FIG. 2

FIG. 3
WELDABLE, CORROSION-RESISTING STEEL

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Invention relates to a hardenable, corrosion-resistant steel, preferably cast steel, which possesses a combination of good weldability and good mechanical properties hitherto never attained and to a process for the preparation of said steel. Such a steel is very useful, for instance, for the manufacture of items such as cast blanks for blades for impellers in water turbines in which a combination of good physical properties and corrosion resistance as well as the possibility of welding is desirable. For such purpose, the so-called 13 chromium steel has hitherto been most widely used.

The typical analyses of these conventional 13 chromium steels are normally: carbon, 0.10-0.25%; chromium, 11-14%; nickel, 0-1.5%, and with ordinary silicon and manganese contents. These steels are usually used after normalizing and subsequent annealing, or after hardening with subsequent tempering at a comparatively high temperature ("hardening and tempering"). In the normal condition, these steels have an ultimate tensile strength in the range of 60-70 kg./mm²; and an impact strength at room temperature according to Charpy V in the range of 2.5 kg./cm².

Due to the great hardenability of these steels their weldability, however, is poor. This is a consequence of the fact that in the course of welding a brittle martensitic transformation zone is created on both sides of a weld. Because of the great hardenability of the steels, this zone cannot be eliminated to any major degree through welding at higher working temperatures (preheating). Even if the work piece is preheated to a high temperature before welding and then allowed to cool directly to room temperature after the welding, there will be martensitic formation in the transformation zone.

The martensitic formation, which per se is cause for brittle material sections, becomes especially objectionable and dangerous because of the possibility of cracking from the hydrogen embrittlement in the transformation zone at the weld. As the hydrogen content in the weld metal to a great extent diffuses into the surrounding base material sections, the transformation zones are further embrittled, and hardening cracks in the form of so-called underbead cracking along the welds are very difficult to avoid.

It has therefore hitherto been necessary to carry out complicated operations in connection with the welding of these 13 chromium steels, e.g., by starting with buttering of all groove surfaces with austenitic electrodes normally of the type 19 chromium/9 nickel/2.5 molybdenum. Such buttering is carried out at a working temperature of 200-300° C. after which a subsequent heat treatment at high temperature is applied. A "subsequent heat treatment" means that the work piece is placed directly (from the working temperature into a furnace without first having been allowed to cool down to a lower temperature (so-called "direct annealing"). The final welding is usually carried out also with austenitic electrodes of the said type and at increased working temperatures, after which, if possible, the final welding is also followed by annealing. For practical reasons, however, it is often very hard to carry out the final annealing directly after the welding without an intermediate cooling step.

From the point of view of structure, the steels with carbon contents and nickel contents within the upper portion of the previously mentioned analysis range are designated as martensitic, i.e., entirely hardenable. Steels with carbon contents or nickel contents within the lower portion of the analysis range are ferritic-martensitic. This means that they cannot, at any temperature, be entirely austenitized and consequently cannot be given an entirely martensitic structure on hardening. The quantity of ferrite in the structure in a typical ferritic-martensitic steel of the said type can amount, e.g., to 30-50%.

Because of the greater hardenability of the 13 chromium steels, the above-mentioned complications also apply to the ferritic-martensitic types of steel. These have, in addition, a very great grain growth in the ferrite phase in the transformation zones. Such coarse-grained ferrite is also particularly brittle.

If a corrosion resistant steel with good weldability is desired, the so-called 18 chromium/8 nickel steel is often used. This is the traditional austenitic stainless steel which can be welded without preheating and without subsequent annealing, but it is not suitable when there are requirements for other desirable physical properties, because it has an ultimate tensile strength of 50-60 kg./mm² and a yield point of 18-25 kg./mm². Consequently, structures made of this material will be very heavy; and,
in addition, extremely expensive because of the heavy weight and the high price per weight unit thereof.

According to the present invention, it is now possible to combine good weldability and good mechanical properties for a corrosion resistant steel. This advantage is achieved by using a specific alloy composition in combination with a very specific heat treatment. The hardenable, corrosion resistant steel with good weldability and good mechanical properties according to the present invention contains 11–14% chromium, 4–8% nickel, 0.03–0.25% carbon, 0.25–2.00% manganese, 0.10–0.70% molybdenum, the remainder being iron with the usual elements of impurities and accessory elements, the carbon content of said steel being low when the chromium content thereof is low, the ratio of the nickel equivalent, calculated as (percent nickel—0.5×percent manganese), and the chromium equivalent, calculated as (percent chromium—15×percent carbon)÷1.5×percent carbon), in the steel ranging from 0.4 to 1.0, the steel having been heat treated to effect a complete austenitizing followed by a cooling to room temperature and then having been reheated to a temperature within the range of 550 °C–650 °C. The steel in accordance with the invention preferably contains 0.05–0.10% carbon, 0.20–0.40% silicon, 0.80–2.00% manganese and 5–7% nickel. The fact that the carbon content must be kept low when there is a low chromium content is due to the requirement for corrosion resistance, as the steel binds the chromium (=15×the carbon content) in carbidies, and the chromium content in the base material is then reduced. If there is high carbon content and a low chromium content, there is a risk that the chromium content in the base material will be below the limit value for good corrosion resistance.

A steel produced in accordance with the present invention possesses good mechanical properties. Its tensile strength lies within the range of 85–95 kg/mm², and the yield point within the range of 55–75 kg/mm². In addition, the impact strength within the high-value lies within the range of 11–13 kg/cm² and with the lower transition temperature of less than —80 °C, and in many cases within the range of —100 to —120 °C. Moreover, the steel according to the present invention not only has a very good weldability, but it can be welded without any special precautions in form of preheating or subsequent heat treatments, and nevertheless without risk for the formation of cracks.

The explanation why the above-mentioned very unexpected combination of good mechanical properties and good weldability is obtained in this case is that, when a steel having the above-mentioned very specific alloy composition is given the previously described very specific heat treatment, a new type of austenite is induced to an extent of between about 15 and 40%. This new type of induced austenite gives the steel a good weldability, without any decrease of the mechanical properties of the steel, as is usually the case with the hitherto usual type of austenite. Although it has been known that austenite can appear after the heat treatment of a steel, the type of austenite that was hitherto been encountered in connection with heat treatment is of a type different from that of the austenite induced during the specific reheating in the present invention. The previously known type of austenite is that which will be retained after the direct hardening of a steel. As has already been explained, such a type of austenite has a very bad influence on the mechanical properties of the steel in the way, e.g., that it decreases the tensile strength. The austenite induced by the reheating according to the present invention, on the other hand, does not have any bad influence on the mechanical properties of the steel. On the contrary, it increases the extent said properties. Moreover, the hitherto usual type of austenite obtained after hardening a steel is not stable during rapid temperature changes, whereas the austenite induced by the reheating according to the present invention is stable. This property is very essential for welds. During the very rapid temperature changes which occur in welding the austenite induced by the reheating according to the present invention remains quite stable, whereas austenite retained after hardening does not remain stable under the same temperature changes. Consequently, although it is possible to obtain retained austenite after hardening (e.g., by using a high carbon content and a high hardening temperature), such retained austenite does not improve the weldability of the steel, as this type of retained austenite is not stable during the rapid temperature changes which always occur during welding.

It is, therefore, very essential to distinguish between the austenite retained after hardening (hereafter called "retained austenite") and the type of austenite induced during the very specific reheating according to the present invention (hereafter called "induced austenite"). The retained austenite is a more or less continuous phase with martensite being present therein as inclusions. In contrast thereto, according to our investigations, however, the induced austenite constitutes in martensite as the continuous phase. Moreover, it appears that the induced austenite has a greater concentration gradients than the retained austenite. In one very important respect, however, the difference between the two types of austenite is very marked. The retained austenite has a very bad influence on the mechanical properties of the steel, whereas the induced austenite, on the contrary, improves said mechanical properties.

The amount of retained austenite depends, among other things, on the amount of nickel content. An increase of the nickel content results in an increase of the amount of retained austenite.

If a hardened steel is reheated, the hardness at room temperature is normally decreased; and this is due to the formation of tempered martensite. When the reheating temperature after hardening, is increased at a certain point, the hardness of the steel after cooling to room temperature no longer decreases but instead increases. The explanation of this minimum function is that, at a certain temperature, the tempered martensite to some extent is transformed into austenite which, after cooling to room temperature, gives rise to untempered martensite with an increased hardness as a consequence. The consensus of metallurgists hitherto has been that one should avoid reheating to the temperature point at which partial transformation of tempered martensite into austenite takes place, because of the subsequent formation of untempered martensite on cooling, which would result only in an undesired increase in hardness and brittleness.

However, we have now discovered that by applying the very specific alloy composition of the present invention to a very specific reheating temperature range it very unexpectedly became possible to obtain stable induced austenite in a matrix of tempered martensite to an extent which gives the steel very good weldability without destroying the good mechanical properties.

The temperature (Ao) at which the formation of austenite during reheating starts is also a function of the nickel content in such a way that an increase of the nickel content will give a lower temperature for the transformation of tempered martensite into austenite. Hitherto, it had been thought that all the austenite formed during reheating underwent direct transformation to untempered martensite on cooling to room temperature. We have discovered, however, that with sufficiently high nickel contents the first formed part of austenite remains stable down to and even below room temperature. This totally unexpected phenomenon occurs only within a very restricted temperature range. An increase of the temperature for reheating above the upper limit of this critical range results in the formation of austenite which is not
Stable on cooling to room temperature. The maximum amount of stable induced austenite which it is possible to obtain in the critical temperature range increase from zero upwards, provided that the nickel content is increased above a certain level.

With nickel contents above the upper limit of the range disclosed in this application, the amount of retained austenite (directly after hardening) will be so large that the effect discussed above may not be seen.

To illustrate the above-discussed conditions some investigations with several different types of steel are now set forth.

The steels used in these investigations had the following compositions:

<table>
<thead>
<tr>
<th>Steel No.</th>
<th>C, Per-cent</th>
<th>Si, Per-cent</th>
<th>Mn, Per-cent</th>
<th>P, Per-cent</th>
<th>S, Per-cent</th>
<th>Cr, Per-cent</th>
<th>Ni, Per-cent</th>
<th>Stable austenite formed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.67</td>
<td>0.41</td>
<td>0.88</td>
<td>0.08</td>
<td>0.00</td>
<td>12.5</td>
<td>1.9</td>
<td>30%</td>
</tr>
<tr>
<td>2</td>
<td>0.60</td>
<td>0.35</td>
<td>0.84</td>
<td>0.08</td>
<td>0.00</td>
<td>13.7</td>
<td>2.1</td>
<td>35%</td>
</tr>
<tr>
<td>3</td>
<td>0.69</td>
<td>0.33</td>
<td>0.88</td>
<td>0.08</td>
<td>0.00</td>
<td>12.1</td>
<td>2.0</td>
<td>40%</td>
</tr>
<tr>
<td>4</td>
<td>0.69</td>
<td>0.33</td>
<td>0.87</td>
<td>0.05</td>
<td>0.00</td>
<td>12.0</td>
<td>2.1</td>
<td>45%</td>
</tr>
<tr>
<td>5</td>
<td>0.67</td>
<td>0.33</td>
<td>1.25</td>
<td>0.08</td>
<td>0.00</td>
<td>13.0</td>
<td>2.1</td>
<td>50%</td>
</tr>
<tr>
<td>6</td>
<td>0.67</td>
<td>0.44</td>
<td>0.56</td>
<td>0.08</td>
<td>0.00</td>
<td>12.1</td>
<td>2.1</td>
<td>55%</td>
</tr>
<tr>
<td>7</td>
<td>0.68</td>
<td>0.32</td>
<td>0.42</td>
<td>0.00</td>
<td>0.00</td>
<td>12.3</td>
<td>2.1</td>
<td>60%</td>
</tr>
</tbody>
</table>

These steels were all heated to 1000° C, during 3 hours and then allowed to cool to room temperature. Then they were annealed at various temperatures and their austenite contents at room temperature then determined. The austenite contents in these steels were also determined before annealing directly after cooling from the austenitizing temperature.

The steel No. 7 containing 9.5% nickel at room temperature directly after cooling, had about 40% retained austenite. Steel No. 1 which corresponds to conventional 13% chromium steel and has 1.2% nickel, at room temperature directly after hardening, is devoid of retained austenite. Also, the steels of the present invention, e.g., corresponding to steel 5, at room temperature after hardening, are devoid of or contain but little retained austenite.

When the nickel content of the steel is low (e.g., those corresponding to steels 1 and 2), all the austenite formed on reheating is converted directly into untempered martensite, when the steel is cooled to room temperature.

When the steel contains 2.8% nickel (No. 3) a certain formation of stable austenite (which is not converted into untempered martensite on cooling) occurs upon reheating to a very narrow temperature range of about 600° C. Further, the amount of stable austenite formed in this case is less than 5% and thus is not sufficient to give the steel the desired good weldability. As previously stated, it is necessary to obtain an austenite content of between 15 and 40% to be sure of attaining the desired good weldability together with good mechanical properties.

Steel No. 4 with a nickel content of 4.1% gives a maximum amount of about 15% of stable austenite formed during reheating. Thus, this nickel content is the lower limit of the amount required to obtain the desired effect of this invention.

For the steel 5 containing 6.1% nickel, the amount of stable austenite is approximately 30%. Also, steel No. 6, containing 8.1% nickel, gives a rather great amount of austenite formed during reheating. But, in the case of the last mentioned steel, an appreciable amount of retained austenite (directly after hardening) is present. This type of retained austenite, as previously stated, has an undesirable effect on the mechanical properties of the steel. Due to this fact a nickel content of 8% is the upper limit for obtaining the desired combination of good weldability and good mechanical properties.

For steel 7, which contains 9.5% nickel, the amount of retained austenite is still greater. The bad effect on the mechanical properties of this steel is so marked that the steel will not satisfy the requirement for the desired properties.

The temperature range which produces the desired amount of 15-40% of induced austenite (formed on reheating) is very critical.

FIG. 1 shows that in foregoing steel No. 5 the percentage of austenite at room temperature is a function of the annealing temperature. In curve A the annealing is carried out during 3 hours and followed by cooling in air; in curve B two heating periods, each of 3 hours duration with cooling to room temperature between the heatings is used; and in curve C there is one heating for 24 hours.

At a temperature below 550° C, the transformation from tempered martensite to austenite and at temperatures above 650° C, the transformation of the formed austenite into untempered martensite upon subsequent cooling it too great to give the desired amount of stable austenite left.

FIG. 2 is a reproduction (enlarged 200×) of a photomicrograph of a steel not within the scope of this invention. This photograph shows the retained austenite (light areas) in the steel, the darker needle-formed areas being the typical martensite needles. The form designated as retained austenite exists in a continuous phase with martensite islands being the discontinuous phase. As the austenite is present in a coherent, continuous phase, this steel has poor physical properties.

FIG. 3 is a reproduction (enlarged 200×) of a photomicrograph of a steel of this invention. The induced austenite obtained by applying the process of this invention exists in a finely distributed form in the martensite matrix.

FIG. 4 is the same photomicrograph reproduction as in FIG. 3, except that it has been enlarged 600×. At this enlargement the austenite is seen in the form of light, isolated parts in the darker, needle-shaped martensite matrix. This form of induced austenite, present in a finely dispersed condition in the martensite matrix, gives the unexpected result of this invention, i.e., with a stainless steel it has now been possible to obtain essentially improved weldability in relation to the previously used 13 Cr steel without any loss in other desirable physical properties which, on the contrary, have been improved in certain respects.

The present invention is illustrated by the following examples:

**Example 1**

<table>
<thead>
<tr>
<th>Steel containing as alloying elements</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.10</td>
</tr>
<tr>
<td>Si</td>
<td>0.20</td>
</tr>
<tr>
<td>Mn</td>
<td>0.36</td>
</tr>
<tr>
<td>Cr</td>
<td>13.1</td>
</tr>
<tr>
<td>Ni</td>
<td>5.2</td>
</tr>
</tbody>
</table>

and the remainder Fe with normal impurities was used for casting of a blank with the following dimensions:

28 x 170 x 315 mm.

The blank was given the following heat treatment:

- Heating to 1000° C.
- Constant temperature for 3 hours.
- Cooling in air to room temperature.
- Heating to 600° C.
- Constant temperature for 1 hour.
- Cooling in air to room temperature.

Thereafter the blank was cold welded clamped to a similar blank using an electrode which gave the following weld metal:

<table>
<thead>
<tr>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
</tr>
<tr>
<td>Si</td>
</tr>
<tr>
<td>Mn</td>
</tr>
<tr>
<td>Cr</td>
</tr>
<tr>
<td>Ni</td>
</tr>
<tr>
<td>Mo</td>
</tr>
</tbody>
</table>

and the remainder Fe with the normal impurities.
3,378,367

The blank had the following physical properties in the uninfluenced base material:

\[ \sigma_0 = 75 \text{ kg/mm}^2 \]
\[ \sigma_B = 93 \text{ kg/mm}^2 \]
\[ \delta_0 = 17.0\% \]
\[ \psi = 55.2\% \]

In the weld or in the transformation zones adjacent to the weld there were no cracks. The said zones contained approximately 25% austenite.

Example 2

A steel containing as alloying elements

<table>
<thead>
<tr>
<th>Element</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.05</td>
</tr>
<tr>
<td>Si</td>
<td>0.39</td>
</tr>
<tr>
<td>Mn</td>
<td>0.82</td>
</tr>
<tr>
<td>Cr</td>
<td>13.3</td>
</tr>
<tr>
<td>Ni</td>
<td>6.6</td>
</tr>
</tbody>
</table>

and the remainder Fe with the normal impurities was used for casting of a blank with the same dimensions as the blanks according to Example 1 and was subjected to the same heat treatment and welded in the same way.

The blank had the following physical properties:

\[ \sigma_0 = 50.3 \text{ kg/mm}^2 \]
\[ \sigma_B = 87.9 \text{ kg/mm}^2 \]
\[ \delta_0 = 19.0\% \]
\[ \psi = 51.0\% \]

The blank had the same good weldability and the transformation zones contained approximately 30% austenite.

Example 3

A steel containing as alloying elements

<table>
<thead>
<tr>
<th>Element</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.07</td>
</tr>
<tr>
<td>Si</td>
<td>0.63</td>
</tr>
<tr>
<td>Mn</td>
<td>1.38</td>
</tr>
<tr>
<td>Cr</td>
<td>6.1</td>
</tr>
</tbody>
</table>

and the remainder Fe with the normal impurities was used for casting of a 90 kg test bar blank.

The blank was submitted to the following heat treatment:

Heating to 1000°C.
Constant temperature for 3 hours.
Cooling in air to room temperature.

Heating to 575°C.
Constant temperature for 3 hours.
Cooling in air to room temperature.

The blank had the following physical properties:

\[ \sigma_0 = 62.5 \text{ kg/mm}^2 \]
\[ \sigma_B = 96.3 \text{ kg/mm}^2 \]
\[ \delta_0 = 17\% \]
\[ \psi = 57\% \]

A 20 mm deep V groove was milled in the blank, which was filled with welding material having the following composition:

<table>
<thead>
<tr>
<th>Element</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.06</td>
</tr>
<tr>
<td>Si</td>
<td>0.6</td>
</tr>
<tr>
<td>Mn</td>
<td>0.6</td>
</tr>
<tr>
<td>Cr</td>
<td>19.4</td>
</tr>
<tr>
<td>Ni</td>
<td>9</td>
</tr>
<tr>
<td>Mo</td>
<td>2.5</td>
</tr>
</tbody>
</table>

and the remainder Fe with the normal impurities.

The welding was carried out without preheating. Two test bars for tensile tests were taken over the weld. During the testing the rupture took place in the center of the weld. This was also considerably deformed in the immediate vicinity of the fusion line. No signs of cracking or ruptures could be noted in the fusion lines or in the heat-influenced base material. The austenite content in the base material varied between 25 and 35%, which values were also found in the transformation zones adjacent to the weld.

Example 4

A steel containing as alloying elements

<table>
<thead>
<tr>
<th>Element</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.07</td>
</tr>
<tr>
<td>Si</td>
<td>0.47</td>
</tr>
<tr>
<td>Mn</td>
<td>0.58</td>
</tr>
<tr>
<td>Cr</td>
<td>13.2</td>
</tr>
<tr>
<td>Ni</td>
<td>5.9</td>
</tr>
</tbody>
</table>

and the remainder Fe with the normal impurities was used for casting of a 90 kg blank for test bars.

The blank was subjected to the following heat treatment:

Heating to 1000°C.
Constant temperature for 3 hours.
Cooling in air to room temperature.

Heating to 575°C.
Constant temperature for 3 hours.
Cooling in air to room temperature.

The blank had the following physical properties:

\[ \sigma_0 = 69.5 \text{ kg/mm}^2 \]
\[ \sigma_B = 93.0 \text{ kg/mm}^2 \]
\[ \delta_0 = 19\% \]
\[ \psi = 60\% \]

The austenite content was 18%.

Example 5

A steel containing as alloying elements

<table>
<thead>
<tr>
<th>Element</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.07</td>
</tr>
<tr>
<td>Si</td>
<td>0.47</td>
</tr>
<tr>
<td>Mn</td>
<td>0.62</td>
</tr>
<tr>
<td>Cr</td>
<td>13.6</td>
</tr>
<tr>
<td>Ni</td>
<td>7.0</td>
</tr>
</tbody>
</table>

and the remainder Fe with the normal impurities was used for casting a 90 kg blank for test bars. The blank was subjected to the same heat treatment as the one according to Example 4.

The blank had the following physical properties:

\[ \sigma_0 = 69.5 \text{ kg/mm}^2 \]
\[ \sigma_B = 96.2 \text{ kg/mm}^2 \]
\[ \delta_0 = 19\% \]
\[ \psi = 59\% \]

The austenite was 22%.

The symbols \( \sigma_{0.2} \) and \( \sigma_B \) designate tensile strength properties as follows:

\( \sigma_{0.2} \) indicates the stress at which a non-proportional elongation equal to 0.2% of the original gauge length occurs (see ISO Rec. 882, 1st ed., February 1959), designated tensile strength properties as follows:

\( \sigma_0 \) indicates the tensile strength (Rm), viz. a maximum load divided by the original cross section area of the test piece, i.e., the stress corresponding to the maximum load (see ISO Rec. 82, Item 3.10).

\( \delta_0 \) indicates percentage elongation after fracture \( A \), viz. the permanent elongation of the gauge length after the fracture. \( L_b = 5L_0 \), expressed as a percentage of the original gauge length \( L_0 \), when said original gauge length \( L_0 \) is five times the diameter of the test piece (see ISO Rec. 82, Item 3.3).

\( \psi \) indicates percentage reduction of area (Z), viz. the ratio of the maximum change in the cross-section area, which has occurred during the test, to the original cross-section area, expressed as a percentage (see ISO Rec. 82, Item 3.4).
It will be understood that the foregoing description of the invention and the examples set forth are merely illustrative of the principles thereof. Accordingly, the appended claims are to be construed as defining the invention within the full spirit and scope thereof.

We claim:

1. A weldable, hardenable and corrosion-resisting steel consisting essentially of:

   carbon ........................................... 0.03–0.25
   manganese ....................................... 0.25–2.00
   chromium ........................................... 11–14
   nickel .............................................. 4–8
   silicon .............................................. 0.10–0.70

   the balance substantially iron, wherein:
   (a) the carbon content is low when the chromium content is low; and
   (b) the ratio of the nickel equivalent, calculated as
       (percent Ni + 0.5% Mn) to the chromium equivalent, calculated as
       (percent Cr – 15 × % C + 1.5 × percent Si), ranges from 0.4 to 1.0,

2. A steel in accordance with claim 1, wherein the essential alloying elements are present in an amount of:

   Percent
   carbon ........................................... 0.05–0.10
   manganese ....................................... 0.80–2.00
   chromium ........................................... 11.0–14
   nickel .............................................. 0.20–0.40
   silicon .............................................. 0.20–0.40

3. A steel in accordance with claim 1, wherein the essential alloying elements are present in an amount of:

   Percent
   carbon ........................................... 0.10
   manganese ....................................... 0.36
   chromium ........................................... 13.1
   nickel .............................................. 0.82
   silicon .............................................. 0.20

4. A steel in accordance with claim 1, wherein the essential alloying elements are present in an amount of:

   Percent
   carbon ........................................... 0.05
   manganese ....................................... 0.36
   chromium ........................................... 13.3
   nickel .............................................. 0.82
   silicon .............................................. 0.20

5. A steel in accordance with claim 1, wherein the essential alloying elements are present in an amount of:

   Percent
   carbon ........................................... 0.07
   manganese ....................................... 0.58
   chromium ........................................... 13.2
   nickel .............................................. 5.9
   silicon .............................................. 0.47

6. A steel in accordance with claim 1, wherein the essential alloying elements are present in an amount of:

   Percent
   carbon ........................................... 0.07
   manganese ....................................... 1.58
   chromium ........................................... 12.8
   nickel .............................................. 6.1
   silicon .............................................. 0.63

7. A steel in accordance with claim 1, wherein the essential alloying elements are present in an amount of:

   Percent
   carbon ........................................... 0.07
   manganese ....................................... 0.62
   chromium ........................................... 13.6
   nickel .............................................. 7.0
   silicon .............................................. 0.47

8. A steel in accordance with claim 1, which has been heat treated as follows:
   (1) heating the steel to effect a complete austenitizing, 
   (2) cooling to room temperature, and
   (3) reheating to a temperature in the range of about 550–650° C.

References Cited

UNITED STATES PATENTS
1,404,907 1/1922 Strauss ------- 148—136 XR
2,747,989 5/1965 Kirkby ------- 75—128
2,802,755 8/1957 Bloom.
2,903,368 9/1959 Waxwell.

OTHER REFERENCES

HYLAND BIZOT, Primary Examiner.
P. WEINSTEIN, Assistant Examiner.