Co≤5%, preferably 2.5%≤Co≤6.5%; better between 2.50 and 3.50%;
[0022] trace amounts N≤0.030%, preferably ≤0.0060%;
[0023] trace amounts O≤0.020%, preferably ≤0.0050%;
[0024] the remainder being iron and impurities resulting from the steelmaking;

[0025] and in that its martensitic transformation beginning temperature Ms calculated by the formula

\[
\text{Ms} = (^{\circ} \text{C}) = 1302 - 288 \cdot \ln(50 - 636 - 42C - 30Mo + 20Al - 12Cr - 25Cu + 10Ti + 4(C + N))
\]  

(1)

[0026] wherein the contents of the different elements are expressed in weight percentages, is greater than or equal to 50° C., preferably greater than or equal to 75° C.

[0027] Preferably, 1.05%≤Al≤2.0%, and preferably 1.05%≤Al≤1.5%.

[0028] The proportion of delta ferrite in its microstructure is preferably less than or equal to 1%. 

[0029] A method for manufacturing a part in martensitic stainless steel is also provided, characterized in that:

[0030] a semi-finished steel product is prepared having the aforesaid composition with one of the following methods:

[0031] liquid steel is prepared having the aforesaid composition, and from this liquid steel, an ingot is cast and solidified and is transformed into a semi-finished product by at least one hot transformation;

[0032] a sintered semi-finished product in a steel having the aforesaid composition is prepared by powder metallurgy,
complete beginning solution heat treatment of the semi-finished product is achieved in the austenitic domain, at a temperature comprised between 800 and 940°C;

a quench of the semi-finished product is carried out down to a final quenching temperature of less than or equal to −60°C, preferably less than or equal to −75°C;

ageing between 450 and 600°C is performed for 4 to 32 h.

Between the solidification of the cast and solidified ingot and the solution heat treatment of the semi-finished product, homogenization of the ingot or of the semi-finished product may be carried out at 1,200-1,300°C for at least 24 h.

Between the quenching and the ageing, it is possible to achieve a cold transformation of the semi-finished product.

The quenching may be carried out in two steps, in two different quenching media.

The first quenching step is carried out in water.

The liquid steel may be prepared by a dual treatment by melting in vacuo, the second treatment in vacuo being an ESR or VAR re-melting treatment.

A part in martensitic stainless steel is also provided, characterized in that it was prepared by the previous method.

This may be an aeronaughtical structural part.

As this will have been understood, a martensitic stainless steel grade is provided which, after having been subject to adequate thermomechanical treatments which, combined with said grade, are also an element of the invention, has simultaneously tensile strength, toughness and ductility properties which make it suitable for its use in the manufacturing of massive parts such as landing gears, as well as an excellent corrosion resistance as compared with the grades already used for this purpose.

The steels of embodiments of the invention are of a martensitic structure which is obtained by:

by complete solution heat treatment in the austenitic domain, therefore carried out beyond the temperature Ac3 of the relevant steel; for the relevant grade, this solution heat treatment temperature is from 800 to 940°C; the solution heat treatment is carried out for a period from 30 mins to 3 hrs; a temperature of the order of 850°C combined with a period of the order of 1 h 30 min are generally adequate for, both obtaining complete solution and moderate growth of the grain; a too coarse grain would be detrimental to the resilience, corrosion under stress and ductility properties;

and then by quenching, preferably carried out from a temperature close to the solution heat treatment temperature, such quenching being prolonged down to a cryogenic temperature, i.e. −60°C or lower, preferably down to −75°C or lower, typically down to −80°C.

The duration for maintaining it in the cryogenic medium should be sufficient so that the cooling at the selected temperature and the sought transformations affect the steel part in all its volume. This duration therefore strongly depends on the mass and on the dimensions of the treated part, and is, of course all the more longer since for example the treated part is thick. Various quenching media may be used: air, water, oil, gas, polymer, liquid nitrogen, dry ice (non-limiting list), and the quenching is not necessarily carried out with a very high cooling rate.

The successive use of two different quenching media may be contemplated, the first medium for example bringing the steel to an intermediate temperature, and the second medium then bringing the steel to −60°C or lower. For the most massive parts, water is a first preferred quenching medium since it gives the possibility of ensuring that the core of the part is cooled sufficiently rapidly. The quenching beginning temperature is preferably the temperature at which occurs the solution, in order to guarantee that between the solution heat treatment and the quenching, no metallurgical transformations occur which are difficult to control and which may unfavorably affect the final mechanical properties of the product.

If the quenching is interrupted for a certain period below Ms and above the end temperature Mf of a martensitic transformation, the interruption should be short in order to avoid the risk of blocking the transformation when the quenching will be resumed.

Another possibility would be to interrupt the quenching above Ms and to then resume it down to the cryogenic temperature.

A possible advantage of such interruptions is that they give the possibility of avoiding the requirement of immediately using a cryogenic quenching medium, therefore avoiding a first very high cooling rate which would risk leading to the occurrence of quenching cracks (surface cracks), or cracks inside the semi-finished product which may be due to differential martensitic transformation phenomena between the surface and the still hot core of the semi-finished product if the latter is relatively thick. But in practice, it is preferable to carry out the quenching in a single step, for more convenience and for not risking the occurrence of undesirable metallurgical effects on the microstructure of the steel, since two-step quenching is often difficult to control as to the final temperature of the first step and as to homogeneity of its effects in the treated part.

The transition to the cryogenic temperature may be accomplished in a solid, gaseous or liquid medium depending on the available treatment technology. In order to obtain an entirely martensitic structure, the beginning of the martensitic transformation upon cooling, Ms should be under control. This point Ms depends on the composition of the alloy and is calculated according to Equation (1):

\[ Ms ({}^\circ C) = 1302 - 2865 \times 50 + 63 - 4200 \times 30 + \frac{20 \times 12}{25 + 0.10[Ti] + 0.04[C + N]} \]

wherein the contents of the various elements are expressed in weight percentages.

Within the scope of the invention, Ms is necessarily greater than or equal to 50°C and preferentially greater than or equal to 75°C. If this condition is not met, the steel has residual quenched austenite which is detrimental to the mechanical properties, in particular to the break strength.

After the solution heat treatment and the prolonged quenching down to the targeted cryogenic temperature, the final mechanical properties are obtained at the end of ageing between 450 and 600°C for a period from 4 to 32 hours. The obtained hardening is ensured by the formation of intermetallic precipitates of the NiAl and NixTi type of nanometric size. During the ageing, reversion austenite may form and contribute to the toughness of the steel. This ageing may optionally be interrupted by means of water quenching for improving the toughness.

The final structure, for the preferred contemplated applications notably in aeronautics, should be free of delta
ferrite which degrades the mechanical properties. A maximum of 1% of delta ferrite is tolerable. The composition of the steel according to embodiments of the invention is exactly selected for avoiding as much as possible that delta ferrite subsists at the end of the treatments carried out during application of the method according to embodiments of the invention. From this point of view, it is highly preferable, in order to ensure this lack of subsisting delta ferrite, that the Cr eq./Ni eq. ratio of the steel, i.e. the ratio between the weighted sum of the contents of the main alphagenic elements like Cr (equivalent chrome) and the weight sum of the contents of the main gammagenic elements like Ni (equivalent nickel), is less than or equal to 1.05, with:

\[
\text{Cr eq.} = 2\text{Si}+\text{Mo}+1.5\text{Ti}+5.5\text{Al}+0.6\text{W}
\]

\[
\text{Ni eq.} = 0.5\text{Mn}+3\text{C}+2\text{Si}+0.3\text{Cu}
\]

[0056] The solidification of the grades of embodiments of the invention should be controlled in order to limit segregation of the ingots which may be detrimental to the mechanical properties, notably when the mechanical stress occurs in the transverse direction, and the contents of oxide and nitride inclusions have to be minimized as much as possible. For this purpose, a preferred method for preparing steels according to embodiments of the invention is dual elaboration by melting in vacuo with induction melting (Vacuum Induction Melting, VIM) and then casting the steel into an ingot in order to obtain an electrode, which is then treated by re-melting with an arc in vacuo (Vacuum Arc Remelting, VAR) or by re-melting under an electrically conducting slag (Electroslag Remelting, ESR). The elaborations in vacuo give the possibility of avoiding oxidations of Al and Ti by the air, therefore the excessive formation of oxidized inclusions, and also allow removal of a portion of the dissolved nitrogen and oxygen. It is thus possible to obtain long lifetimes in fatigue.

[0057] After obtaining the solidified ingot, hot transformations are carried out (rolling, forging, die-stamping . . . ) which shape it into a semi-finished product (bar, flat, block, forged or die-stamped part . . . ) for giving it dimensions at least close to its definitive dimensions. These hot transformations are quite simply those which are customary for the targeted semi-finished products with general compositions comparable with those of the embodiments of invention, both as regards deformations and treatment temperatures.

[0058] Preferably, a homogenization treatment of the ingot or of the semi-finished product is also carried out at a temperature from 1,200 to 1,300°C for at least 24 hrs in order to limit segregation of the various elements present and thus more easily ensure the obtaining of the targeted mechanical properties. However, homogenization generally, preferably, does not take place during the last hot shaping operations or after the latter, in order to more surely preserve an acceptable grain size on the products, depending on their future use.

[0059] The semi-finished product then undergoes, according to the embodiments of invention a heat treatment consisting in:

[0060] Solution heat treatment between 800 and 940°C practiced, as this is conventional, for a sufficient period for dissolving the precipitates present in the entirety of the semi-finished product and which therefore closely depends on the dimensions of said semi-finished product, followed by quenching down to a temperature of -60°C or less, preferably -75°C or less, said quenching preferably beginning at a temperature close to the solution heat treatment temperature, and which may be carried out in two separate steps by dwelling at an intermediate temperature (for example room temperature, or a temperature comprised between the beginning and the end of the martensitic transformation, or a temperature above the beginning temperature of the martensitic transformation);

[0061] And then optionally, cold shaping of the semi-finished product;

[0062] And then ageing between 450 and 600°C, for 4 to 32 hours giving the possibility of balancing the resistance, toughness and ductility properties according to the following criteria:

[0063] The attained maximum strength decreases when the ageing temperature increases, but conversely the ductility and the toughness increase;

[0064] The ageing period required for causing a given hardening increases when the ageing temperature decreases;

[0065] At each temperature level, the strength passes through a maximum for a determined period, which is called a <<hardening peak>>;

[0066] For each targeted strength level, which may be attained with several pairs of time-temperature variables, there exists only one pair which gives the best strength/ductility compromise to the steel; these optimum conditions correspond to a beginning of over-ageing of the structure, and are obtained when one goes beyond the hardening peak; one skilled in the art may experimentally determine which is the optimum pair by means of routine reflections and tests.

[0067] The alloy elements of the steel according to embodiments of the invention are present in the indicated amounts for the reasons which will be discussed. As stated, the percentages are weight percentages.

[0068] The C content is at most 0.030% (300 ppm), preferably at most 0.010% (100 ppm). In practice, it is generally present as the condition of a residual elements resulting from the melting of the raw materials and from the steelmaking, with any voluntary addition having been carried out. It may form Cr carbides of the M_{23}C_6 type and thus be a penalty to the corrosion resistance by capturing Cr which is thus no longer available for ensuring the stainless nature of the steel in a satisfactory way. It may also be associated with Ti in order to form detrimental carbides and carbonitrides for fatigue strength, and consumption of Ti under these forms would decrease the formed amount of hardening intermetallic compounds.

[0069] The Si content is of at most 0.25%, preferably at most 0.10% in order to better ensure good compromise between the sought Rm and KIC. Typically, this is only a residual element which is not added voluntarily. It tends to lower Ms (see equation (1)) and to embrittles the steel, whence its undesirable nature of greater amounts than what has been stated.

[0070] The Mn content is of at most 0.25%, preferably at most 0.10%. Typically, this is only a residual element which is not added voluntarily. It tends to lower Ms (see equation (1)). It may optionally be used as a partial substitution for Ni in order to avoid the presence of delta ferrite and to contribute to the presence of reversion austenite during the hardening ageing. But the ease with which it evaporates during vacuum treatments makes it difficult to control and leads to fouling of the devices for removing dusts from the
fumes of the furnaces. A significant presence of Mn in the steels of embodiments of the invention is therefore not recommended.

[0072] The S content is of at most 0.020% (200 ppm), preferably at most 0.005% (50 ppm), in order to better ensure the good sought compromise between Rm and K1C. There again it is present in a residual state and if necessary its content should be controlled by careful selection of the raw materials and/or a desulfurization metallurgical treatment during the melting step and adjustment of the steel composition. It reduces the toughness by segregation at the grain boundaries, and forms sulfides which may be damaging for the mechanical properties.

[0073] The Ni content is comprised between 8 and 14%, preferably between 11.3 and 12.5%. This is a gammagenic element, and it should be at a sufficiently high level for avoiding stabilization of delta ferrite during the solution heat treatment and homogenization operations. It also has the function of forming reverse austenite during ageing, which finely precipitates between the martensite laths and provides their ductility and their toughness to the steels of embodiments of the invention.

[0074] The Cr content is comprised between 8 and 14%, preferably between 8.5 and 10%. It is the main element which provides corrosion resistance, which justifies the lower limit of 8%. But its content should be limited to 14% so that it does not contribute to stabilization of delta ferrite and that it does not have Ms, calculated according to equation (1), pass below 50°C. Oct. 6, 2016

[0075] The Mo+W/2 content is comprised between 1.5 and 3.0%, preferably between 1.5 and 2.5%. Mo participates in the corrosion resistance and is capable of forming a hardening phase Fe₇Mo₃. However, addition of an excessive amount of Mo may lead to the formation of a μ phase Fe₃Mo, and thus decrease the amount of available Mo for limiting corrosion. Optionnally, at least one portion of Mo may be replaced with W. It is well known that in steels, both of these elements are functionally often comparable, and that for an equal mass percentage, W is twice more effective than Mo.

[0076] The Al content is comprised between 1.0 and 2.0%, preferably between 1.05 and 2.0%, better between 1.0 and 1.5%, optimally between 1.05 and 1.5%. During ageing, the hardening phase Ni₃Al forms. Al usually has the reputation of degrading ductility, but this drawback is canceled out by the possibility provided by embodiments of the invention of carrying solution heat treatment at relatively low temperatures.

[0077] The Ti content is comprised between 0.5 and 2.0%, preferably between 1.10 and 1.55%. It also participates in the hardening during the ageing by forming the phase Ni₅Ti._It also allows binding of C and N as Ti carbides and carbonitrides and thus avoids the detrimental effects of C. However, as this has been stated, these carbides and carbonitrides are detrimental to the fatigue strength, and one cannot afford to form them in a too large amount. The C, N and Ti contents therefore have to be maintained within the prescribed limits.

[0078] The Co content is comprised between 2 and 9%, preferably between 2.50 and 6.5%, better between 2.50 and 3.50%. This allows stabilization of the austenite at the homogenization and solution heat treatment temperatures, and therefore avoids formation of delta ferrite. It participates in the hardening by its presence in a solid solution and also in that it promotes precipitation of the Ni₃Al and Ni₅Ti phases. It is possible to add it as a substitution for Ni so as to increase the Ms temperature and ensure that it is greater than 50°C. As compared with the steel described in EP-A-1 896 624 wherein Co has to be at most 2%, the purpose here is to use Co for significantly contributing to the hardening, this in combination with the other elements present and the required heat treatments. The targeted preferential content of 2.50-3.50% represents the best compromise between the cost of the steel and its performances.

[0079] N should be at most 0.030% (300 ppm), preferably at most 0.0060% (60 ppm) in order to better ensure the good sought compromise between Rm and K1C. Nitrogen is not added voluntarily to the liquid metal and the vacuum treatments which are generally practiced during the steelmaking give the possibility of protecting the liquid steel against absorptions of atmospheric nitrogen, or even removing a portion of the dissolved nitrogen. N is unfavorable for ductility of the steel and forms angular Ti nitrides which may be sites for initiating cracks during fatigue stresses.

[0080] O should be at most 0.020% (200 ppm), preferably 0.0050% (50 ppm) in order to ensure the sought good compromise between Rm and K1C. Itself is also unfavorable for ductility, and the oxidized inclusions which it forms are also potentially sites for initiation of fatigue cracks. The O content will have to be selected according to the usual criteria for one skilled in the art, depending on the specific mechanical characteristics required for the final product.

[0081] Generally, the mechanical properties of the steel of embodiments of the invention are unfavorably affected by oxide and nitride inclusions. The use of steelmaking methods aiming at minimizing their presence in the final steel (VIM, ESR, VAR) is notably preferred for this reason.

[0082] The other elements present in the steel of embodiments of the invention are iron and impurities resulting from the steelmaking.

[0083] It should be understood that the ranges given as preferential for each element are independent of each other, i.e. the composition of the steel may only be located in these preferential ranges for only certain elements.

BRIEF SUMMARY OF THE DRAWING

[0084] FIG. 1 expresses the results of table 3 in terms of a compromise between Rm and K1C for samples stemming from 150 kg ingots.
Tests were carried out on samples stemming from castings of ingots having the compositions stated in Table 1.

<table>
<thead>
<tr>
<th>C %</th>
<th>Si %</th>
<th>Mn %</th>
<th>S %</th>
<th>P %</th>
<th>Ni %</th>
<th>Cr %</th>
<th>Mo %</th>
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<td>&lt;0.01</td>
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<td>0.029</td>
<td>&lt;0.01</td>
<td>0.0014</td>
<td>&lt;0.0050</td>
<td>11.47</td>
<td>10.14</td>
<td>1.99</td>
</tr>
<tr>
<td>10</td>
<td>0.0038</td>
<td>0.041</td>
<td>&lt;0.01</td>
<td>0.0013</td>
<td>&lt;0.0050</td>
<td>11.32</td>
<td>10.06</td>
<td>2.00</td>
</tr>
<tr>
<td>11</td>
<td>0.0032</td>
<td>0.036</td>
<td>&lt;0.01</td>
<td>0.0016</td>
<td>&lt;0.0050</td>
<td>11.26</td>
<td>9.16</td>
<td>2.00</td>
</tr>
<tr>
<td>12</td>
<td>0.0030</td>
<td>0.063</td>
<td>&lt;0.01</td>
<td>0.0001</td>
<td>&lt;0.0050</td>
<td>12.43</td>
<td>8.98</td>
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</tr>
<tr>
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<td>&lt;0.01</td>
<td>0.0001</td>
<td>&lt;0.0050</td>
<td>11.75</td>
<td>9.40</td>
<td>2.06</td>
</tr>
<tr>
<td>14</td>
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<td>0.022</td>
<td>&lt;0.01</td>
<td>0.0003</td>
<td>&lt;0.0050</td>
<td>11.82</td>
<td>9.60</td>
<td>2.03</td>
</tr>
<tr>
<td>15</td>
<td>0.0052</td>
<td>0.024</td>
<td>&lt;0.01</td>
<td>0.0004</td>
<td>&lt;0.0050</td>
<td>11.77</td>
<td>9.39</td>
<td>2.01</td>
</tr>
<tr>
<td>16</td>
<td>0.0049</td>
<td>0.024</td>
<td>&lt;0.01</td>
<td>0.0004</td>
<td>&lt;0.0050</td>
<td>11.15</td>
<td>9.55</td>
<td>2.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ti %</th>
<th>Co %</th>
<th>N %</th>
<th>O %</th>
<th>Fe</th>
<th>Ms (°C) according to equation (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.18</td>
<td>&lt;0.010</td>
<td>0.0029</td>
<td>0.0008</td>
<td>remainder 85</td>
</tr>
<tr>
<td>B</td>
<td>1.17</td>
<td>6.11</td>
<td>0.0021</td>
<td>0.0009</td>
<td>remainder 16</td>
</tr>
<tr>
<td>C</td>
<td>1.15</td>
<td>9.11</td>
<td>0.0016</td>
<td>0.0016</td>
<td>remainder 19</td>
</tr>
<tr>
<td>D</td>
<td>1.15</td>
<td>&lt;0.010</td>
<td>0.0024</td>
<td>0.0010</td>
<td>remainder 88</td>
</tr>
<tr>
<td>E</td>
<td>1.17</td>
<td>&lt;0.010</td>
<td>0.0022</td>
<td>0.0013</td>
<td>remainder 72</td>
</tr>
<tr>
<td>F</td>
<td>0.094</td>
<td>8.22</td>
<td>0.0018</td>
<td>0.0008</td>
<td>remainder 210</td>
</tr>
<tr>
<td>1</td>
<td>1.18</td>
<td>3.06</td>
<td>0.0015</td>
<td>0.0015</td>
<td>remainder 53</td>
</tr>
<tr>
<td>2</td>
<td>1.18</td>
<td>3.07</td>
<td>0.0017</td>
<td>0.0019</td>
<td>remainder 81</td>
</tr>
<tr>
<td>3</td>
<td>1.17</td>
<td>6.13</td>
<td>0.0014</td>
<td>0.0012</td>
<td>remainder 73</td>
</tr>
<tr>
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<td>1.18</td>
<td>6.11</td>
<td>0.0015</td>
<td>0.0010</td>
<td>remainder 135</td>
</tr>
<tr>
<td>5</td>
<td>1.18</td>
<td>6.14</td>
<td>0.0004</td>
<td>0.0013</td>
<td>remainder 165</td>
</tr>
<tr>
<td>6</td>
<td>1.20</td>
<td>3.19</td>
<td>0.0009</td>
<td>0.0010</td>
<td>remainder 69</td>
</tr>
<tr>
<td>7</td>
<td>1.23</td>
<td>6.02</td>
<td>0.0008</td>
<td>0.0006</td>
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</tr>
<tr>
<td>8</td>
<td>1.17</td>
<td>6.22</td>
<td>0.0021</td>
<td>0.0026</td>
<td>remainder 128</td>
</tr>
<tr>
<td>9</td>
<td>1.16</td>
<td>5.40</td>
<td>0.0009</td>
<td>0.0007</td>
<td>remainder 70</td>
</tr>
<tr>
<td>10</td>
<td>1.22</td>
<td>3.09</td>
<td>0.0016</td>
<td>0.0006</td>
<td>remainder 88</td>
</tr>
<tr>
<td>11</td>
<td>1.17</td>
<td>6.20</td>
<td>0.0019</td>
<td>0.0008</td>
<td>remainder 111</td>
</tr>
<tr>
<td>12</td>
<td>1.23</td>
<td>3.12</td>
<td>0.0039</td>
<td>0.0009</td>
<td>remainder 79</td>
</tr>
<tr>
<td>13</td>
<td>1.21</td>
<td>3.09</td>
<td>0.0029</td>
<td>0.0005</td>
<td>remainder 106</td>
</tr>
<tr>
<td>14</td>
<td>1.45</td>
<td>3.06</td>
<td>0.0044</td>
<td>0.0003</td>
<td>remainder 91</td>
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<td>3.03</td>
<td>0.0036</td>
<td>0.0013</td>
<td>remainder 112</td>
</tr>
<tr>
<td>16</td>
<td>1.45</td>
<td>4.08</td>
<td>0.0016</td>
<td>0.0010</td>
<td>remainder 124</td>
</tr>
</tbody>
</table>

The compositions of the samples A to E correspond to reference steels: A, D and E are compliant with the teaching of EP A-1 896 624. B and C are two reference examples which give the possibility of underlining the benefit of imposing Ms according to embodiments of the invention. The compositions of the samples 1 to 16 correspond to steels according to embodiments of the invention. The samples A, B, C and 1 to 5 stem from 6 kg ingots, and the other samples stem from 150 kg ingots. The 6 kg ingots were elaborated in a first phase for a first validation of the concept of embodiments of the invention, and their encouraging properties led to the continuation of the experiments with 150 kg castings in order to confirm and refine the definition of embodiments of the invention. The 6 kg ingots also gave the possibility of directly carrying out tensile tests, while it was necessary to form the 150 kg ingots in order to then extract therefrom the samples on which the measurements of the parameters governing the toughness were conducted.
TABLE 2

Treatment conditions and mechanical properties of the samples stemming from the 6 kg ingots

<table>
<thead>
<tr>
<th>Sample</th>
<th>Heat treatment</th>
<th>Quenching</th>
<th>Aging</th>
<th>Rm (MPa)</th>
<th>Rp0.2 (MPa)</th>
<th>A (%)</th>
<th>Z (%)</th>
<th>Hardness (HV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>850/1.5</td>
<td>80</td>
<td>510</td>
<td>16</td>
<td>1868</td>
<td>1758</td>
<td>11</td>
<td>48</td>
</tr>
<tr>
<td>B</td>
<td>850/1.5</td>
<td>80</td>
<td>510</td>
<td>16</td>
<td>Tests not carried out</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>850/1.5</td>
<td>80</td>
<td>510</td>
<td>16</td>
<td>too much austenite in the structure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>850/1.5</td>
<td>80</td>
<td>510</td>
<td>16</td>
<td>1826</td>
<td>1678</td>
<td>11</td>
<td>48</td>
</tr>
<tr>
<td>2</td>
<td>850/1.5</td>
<td>80</td>
<td>510</td>
<td>16</td>
<td>1947</td>
<td>1797</td>
<td>11</td>
<td>49</td>
</tr>
<tr>
<td>3</td>
<td>850/1.5</td>
<td>80</td>
<td>510</td>
<td>16</td>
<td>1910</td>
<td>1794</td>
<td>11</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
<td>850/1.5</td>
<td>80</td>
<td>510</td>
<td>16</td>
<td>1966</td>
<td>1872</td>
<td>11</td>
<td>49</td>
</tr>
<tr>
<td>5</td>
<td>850/1.5</td>
<td>80</td>
<td>510</td>
<td>16</td>
<td>1977</td>
<td>1893</td>
<td>8</td>
<td>25</td>
</tr>
</tbody>
</table>

[0087] It will be noted that the excessive presence of austenite in the structure is expressed, for the reference samples B and C, by very low hardness, which was the clue of poor tensile strength and surely insufficient with respect to the requirements of embodiments of the invention. It was then estimated to be useless to proceed with other mechanical tests on these samples. These samples have compositions which, as regards individual contents of each element, were compliant with the requirements of embodiments of the invention, but which taken together, provided a too low martensitic transformation temperature Ms (less than 50°C). The quench, carried out under the experimental conditions, which correspond to what is usually practiced industrially, did not give the possibility of obtaining a sufficiently martensitic structure in the case of these samples. This shows that the condition posed on Ms is important to consider within the scope of the invention.

[0088] As regards the 150 kg ingots (D, E, 6 to 16), they were elaborated in vacuo, cast and then re-melted also in vacuo with the VAR method for obtaining ingots with a diameter of 200 mm. They were then homogenized at 1,250°C for 48 hrs, and then forged at this temperature into semi-finished products with an octagonal section of 110 mm, and then, after heating to 940°C, again forged, this time into bars with a section of 80×40 mm. Table 3 states the conditions under which were carried out the heat treatments which followed, and the mechanical properties measured in the longitudinal direction on the samples. As compared with the tests of table 2, no measurement of hardness was carried out which would have been duplicated with the measurements of Rm, and resilience tests (measurement of Kv) and toughness tests (measurement of KIC) were conducted.

TABLE 3

Treatment conditions and mechanical properties of the samples stemming from the 150 kg ingots

<table>
<thead>
<tr>
<th>Sample</th>
<th>Heat treatment</th>
<th>Quenching</th>
<th>A ageing</th>
<th>Rm (MPa)</th>
<th>Rp0.2 (MPa)</th>
<th>A (%)</th>
<th>Z (%)</th>
<th>Kv (J) (MPa m^{1/2})</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>850/1.5</td>
<td>-80</td>
<td>480</td>
<td>16</td>
<td>1952</td>
<td>1825</td>
<td>10</td>
<td>47</td>
</tr>
<tr>
<td>E</td>
<td>850/1.5</td>
<td>-80</td>
<td>460</td>
<td>16</td>
<td>1900</td>
<td>1696</td>
<td>10</td>
<td>48</td>
</tr>
<tr>
<td>F</td>
<td>850/1.5</td>
<td>-80</td>
<td>510</td>
<td>16</td>
<td>1829</td>
<td>1733</td>
<td>11</td>
<td>53</td>
</tr>
<tr>
<td>G</td>
<td>850/1.5</td>
<td>-80</td>
<td>510</td>
<td>16</td>
<td>1701</td>
<td>1593</td>
<td>13</td>
<td>58</td>
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<tr>
<td>H</td>
<td>850/1.5</td>
<td>-80</td>
<td>490</td>
<td>16</td>
<td>1872</td>
<td>1712</td>
<td>12</td>
<td>47</td>
</tr>
<tr>
<td>I</td>
<td>850/1.5</td>
<td>-80</td>
<td>510</td>
<td>16</td>
<td>1845</td>
<td>1685</td>
<td>13</td>
<td>53</td>
</tr>
<tr>
<td>J</td>
<td>850/1.5</td>
<td>-80</td>
<td>510</td>
<td>16</td>
<td>1885</td>
<td>1761</td>
<td>12</td>
<td>48</td>
</tr>
<tr>
<td>K</td>
<td>850/1.5</td>
<td>-80</td>
<td>510</td>
<td>16</td>
<td>1949</td>
<td>1809</td>
<td>14</td>
<td>52</td>
</tr>
<tr>
<td>L</td>
<td>850/1.5</td>
<td>-80</td>
<td>510</td>
<td>16</td>
<td>1908</td>
<td>1756</td>
<td>12</td>
<td>48</td>
</tr>
<tr>
<td>M</td>
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<td>-80</td>
<td>460</td>
<td>16</td>
<td>1892</td>
<td>1748</td>
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<td>53</td>
</tr>
<tr>
<td>N</td>
<td>850/1.5</td>
<td>-80</td>
<td>510</td>
<td>16</td>
<td>1814</td>
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<td>58</td>
</tr>
<tr>
<td>O</td>
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<td>-80</td>
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<td>16</td>
<td>1692</td>
<td>1563</td>
<td>16</td>
<td>59</td>
</tr>
<tr>
<td>P</td>
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<td>1888</td>
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<tr>
<td>Q</td>
<td>850/1.5</td>
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<td>16</td>
<td>1897</td>
<td>1755</td>
<td>13</td>
<td>53</td>
</tr>
<tr>
<td>R</td>
<td>850/1.5</td>
<td>-80</td>
<td>510</td>
<td>16</td>
<td>1809</td>
<td>1660</td>
<td>14</td>
<td>58</td>
</tr>
<tr>
<td>S</td>
<td>850/1.5</td>
<td>-80</td>
<td>530</td>
<td>16</td>
<td>1682</td>
<td>1521</td>
<td>16</td>
<td>61</td>
</tr>
<tr>
<td>T</td>
<td>850/1.5</td>
<td>-80</td>
<td>460</td>
<td>16</td>
<td>2078</td>
<td>1970</td>
<td>10</td>
<td>42</td>
</tr>
<tr>
<td>U</td>
<td>850/1.5</td>
<td>-80</td>
<td>510</td>
<td>16</td>
<td>2021</td>
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</tr>
<tr>
<td>V</td>
<td>850/1.5</td>
<td>-80</td>
<td>530</td>
<td>16</td>
<td>1820</td>
<td>1753</td>
<td>11</td>
<td>50</td>
</tr>
<tr>
<td>W</td>
<td>850/1.5</td>
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<td>16</td>
<td>1920</td>
<td>1768</td>
<td>12</td>
<td>52</td>
</tr>
</tbody>
</table>
The properties of the different samples may receive comments as follows. The reference samples A, D and E correspond to the steels with a low or zero Co content described in EP-A-1 896 624. As compared with the steels of embodiments of the invention, it is seen that their Rm is relatively small.

The reference samples B and C have an Ms of at least 50°C., therefore too low for being compliant with embodiments of the invention. This explains the excessive presence of residual austenite which prevents the obtaining of a sufficient Rm, expressed by low hardness.

The reference sample F shows a too high Mo content and a too low Ti content with respect to the requirements of embodiments of the invention leading to obtaining mechanical properties which are only at the level of those of the other reference samples.

Sample 1 is compliant with an embodiment of the invention, but has an Ms less than the optimum of 75°C. and more. Its Rm is therefore relatively small and will not be suitable for all the conceivable applications. The same thing may be said but to a lesser extent, of the sample 3.

The sample 2 on the contrary has an Ms according to the optimum, and its Rm of 1,947 MPa is excellent.

The samples 4 and 5, with a high Ms because of their substantial substitution of Ni with Co, have an excellent Rm of 1,866 and 1,977 MPa respectively.

The sample 6 has an Ms which is not optimum with respect to the sample 2 which it also has about 3% Co. Also for sample 7 which has a Co content of about 6%, but a poorer Rm than the sample 4 because of its lower Ms.

The very high Rm of the sample 8 is due to its high Ms combined with a Co content of about 6%.

Sample 9 with 5% Co has an Ms less than the optimum and its Rm is relatively limited. This actually shows that a relatively high Co content is not sufficient for ensuring a high Rm within the scope of the invention.

Samples 10 and 12 are those which have the best compromise between Rm and KIC. In fact, their compositions are compliant with the preferential contents on all the elements.

Sample 11 has a high Ms, and a high Rm. The balance between Rm and KIC is better than for sample 8 because of better balancing between the Ni and Cr contents.

The comparison between the samples 13, 14 and 15 show the advantageous effect of the partial substitution of Al with Ti: the sample 14 is the one which has the best compromise between Rm and KIC. It will also be noted that...
these samples have a higher Cr content (9.4-9.6%) than that (about 9%) of the samples 10 and 12.

[0102] Sample 16 has a high Ms. Its Rm is equivalent to that of sample 12 but its KIC is less favorable because of a slightly higher Cr content.

[0103] FIG. 1 expresses the results of table 3 in terms of a compromise between Rm and KIC for samples stemming from 150 kg ingots, the latter being the only ones for which the toughness was measured. Globally, KIC decreases when Rm increases, and the steels according to embodiments of the invention have a better compromise between both of these properties than the reference steels D and E for which the compositions are relatively close to those of embodiments of the invention except on the Co content.

[0104] For the reference samples, an Rm of 1,701 MPa corresponds to a toughness of 66 MPa-m\(^{1/2}\). This steel would therefore not at all be adapted to the preferred uses contemplated because its Rm is highly insufficient. The maximum Rm of the reference samples is 1,952 MPa, which would be appropriate for said uses, but the corresponding toughness is only 43 MPa-m\(^{1/2}\), which would be highly insufficient. The best strength/toughness compromises are obtained for Rms from 1,845 to 1,900 MPa, to which correspond toughnesses of the order of 46 to 56 MPa-m\(^{1/2}\). These mechanical properties taken as a whole are therefore not as favorable as for the carbon steels of the 300M type.

[0105] As for the samples according to embodiments of the invention, it is seen in FIG. 1 that a very good compromise between Rm and KIC is generally obtained for Rms of the order of 1,950 MPa, which correspond to KICs of the order of 46 to 63 MPa-m\(^{1/2}\), most often greater than 50 MPa-m\(^{1/2}\). Therefore one returns to the orders of magnitude of the corresponding properties of 300M steels.

[0106] It is also seen that if a decrease in Rm was acceptable, the toughness would be increased in large proportions, and vice versa. The steels according to embodiments of the invention therefore provide the user with great flexibility in the selection of their properties, which may be modulated by the composition, the heat treatments and the final ageing selected within the scope which was mentioned.

[0107] As regards ductility, the values of A % and Z % of the samples according to embodiments of the invention are very comparable with those which are obtained on steels of the 300M type. Embodiments of the invention therefore do not provide any degradation as compared with 300M from this point of view.

[0108] On some of these same samples stemming from castings of 150 kg ingots (samples D. 6 to 8 and 10 to 16), corrosion tests with a saline mist were also conducted in an aqueous solution of 50 g/l of NaCl at 35°C. First they had all been subject to the same solution heat treatment at 850°C for 1 h 30 min, to quenching at ~80°C and to ageing at 510°C for 16 hrs. None of these samples showed any traces of corrosion after 200 hrs of exposure. The steels according to embodiments of the invention therefore do not have their results in the corrosion test with a saline mist degraded with respect to the reference steel D which does not contain any Co.

[0109] Corrosion tests under stress were also conducted in an aqueous medium with 3.5% of NaCl at 23°C, on the samples E and 10, subject to solution heat treatment at 850°C for 1 h 30 min, to quenching at ~80°C and ageing at 510°C for 16 hrs. The toughness KIC in air was measured and the periods before breakage were measured for loads equal to 75% of K1C. In both cases, the samples resisted for more than 500 hrs before breakage. This is a good result, and embodiments of the invention therefore do not degrade the resistance to corrosion under stress as compared with the reference steels without Co.

[0110] The steels according to embodiments of the invention may therefore be substituted in a satisfactory mechanical way for the steels of the 300M type, with additionally the fact that they have performances of corrosion resistance in a saline mist and in corrosion under stress which are quite favorable, since they are comparable with those of the stainless steels with which the 300M steels may conceivably be replaced.

[0111] It should be understood that in all this description, the solidified <<ingot>> which is cast from liquid metal may have any shape which may lead, after the diverse deformations, to a final product having the desired shape and dimensions for its use. In particular, the casting in a conventional ingot mold provided with a bottom and fixed side walls is only one of the possible ways for proceeding, and the different methods for continuous casting in a bottomless ingot mold with fixed or movable walls may be used for producing the solidification of the "ingot".

[0112] An alternative solution to the one which has just been described is to carry out the sequence of heat treatments on a semi-finished product stemming not from a hot rolled transformed ingot, by rolling, forging, die-stamping or other treatments, but on a sintered semi-finished product manufactured by powder metallurgy, to which it would therefore be possible to directly give an optionally complex shape, and dimensions very close to that of the definitive part. The powder used is a metal powder which has the composition of the steel according embodiments of to the invention. In its case, homogenization of the sintered semi-finished product is not necessary. But the manufacturing process may include prior to the sintering strictly speaking, as this is standard for one skilled in the art, a pre-sintering step carried out under less severe conditions as the sintering in terms of temperature and/or duration. Generally, the sintering process is conducted like one skilled in the art would do by using his/her usual knowledge.

1-28. (canceled)

29: A martensitic stainless steel, comprising a composition, in weight percentages:

trace amountFe≤0.030%;
trace amountSi≤0.25%;
trace amountMn≤0.25%;
trace amountS≤0.020%;
trace amountP≤0.040%;
8%≤N≤14%;
8%≤Cr≤14%;
1.5%≤Mo+W≤3.0%;
1.0%≤Al≤2.0%;
0.5%≤Ti≤2.0%;
2%≤Co≤9%;
trace amountN≤0.030%;
trace amountO≤0.020%;
the remainder being iron and impurities resulting from the steelmaking;
and its martensitic transformation beginning temperature Ms calculated by the formula

\[
Ms = 1302 - 28SI - 50Mn - 63Ni - 42Cr - 30Mo + 20Al - 12Co + 25Cu + 10(Ti + 4(Cr + N))
\]
wherein the contents of the different elements are expressed in weight percentages, is greater than or equal to 50°C, preferably greater than or equal to 75°C.

30: The martensitic stainless steel according to claim 29 wherein trace amount ≤Cs ≤0.010%.
31: The martensitic stainless steel according to claim 29 wherein trace amount ≤Si ≤0.10%.
32: The martensitic stainless steel according to claim 29 wherein trace amount ≤Mn ≤0.10%.
33: The martensitic stainless steel according to claim 29 wherein trace amount ≤S ≤0.005%.
34: The martensitic stainless steel according to claim 29 wherein trace amount ≤P ≤0.020%.
35: The martensitic stainless steel according to claim 29 wherein ≤N ≤12.5%.
36: The martensitic stainless steel according to claim 29 wherein ≤Cr ≤10%.
37: The martensitic stainless steel according to claim 29 wherein ≤Mo+W ≤2.5%.
38: The martensitic stainless steel according to claim 29 wherein ≤Al ≤1.5%.
39: The martensitic stainless steel according to claim 29 wherein ≤Ti ≤1.5%.
40: The martensitic stainless steel according to claim 29 wherein ≤Co ≤0.5%.
41: The martensitic stainless steel according to claim 29 wherein ≤Co ≤3.50%.
42: The martensitic stainless steel according to claim 29 wherein trace amount ≤N ≤0.0005%.
43: The martensitic stainless steel according to claim 29 wherein trace amount ≤O ≤0.0050%.
44: The martensitic stainless steel according to claim 29 wherein ≤Al ≤2.0%.
45: The martensitic stainless steel according to claim 29 wherein ≤Al ≤1.5%.
46: The martensitic stainless steel according to claim 29 wherein ≤Al ≤1.5%.

\[ \text{Cr} \text{eq} = \text{Cr} + 2\text{Si} + 5\text{Mo} + 1.5\text{Ti} + 5.5\text{Al} + 0.6\text{W} \]
\[ \text{Ni} \text{eq} = 2\text{Ni} + 0.5\text{Mn} + 3\text{Cr} + 25\text{N} + 1.5\text{Cu} \]

47: The martensitic stainless steel according to claim 29 wherein the proportion of delta ferrite in its microstructure is less than or equal to 1%.
48: A method for manufacturing a part in martensitic stainless steel comprising:

preparing a semi-finished product in steel having the composition according to claim 29 by one of the following methods:

a liquid steel having the composition according to claim 29, is prepared and from the liquid steel, an ingot is cast and solidified and is transformed into a semi-finished product by at least one hot transformation;

a sintered semi-finished product in a steel having the composition according to claim 29 is prepared by power metallurgy;

achieving a complete solution heat treatment of the semi-finished product in the austenite domain, at a temperature comprised between 800 and 940°C;

quenching of the semi-finished product down to a final quenching temperature of less than or equal to −60°C;

and

carrying out an ageing between 450 and 600°C for 4 to 32 h.

49: The method according to claim 48 wherein the quenching of the semi-finished product is performed down to a final quenching temperature of less than or equal to −75°C.

50: The method according to claim 48 wherein an ingot is cast and solidified, and between the solidification of the ingot and the solution heat treatment of the semi-finished product, homogenization of the ingot or of the semi-finished product is carried out at 1,200-1,300°C for at least 24 h.

51: The method according to claim 48 wherein between the quenching and the ageing, a cold transformation of the semi-finished product is achieved.

52: The method according to claim 48 wherein the quenching is carried out in two steps, in two different quenching media.

53: The method according to claim 52 wherein the first quenching step is carried out in water.

54: The method according to claim 48 wherein the liquid steel is prepared by a dual treatment by melting in vacuo, the second treatment in vacuo being an ESR or VAR re-melting treatment.

55: A martensitic stainless steel part, wherein it was prepared by the method according to claim 48.

56: The martensitic stainless steel part according to claim 55 wherein the martensitic stainless steel part is an aeronautical structural part.

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