Steel for surface-treated mechanical parts with high characteristics, and mechanical parts in this steel and manufacturing method thereof

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C21D 8/00 (2006.01)
C22C 38/54 (2006.01)

Steel for which the composition is, in weight percentages: 0.35%≤C≤0.50%; 0.30%≤Mn≤1.50%; trace amounts ≤Cr≤1.50%; 0.05%≤Mo≤0.50%; 0.15%≤Si≤1.20%; trace amounts ≤Ni≤1.0%; trace amounts ≤Cu≤1.0%; trace amounts ≤V≤0.35%; trace amounts ≤Al≤0.10%; trace amounts ≤B≤0.005%; trace amounts ≤Ti≤0.10%; trace amounts ≤Nb≤0.10%; trace amounts ≤Sn≤0.15%; trace amounts ≤S≤0.010%; trace amounts ≤Te≤0.030%; trace amounts ≤Se≤0.050%; trace amounts ≤Bi≤0.050%; trace amounts ≤Pb≤0.100%; trace amounts ≤N≤0.020%; the remainder being iron and impurities resulting from the elaboration, and the C, Mn and Cr contents being such that 830-270 C %≤90 Mn %≤70 Cr %≤620.
**Figure 1 - PRIOR ART**

- **Bearing**
- **Fillet**

**Hardness (HV 0.5)** vs **Depth (mm)**

**Figure 2**
STEEL FOR SURFACE-TREATED MECHANICAL PARTS WITH HIGH CHARACTERISTICS, AND MECHANICAL PARTS IN THIS STEEL AND MANUFACTURING METHOD THEREOF

[0001] The invention relates to steels for mechanical parts with high characteristics, obtained by hot shaping (notably forging or rolling), and being subject, in their manufacturing range, to a heat treatment for surface hardening with the purpose of obtaining a microstructure with high hardness over a controlled depth.

[0002] The parts made with these steels may as non-limiting examples be racks machined from rolled and then made into slugs, or crankshafts of automobile vehicles.

[0003] In order to make parts with high mechanical characteristics, presently the use of steel grades so called "micro-alloyed" steels is known, which, after forging or hot rolling, give the possibility of obtaining mechanical characteristics which are superior to those of the usual ferrito-perlitic grades without however requiring any additional heat treatment.

[0004] Thus, the grade 38MnSiV5 (which contains about in weight %, 0.38% of C, 1.25% of Mn, 0.6% of Si, 0.12% of V) is widely used for manufacturing automobile crankshafts, since it allows, considering the typical dimensions of the part, tensile strength Rm to be obtained of the order of 900 MPa at best. Moreover, the carbon content of 0.38% guarantees the obtaining in a surface area of the product, of hardnesses greater than or equal to 620-650 HV after executing a localized heating surface treatment by induction followed by quenching.

[0005] However, it is also well known that ferrito-perlitic microstructures are not the best suitable for fast local hardening treatments such as surface quenching by induction. Indeed, the pro-eutectoid ferrite areas, the size of which is typically measured in tens of pm, form strongly carbon-depleted areas. In order to retrieve a homogenous austenite after quenching, the diffusion of carbon is therefore required over the corresponding lengths. If this is not a problem for conventional austenitization methods, the very short times used for quenching by induction (or the laser surface hardening which is an alternative solution) that the old ferritic grains may remain carbon-depleted upon quenching. The resulting microstructure is then heterogeneous.

[0006] If the mechanical characteristics in the bulk of 38MnSiV5 (or of other micro-alloyed ferrito-perlitic grades) are estimated to be insufficient for the contemplated application, so called quenching-annealing martensitic grades, for example the grade 42CrMo4 (which contains about 0.42% of C, 1% of Cr, 0.2% of Mo). Subsequently to forging, rolling, or to any other hot shaping method, the manufactured parts with these grades require an austenitization and quenching heat treatment, for which the financial drawbacks do no longer need to be demonstrated in a context of an always increasing cost of energy. One advantage is nevertheless that martensitic microstructures, except if they are strongly annealed, austenitize much more easily than ferrito-perlitic structures.

[0007] Today, there exist many steel grades giving the possibility of obtaining high mechanical characteristics on a forged part or a raw rolling bar, without use of any controlled cooling or subsequent heat treatment. These grades, described in the documents mentioned in table 1, are based on obtaining a microstructure which is in majority bainitic after shaping. As shown in Table 1, they are very widely based on carbon contents of less than or equal to 0.35%. These contents are weight contents like all the ones which will be given in this text.

<table>
<thead>
<tr>
<th>Document</th>
<th>Claimed C contents (%)</th>
<th>C contents (%) of the examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>EP-B-2 245 290</td>
<td>0.18-0.25</td>
<td>0.19-0.22</td>
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<tr>
<td>EP-A-2 103 704</td>
<td>0.20-0.25</td>
<td>0.22</td>
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<tr>
<td>EP-A-2 453 027</td>
<td>0.15-0.30</td>
<td>0.04-0.11</td>
</tr>
<tr>
<td>EP-A-1 905 857</td>
<td>0.15-0.30</td>
<td>0.22</td>
</tr>
<tr>
<td>EP-B-1 365 587</td>
<td>0.02-0.10</td>
<td>0.08</td>
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<tr>
<td>EP-A-1780 293</td>
<td>0.08-0.25</td>
<td>0.21</td>
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<tr>
<td>EP-A-0 717 116</td>
<td>0.05-0.12</td>
<td>0.08</td>
</tr>
<tr>
<td>EP-A-0 775 756</td>
<td>0.05-0.12</td>
<td>0.08</td>
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<tr>
<td>EP-A-0 845 544</td>
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<tr>
<td>WO-A-2005/13856</td>
<td>0.10-0.35</td>
<td>0.15-0.25</td>
</tr>
<tr>
<td>EP-B-0 787 812</td>
<td>0.10-0.40</td>
<td>0.25-0.28</td>
</tr>
<tr>
<td>EP-A-1 426 453</td>
<td>0.06-0.35</td>
<td>0.06-0.24</td>
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</tbody>
</table>

[0008] Two of the previous examples are distinguished from the others. The first, EP-A-0 717 116, in fact does not concern the initial obtaining of the bainitic microstructure but the response to subsequent partial heating up of a part which would already have such a microstructure. The second, EP-B-0 787 812 actually concerns grades leading to a bainitic microstructure, but they have other limitations which will be discussed subsequently.

[0009] It is shortly recalled here that the surface hardening treatments concerned by the present invention are those which consist, in a first phase, of locally heating (and therefore often rapidly) the area close to the surface of the part, and then in a second phase, of quenching it in order to obtain in the vicinity of the surface, in the area heated up beforehand, a layer in majority formed with fresh martensite. The hardness attained in such an area is then essentially conditioned by the carbon content of the steel grade used. An HV hardness is usually obtained of the order of 400 to 500 for a C content of 0.1%, and an HV hardness of the order of 900 to 1,000 for a C content of 0.6%, with, between both of these ranges, a substantially linear hardness/C content relationship.

[0010] It is difficult to obtain reliably hardnesses of the order of 650-700 HV for carbon contents of less than 0.35-0.37% by weight. Now, these are specifically ranges of compositions for which at the present time there is no so-called <<bainitic>> solution.

[0011] As it was possible to see this previously, a bainitic grade having such carbon contents would either allow provision of improved mechanical core characteristics as compared with microalloyed ferrito-perlitic grades, or obtaining identical performances with the grades which are quenched-annealed without, however, requiring any heat treatment. Further, the bainitic microstructure lends itself well to fast austenitization and therefore provides an additional advantage as compared with ferrito-perlitic microstructures, as this will be demonstrated subsequently.

[0012] These <<bainitic solutions>> are however difficult to obtain for high carbon contents.

[0013] Of course, it is well known to one skilled in the art that, if there is total freedom in the choice of a heat treatment, it is possible to obtain on most special steels the
whole of the possible microstructures in a steel. As an example, the isothermal transformation at 400° C. of a carbon steel C50 may be contemplated for obtaining a bainitic microstructure. For this, in a first phase, the component must be austenitized and then quenched to the sought transformation temperature, at which it is maintained until complete transformation before letting it cool down to room temperature. This however requires, in order to avoid the formation of ferrite-perlite, cooling the part at a high rate, of the order of 100° C/s, between the austenitization temperature and the transformation temperature. Even with the use of salt baths for quenching, this constraint therefore limits the possibility of obtaining a bainitic structure in the whole of the part, to parts of very small dimensions (a thickness of a few millimeters).

[0014] It is therefore seen through this example that if the obtaining of a bainitic microstructure is always in principle possible, the joint limitations inherent to the application methods and to the dimensions of the parts are the ones which will very often generate difficulties in obtaining the structure, and will require adaptation of steel grades. Thus, in order to prevent the formation of ferrite-perlite in the previous example, it is necessary to increase the contents of alloy elements such as Mn, Cr, Mo. The risk is then that the bainitic transformation becomes so slow, that it is no longer possible during continuous cooling. Reduction of the carbon content is then imposed, since this is the element having the most pronounced effect on the transformation rate of austenite into bainite. This is why the totality of the solutions shown in Table 1 are preferentially oriented towards carbon contents of less than 0.25%, as this is seen on their exemplary applications.

[0015] The object of the invention is therefore to propose a novel steel grade having a carbon content compatible with the use of a surface treatment by induction followed by quenching (therefore ≥35%), and giving the possibility of obtaining superior mechanical characteristics after hot shaping. For this and more specifically, the steel grade should give the possibility of obtaining a microstructure which is in majority bainitic for parts with typical dimensions of 20 to 100 mm in thickness by natural cooling after hot rolling or hot forging, and of thereby attaining tensile strengths Rm of a minimum of 920 MPa (for a diameter of 50 mm), or at least 10% superior to what is obtained with the best ferrito-perlitic microalloyed solutions used identically.

[0016] It is specified that by <<microstructure in majority bainitic>>, in the scope of the invention, is meant the presence of at most 20% of martensite and/or ferrite-perlrite, but that the residual austenite is considered as an integral part of the bainitic microstructure.

[0017] Further it is specified that the morphologies of bainites sometimes called <<acinular ferrite>> or <<intra-granular bainite>> are not considered distinctly from the bainitic microstructure for the steels of the invention, and that the term of <<bainite>> should generally be understood, therefore excluding ferrite-perlite, Widmanstatten ferrite, or martensite.

[0018] For this purpose, the object of the invention is a steel for surface-treated mechanical parts with high characteristics, characterized in that its composition is, in weight percentages:

- [0019] 0.35%≤C≤0.50%;
- [0020] 0.30%≤Mn≤1.50%;
- [0021] trace amounts ≤Cr≤1.50%;
- [0022] 0.05%≤Mo≤0.50%;
- [0023] 0.15%≤Si≤1.20%;
- [0024] trace amounts ≤N≤1.0%;
- [0025] trace amounts ≤S≤0.10%;
- [0026] trace amounts ≤V≤0.35%;
- [0027] trace amounts ≤Ni≤0.10%;
- [0028] trace amounts ≤Al≤0.05%;
- [0029] trace amounts ≤Ti≤0.10%;
- [0030] trace amounts ≤B≤0.10%;
- [0031] trace amounts ≤Sn≤0.15%;
- [0032] trace amounts ≤As≤0.01%;
- [0033] trace amounts ≤Cu≤0.30%;
- [0034] trace amounts ≤Be≤0.05%;
- [0035] trace amounts ≤Sb≤0.50%;
- [0036] trace amounts ≤P≤0.10%;
- [0037] trace amounts ≤S≤0.20%;
- [0038] the remainder being iron and impurities resulting from the elaboration,

and the C, Mn and Cr contents being such that 830-270 C %-%. Mn %-%.Cr %<620.

[0040] It may contain trace amounts ≤Ni≤0.5%.
[0041] It may contain 0.15%≤Mo≤0.30%.
[0042] It may contain 0.005%≤Al≤0.10%.
[0043] It may contain 0.0005%≤B≤0.005%.
[0044] It may contain 0.005%≤Cu≤0.03%.
[0045] If it contains 0.0005 to 0.005% of B, it may contain trace amounts ≤N≤0.0080% with ≤Ti≤3.5 N.
[0046] It may contain 0.005%≤S≤0.15%.

[0047] The object of the invention is also a method for manufacturing a mechanical steel part, characterized in that it includes the following steps:

- [0048] a steel for which the composition is compliant with what has been described is cast and solidified;
- [0049] hot forming of said solidified steel is carried out in the austenitic domain, notably by forging or hot rolling, in order to obtain a hot formed semi-finished product;
- [0050] the hot formed semi-finished product is cooled at a rate giving it a bainitic structure containing a total of at most 20% of martensite and/or of perlrite and/or of ferrite;
- [0051] it is optionally proceeded with one or several machining operations for giving the part its intended dimensions;
- [0052] it is proceeded with a partial heat treatment with the purpose of locally obtaining a weakly or non-annealed martensitic microstructure;
- [0053] it is optionally proceeded with rectification for giving the part its final dimensions.

[0054] The partial heat treatment may be a surface treatment.

[0055] Said surface treatment may be a surface treatment by induction followed by local quenching.

[0056] The cooling of the hot formed semi-finished product may be followed by annealing at 200-400° C for 30 min to 8 h.

[0057] The partial heat treatment may be followed by annealing between 150 and 350° C.

[0058] Before or after the machining(s), it is possible to proceed with annealing carried out at 200-400° C for 1-2 hours.

[0059] The cooling following the hot forming of the semi-finished product may take place in calm air.

[0060] The cooling following the hot forming of the semi-finished product may take place in pulsed air.
The object of the invention is also a mechanical steel part, characterized in that it is obtained by the previous method.

This may be a rack machined from a bar which has been rolled then cut into slugs.

This may be a forged crankshaft whose grooves and/or crank pins and/or bearings have been reinforced by means of said partial heat treatment.

As this will have been understood, the invention is based on a well-defined steel composition and on its association with a metallurgical structure which in a very large majority is bainitic in the sense defined earlier, the latter may be obtained by simple means such as cooling in calm or pulsed air.

The invention will be better understood upon reading the description which follows, referring to the following figures;

FIG. 1 which shows the Hv hardness 0.5 measured from the surface towards the core of a groove of a crankshaft made in a reference steel of the 38MnSiV5 type, surface treated by quenching by induction, for two different positions in the treated area, i.e. a bearing and a general fillet.

FIG. 2 which shows hardness measurements comparable with those of FIG. 1 conducted on a steel according to the invention.

In association with the aforementioned method conditions, the grades of the present invention give the possibility of obtaining, tensile strengths Rm greater than or equal to 920 MPa at least and which may attain 1,150 MPa, on one hand, and hardnesses of the order of 650 Hv in the areas hardened by a treatment as described earlier (surface quenching by induction for example).

However, these grades in terms of mechanical properties in the bulk, after their forging and natural cooling, or in the raw hot rolling state after natural cooling, provide relatively low Re/Rm ratios, which vary between 0.55 and 0.70, expressing elasticity limits Re significantly less than those obtained on quenched-tempered grades of same mechanical strength. If necessary for the contemplated application of the part, this may be improved by using annealing at temperatures comprised between 200 and 400°C, or, in the case when addition of vanadium has been carried out in an amount of at least 0.1%, annealing at temperatures comprised between 550 and 680°C.

The selection of the composition ranges for the diverse elements of the grade according to the invention will now be justified. As stated, all the contents are given in weight percentages.

The C content is comprised between 0.35 and 0.50%. This interval, which up to now has been seen as being implicitly considered as not very suitable for obtaining a bainitic microstructure during natural cooling, is imposed by the requirement of obtaining a minimum hardness of about 600 Hv in the area concerned by the local treatment discussed earlier (induction, laser, etc.). Beyond 0.50%, obtaining a homogeneous bainitic microstructure becomes difficult or even impossible, without a very accurate control of the cooling path of the whole of the part which generally cannot be carried out on the industrial installations for manufacturing parts mainly concerned by the invention.

The Mn content is comprised between 0.30 and 1.50%. Manganese is used, together with chromium, for lowering the temperature Bs of the beginning of formation of bainite during continuous cooling. However, Mn significantly contributes to the formation of segregated bands, which would be, in the required range of carbon contents, particularly detrimental. Indeed, they may lead, depending on the cooling path, to the formation of martensitic bands of very high hardness. For this reason, the maximum Mn content is limited to 1.5%.

The Cr content is comprised between trace amounts and 1.5%. In the present invention, Cr is used in the same way as Mn, for lowering the temperature of the beginning of the bainitic transformation Bs.

The C, Mn and Cr contents further should be such that 830-270°C C.% 0-90 Mn % 70 Cr % 620. It will be noted that this value (noted as Bs’ subsequently) does not strictly reflect the value of Bs which will be obtained, but it is correlated with it, since the effect of Mo is notably excluded from it deliberately. Indeed, it is known that Mo influences in a much more significant way the ferrito-perlitic transformation, on which it has a very pronounced retarding effect, than the bainitic transformation, on which it has relatively little influence. Therefore, it is not its small influence on the temperature of the beginning of formation of bainite which is sought, but only its role on the ferrito-perlitic transformation. It will be seen later on why Bs’ should not exceed 620.

Si is comprised between 0.15 and 1.20%. As this is well known, silicon may be used for avoiding the formation of carbides during the bainitic transformation. However, the minimum quoted in the scientific literature for obtaining this effect is located at 1.2 or 1.5%. As this will be demonstrated subsequently, the present invention inter alia uses the discovery by the inventors that this limit may in fact be significantly lower for the relevant compositions, and notably of the order of 0.5-0.6%, or even less. Further, it will be seen that the level of Si may be used for adjusting the mechanical strength value for maintaining it in the expected range. Additions of Si beyond 1.20% are undesirable since they worsen the segregation and decarburization problems at the forge or upon heat treatment, which should be particularly avoided in the case of the invention when the C content is relatively high, and when the segregated bands may therefore be again found with a very hard martensitic structure.

Ni is comprised between trace amounts and 1.0%, preferably between trace amounts and 0.50%. It may be present exclusively because of its introduction through the raw materials as a residual element, or be added in a small amount in order to contribute to reduction of the temperature Bs. But its content is limited to 1%, better 0.5%, for reasons of cost, this element being expensive and liable to have its price strongly fluctuate on the market.

Mo is comprised between 0.050 and 0.500%, preferably between 0.15 and 0.30%. The role of molybdenum on the quenchability is well established: it gives the possibility of avoiding the formation of ferrite and perlite but nevertheless, it does not slow down, or only very little, the formation of the bainite. It may therefore be added in a variable amount depending on the diameter of the part. A second benefit of molybdenum is to limit the sensitivity to the reversible brittleness upon annealing (see Bhadeshia, Mater. Sci. Forum, High Performance Bainitic Steels, Vol 500-501, 2005). In the present case, the difficulty in using high Mn contents, because of the requirement of limiting segregations, makes the use of Mo most particularly necessary. The upper limit is mainly established for economical reasons.
[0078] V is comprised between trace amounts and 0.35%. By adding vanadium it is possible to increase the quenchability in a similar way to what it obtained with Mo on the one hand, i.e. with a substantial slowing down of the formation of ferrite-perlite and a substantially lower slowing down of the bainitic transformation. In so far that V does not precipitate during the bainitic transformation, it gives the possibility of obtaining a secondary hardness and a highly significant increase in the elastic limit Re during a subsequent annealing of the part as described earlier. Its addition is limited to 0.35% for economical reasons.

[0079] Cu is comprised between trace amounts and 1.0%, it may optionally be used for contributing to the hardening but causes difficulties in application for contents of more than 1%, notably embrittlement by the formation of liquid metal at high temperatures, which may lead to the problem known by rolling mill workers under the term of crazing or orange peel.

[0080] Al is comprised between trace amounts and 0.10%, preferably between 0.005 and 0.15%. Al is optionally added for ensuring de-oxidation of the steel and preventing excessive growth of the austenitic grains when maintained at a high temperature (for example a cementation treatment) which would be carried out on the part after applying the method according to the invention.

[0081] B is comprised between trace amounts and 0.005%, preferably between 0.0005 and 0.005%. This optional element may be used for parts with large diameters in order to guarantee the homogeneity of the structure by limiting the presence of ferrite. In this case, it may be preferable to couple the addition of B with addition of Ti which captures the nitrogen in order to form nitrides, and thus avoids the formation of boron nitrides. Thus the whole boron is maintained in solution and is therefore available for playing its role for homogenizing the structure.

[0082] Ti is comprised between trace amounts and 0.03%, preferably between 0.005 and 0.03%. As this has been stated, this optional element should mainly be used for grades with boron. In the case of an elaboration with boron, when B is of at least 5 ppm, N will be limited to at most 80 ppm and one should make sure that the addition of Ti verifies the relationship Ti<3.5N.

[0083] Nb is comprised between trace amounts and 0.10%. This optional element may be used for refining the austenitic structure after forging or hot rolling, with the consequence of decreasing the sizes of bainite packets and acceleration of the bainitic transformation.

[0084] S is comprised between trace amounts and 0.15%.
As this is well known, this element may if necessary be left at a relatively high level in the steel types concerned by the invention, or even be added voluntarily, in order to improve the machinability of the steel. A content of 0.005 to 0.15% is then given to it. Preferably, this significant presence of S is accompanied by addition of Cu up to 0.010%, and/or of Te up to 0.030%, and/or of Sc up to 0.050%, and/or of B up to 0.050% and/or of Pb up to 0.100%. It is not especially troublesome to find these elements in the steel of the invention even if the S content is low.

[0085] The other elements contained in the steel according to the invention are iron and impurities resulting from the elaboration, present at usual contents for the types of relevant steels.

[0086] The preferential ranges mentioned for diverse elements are independent of each other. A steel for which the composition would be located in only one or certain of these preferential ranges and not in the others would therefore be considered as being part of the invention.

[0087] Industrially, the part may be produced by a method for hot forming a slug, a bar or a bloom having the composition described earlier, such as hot forging or hot rolling. The method for manufacturing the part may also include the machining of bars (or other semi-finished products) ready to use in so far that the manufacturing of the latter was carried out according to the first steps of the described method.

[0088] After casting and solidification by any method (ingot or continuous casting) of a steel having the required composition, the industrial method first involves a step for hot forming carried out in the austenitic phase (typically but not exclusively in the range 1,100-1,300° C.), followed by natural cooling. One of the significant points of the invention is the possibility of obtaining high mechanical characteristics without using heat treatments which would be carried out after forging or rolling, and without any particular control highly limiting the cooling rate after hot shaping, which may be carried out naturally, in calm air. Nevertheless, if the facilities allow this, adaptation of the cooling may in certain cases be used, either because of the diameter of the parts (with parts of large dimensions, too slow cooling may lead to occurrence of ferrite and/or perlite in a too large amount), or for obtaining mechanical characteristics superior to those which would be obtained by natural cooling. Cooling with pulsed air may be sufficient for attaining this goal. However, one should take care that the cooling is not too rapid to the point of causing a massive occurrence of martensite. One skilled in the art may determine the optimum conditions of such cooling for parts with given dimensions, by systematic modeling and tests.

[0089] Further, an annealing heat treatment at low temperature (200 to 400° C. for periods from 30 minutes to 8 hours) following cooling gives the possibility of obtaining, on the grades according to the invention, a highly significant increase in the elasticity limit without increasing the hardness and without decreasing resilience.

[0090] Depending on the nature of the relevant parts and on the requirements from the manufacturer, one or several machine operations may take place following forging or hot rolling, and/or after an optional annealing, in order to obtain the dimensions and the specific surface characteristics desired for the final part.

[0091] As the required mechanical characteristics are often accessible by natural cooling as was stated, they are therefore able to be in certain cases attained by starting from a forged or hot rolled semi-finished product (for example a bar), ready to use, if the latter already has the sought metallurgical structure (essentially bainitic) which will be described later on. The composition of the steels of the invention is such that the probability of naturally obtaining the targeted structure after simple cooling in air of the forged or hot rolled semi-finished product under usual conditions is not negligible, if the dimensions of the semi-finished product lead to an adequate cooling rate on the whole of its volume.

[0092] And then it is proceeded with a partial heat treatment, in particular a surface treatment of the semi-finished product, with the purpose of locally obtaining a weakly or non-annealed martensitic microstructure; an example of
such a treatment being a surface treatment by induction, followed by local quenching and optionally annealing between 150 and 350 °C.

[0093] Such a partial treatment is practiced in a known way for local reinforcement of certain steering racks or grooves, crank pins and/or crankshaft bearings for automobiles and trucks.

[0094] Finally, it is optionally proceeded with rectification in order to give the part its final dimensions and its specific surface condition.

[0095] In every case, the carbon content required according to the invention guarantees obtaining an adequate hardness in the locally hardened areas (by induction, but also by laser or by any other functionally equivalent method resulting in surface hardening by localized heating and cooling).

[0096] It should be understood that the list of the treatments carried out is not necessarily exhaustive and that other thermal or thermomechanical or shaping treatments may be added thereto for example. The essential point is that the hot shaping operation and the subsequent cooling, carried out on steels having the specified composition, result in the bainitic microstructure to at least 80% as desired, and that the localized heat treatment is carried out on this microstructure, with the result of forming a weakly or non-annealed martensitic microstructure in the area concerned by this treatment.

[0097] Now, results obtained with five steels having a composition according to the invention and with a reference steel which is of the conventional 38MnSiV5 type will be discussed. These results are obtained on laboratory castings forged into circles of 40 mm, or on industrial castings, forged or hot rolled into bars of different diameters. The compositions of these samples are exhibited in Table 2, as well as the values of the parameter Bs' as defined earlier, which is correlated with the temperature of the onset of bainitic transformation Bs but which is always above it. The other elements, not specified in Table 2 are only present in trace amounts, metallurgically without any effect.

[0098] The samples of Ref and Inv.1 stem from elaborations carried out under industrial conditions finished by hot rolling into bars of 80 mm. The other samples are laboratory samples forged into bars of 40 mm and then they were cooled naturally in free and calm air therefore without attempting to particularly control their cooling rate. It should be clear that this austenitization is not itself a step of the method of the invention, even if industrially proceeding with it would not be excluded. But, it gives the possibility of obtaining the microstructures mentioned in Table 3, which correspond to those which would be obtained industrially at the end of the hot shaping and of the cooling which follows as described earlier. These tests are therefore above all representative of what is provided by the application of localized quenching to steels having the composition and the global microstructure required by the invention at the moment when this partial heat treatment is carried out thereon.

[0100] Next, in every case, a treatment according to the invention after the hot forming was applied to the bars. Table 3 shows the mechanical characteristics (elasticity limit Re, tensile strength Re, Re/Rm ratio and resilience KCU) measured on the thereby obtained products.

[0101] Here it should be emphasized that the obtained results, in absolute value, should only be analyzed in the specific context to which they refer. The hierarchy between the examined grades will remain nevertheless identical for samples all having the same dimensions, which would be different from those of the examples mentioned here.

### TABLE 2

<table>
<thead>
<tr>
<th>Microstructure</th>
<th>Including residual austenite</th>
<th>Re (MPa)</th>
<th>Rm (MPa)</th>
<th>Re/Rm</th>
<th>KCU (J/cm²)</th>
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<tbody>
<tr>
<td>Ref. 25% Ferrite + 75% perlite</td>
<td>~0%</td>
<td>590</td>
<td>885</td>
<td>0.67</td>
<td>~30</td>
</tr>
<tr>
<td>Inv. 1 Bainite + 5% martensite</td>
<td>&lt;5%</td>
<td>705</td>
<td>998</td>
<td>0.71</td>
<td>~25</td>
</tr>
<tr>
<td>Inv. 2 Bainite 100%</td>
<td>&lt;5%</td>
<td>644</td>
<td>915</td>
<td>0.70</td>
<td>30</td>
</tr>
<tr>
<td>Inv. 3 Bainite 100%</td>
<td>~20%</td>
<td>628</td>
<td>1010</td>
<td>0.62</td>
<td>34</td>
</tr>
<tr>
<td>Inv. 4 Bainite 100%</td>
<td>~25%</td>
<td>636</td>
<td>1070</td>
<td>0.59</td>
<td>41</td>
</tr>
<tr>
<td>Inv. 5 Bainite 100%</td>
<td>~25%</td>
<td>671</td>
<td>1150</td>
<td>0.58</td>
<td>47</td>
</tr>
</tbody>
</table>

### TABLE 3

<table>
<thead>
<tr>
<th>Compositions and Bs' of the tested samples; the Ti, Nb and B contents are 0.030%, 0.025% and 0.003% respectively, when these elements are present respectively.</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>C (%)</td>
<td>Mn (%)</td>
</tr>
<tr>
<td>Ref.</td>
<td>0.36</td>
</tr>
<tr>
<td>Inv. 1</td>
<td>0.37</td>
</tr>
<tr>
<td>Inv. 2</td>
<td>0.39</td>
</tr>
<tr>
<td>Inv. 3</td>
<td>0.38</td>
</tr>
<tr>
<td>Inv. 4</td>
<td>0.41</td>
</tr>
<tr>
<td>Inv. 5</td>
<td>0.39</td>
</tr>
</tbody>
</table>

[0099] In order to obtain on all these samples microstructures representative of the condition of a forged part, in particular a grain size of 5 to 7 ASTM, and thus ensuring the validity of the comparisons of one sample with the other, it was systematically proceeded with austenitization of the
microstructural homogeneity (Inv.1, where the presence of martensite is noted on a bar with a diameter of 40 mm cooled in calm air) and of the resilience. But, subsequently we will return to the advantages which these grades have, however within the scope of a surface quenching treatment by induction (or equivalent).

[0013] As regards the highest Si contents of the invention, Table 2 clearly demonstrates the possibility of obtaining suppression of carbides and formation of residual austenite for silicon contents remaining substantially less than the mentioned 1.2 or 1.5% in the literature as allowing this effect to be obtained. Indeed, only a stronger presence of Si distinguishes the steels making up the examples Inv.2 and Inv.3 (Si=0.31% and 0.59% respectively). As this is seen, the modification of microstructure caused by this addition of Si is correlated with a highly significant increase in the mechanical strength Rm, with in both cases considerably larger values than that of the reference (up to +30%). And the other measured properties Re and KCU are practically not affected. Even higher additions of Si as in the examples Inv 4 and Inv.5 give the possibility of further raising the Rm level.

[0014] In order to compare the response to surface quenching treatment by induction, test specimens were treated on a piece of industrial equipment designed for quenching by induction of crankshaft grooves. The steels corresponding to Ref. and Inv.1 were treated under identical conditions, i.e. nine heating rounds at a power of 60 kW, with one round per second, and then the examined microstructure and the hardening depth were measured. FIGS. 1 and 2 clearly illustrate the benefit brought by the initial bainitic microstructure (Inv.1, FIG. 2) as compared with the ferrito-perlitic reference (FIG. 1). Indeed, although the hardness maxima are approximately identical, the reference ferrito-perlitic grade, has greater difficulty to be austenitized which is expressed by a reduced hardening depth and by a more pronounced heterogeneity.

[0015] Metallographic examinations conducted in scanning electron microscopy moreover demonstrated on the samples of the reference steel that non-martensitic constituents existed in place of the old ferritic grains, and this even at less than 0.5 mm from the surface. This type of constituent is not identified on the sample Inv.1.

1. A method for manufacturing a mechanical steel part, including the following steps:
   a steel for surface-treated mechanical parts with high characteristics is cost and solidified, the composition of which is, in weight percentages:

   - 0.35%≤C≤0.50%;
   - 0.30%≤Mn≤1.50%;
   - trace amounts ≤Cr≤1.50%;
   - 0.05%≤Mo≤0.50%;
   - 0.15%≤Si≤1.20%;
   - trace amounts ≤Ni≤1.0%;
   - trace amounts ≤Cu≤1.0%;
   - trace amounts ≤V≤0.35%;
   - trace amounts ≤Al≤0.10%;
   - trace amounts ≤Si≤0.05%;
   - trace amounts ≤S≤0.020%;
   - trace amounts ≤N≤0.050%;
   - trace amounts ≤S≤0.100%;
   - trace amounts ≤N≤0.050%;

the remainder being iron and impurities resulting from the elaboration, and the C, Mn and Cr contents being such that 830-270 C %; Mn %; Cr %) 620;

2. The method according to claim 1, wherein the steel contains trace amounts ≤Si≤0.5%.

3. The method according to claim 1, wherein the steel contains ≤Mo≤0.30%.

4. The method according to claim 1, wherein the steel contains ≤Al≤0.10%.

5. The method according to claim 1, wherein the steel contains ≤Si≤0.05%.

6. The method according to claim 1, wherein the steel contains ≤Ti≤0.5%.

7. The method according to claim 1, wherein the steel contains ≤B≤0.005%.

8. The method according to claim 1, wherein the steel contains ≤N≤0.0080%.

9. The method according to claim 1, wherein the steel contains ≤S≤0.15%.

10. The method according to claim 1, wherein the partial heat treatment is a surface treatment.

11. The method according to claim 1, wherein said partial heat treatment is a surface treatment by induction followed by local quenching.

12. The method according to claim 1, wherein the partial heat treatment is followed by annealing between 150 and 350°C.

13. The method according to claim 1, wherein the cooling following the hot-forming of the semi-finished product takes place in calm air.

14. The method according to claim 1, wherein the cooling following the hot-forming of the semi-finished product takes place in pulsed air.

15. The method according to claim 1, wherein hot-forming of the solidified steel in the austenitic domain is performed by hot-forging or hot-rolling of the solidified steel.

16. The method according to claim 1, wherein it is proceeded with or several machining operations in order to give the part its intended dimensions.

17. The method according to claim 16, wherein, before or after the machining operation(s), it is proceeded with annealing carried out at 200-400°C for 1-2 hours.

18. The method according to claim 1, wherein it is proceeded with rectification in order to give the part its final dimensions.
19. A mechanical steel part which has been obtained with a method including the following steps:

- a steel for surface-treated mechanical parts with high characteristics is cost and solidified, the composition of which is, in weight percentages:

  - 0.35%≤C≤0.50%;
  - 0.30%≤Mn≤1.50%;
  - trace amounts ≤Cr≤1.50%;
  - 0.05%≤Mo≤0.50%;
  - 0.15%≤Si≤1.20%;
  - trace amounts ≤Ni≤1.0%;
  - trace amounts ≤Cu≤1.0%;
  - trace amounts ≤V≤0.35%;
  - trace amounts ≤Al≤0.10%;
  - trace amounts ≤B≤0.005%;
  - trace amounts ≤Ti≤0.10%;
  - trace amounts ≤Nb≤0.10%;
  - trace amounts ≤S≤0.15%;
  - trace amounts ≤Ca≤0.010%;
  - trace amounts ≤Te≤0.030%;
  - trace amounts ≤Se≤0.050%;
  - trace amounts ≤Bi≤0.050%;

- the remainder being iron and impurities resulting from the elaboration; and the C, Mn and Cr contents being such that 830-270 C %, 90 Mn %, 70 Cr % ≤620;

- hot-forming of said solidified steel is carried out in the austenitic domain in order to obtain a hot-formed semi-finished product;

- the hot-formed semi-finished product is cooled at a rate giving it a bainitic structure containing a total of at most 20% of martensite and/or perlite and/or ferrite;

- it is proceeded with a partial heat treatment with the purpose of locally obtaining a weakly or non-annulled martensitic microstructure.

20. The mechanical part according to claim 19, being a rack machined from a bar which has been rolled then cut into slugs.

21. The mechanical part according to claim 19, being a forged crankshaft whose grooves and/or crankpins and/or bearings have been reinforced by means of said partial heat treatment.