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(54) **STEEL FOR SPRINGS OF HIGH RESISTANCE AND HARDENABILITY**

(57) The present invention relates to high-strength steel with a specific composition of the following elements: $0.47\% \leq C \leq 0.55\%$, $0.90\% \leq Si \leq 2.00\%$, $0.75\% \leq Mn \leq 1.20\%$, $0.80\% \leq Cr \leq 1.25\%$, $0.10\% \leq Mo < 0.30\%$ and $0.05\% \leq V < 0.30\%$ which, with a method for obtaining said steel, achieves low P and S contents, high inclusion cleanliness and high-quench hardenability, with an ideal

critical parameter equal to or greater than 235 mm, contributes to raising the mechanical strength of the steel to values greater than 1800 MPa, and with high ductility, reduction of area with values greater than 30%, when a part manufactured using said steel is subjected to a specific hardening and tempering treatment.

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DescriptionObject of the Invention

- 5 **[0001]** The present invention relates to a high-strength and high-quench hardenability leaf spring steel, with a long fatigue life, which can be applied in the iron and steel industry, which allows being used for metal structures in the construction sector. Said parts are particularly suitable in the automotive industry, for example, for manufacturing leaf springs or other suspension supporting elements for industrial vehicle suspension systems.
- 10 **[0002]** The invention allows obtaining leaf spring steel, from a chemical composition and by means of a metallurgical process, that has high mechanical strength while at the same time it has a long fatigue life and strength, in addition to having optimal quench hardenability.

Background of the Invention

- 15 **[0003]** The main feature of leaf spring steels is their elastic behavior, such that they become deformed in response to an external stress and recover their original shape when that stress disappears.
- [0004]** One of the applications of spring steels are suspension elements, particularly springs, leaf springs and other elements and devices used in automotive vehicles, railway vehicles and industry. In this field, leaf spring steels must have very high tensile strength and yield strength values to assure the elastic behavior of the element. Furthermore,
- 20 these properties must be maintained over time, preventing permanent plastic deformations from occurring.
- [0005]** These features are largely determined by the carbon content in the steel, which ranges between 0.40% and 0.65% by weight, as well as the content of other alloy elements such as Si, Mn, Cr, Ni, Mo and V, for example, the purpose of which is to increase the quench hardenability of the steel and assure that the microstructure of the quench hardened part is martensite throughout the entire section.
- 25 **[0006]** Furthermore, other requirements for leaf spring steels is that they have to have a good fatigue response, considering the cyclical service demands of suspension elements; good corrosion resistance given that, due to the location thereof in the vehicle and despite incorporating paint or other anticorrosion protection, they are exposed to atmospheric inclemencies and/or to impacts that degrade their protective layer; low hydrogen embrittlement sensitivity, which accelerates the progression of small cracks, and moderate toughness at room temperature and at a low temper-
- 30 ature, given that they can be used in environments with sub-zero temperatures.
- [0007]** There are a number of leaf spring and spring steels classified as such in international standards which have a tensile strength ranging between 1300 MPa and 2000 MPa. These values, however, depend considerably on the thickness of the part and the highest values are only obtained in springs that are not very thick, in general coil springs manufactured from cold and hot formed wire rod.
- 35 **[0008]** For very thick suspension elements, such as leaf springs used in industrial vehicles, very high-quench hardenability steels are required, the most common steel grades being 55Cr3, 51CrV4 or 52CrMoV4 and rounded rectangular section.
- [0009]** Leaf spring steels are hot formed at a temperature between 950°C and 1150°C, after a heating process that can be from gas combustion, induction and other means and that usually is done in the presence of an oxidizing
- 40 atmosphere for a more or less prolonged time, for example between 30-75 minutes for each end. These processes deteriorate the steel surface either due to decarburization, surface scale formation, which negatively affects the fatigue behavior of the part.
- [0010]** In the case of coil springs, said time is substantially less, so the problem of decarburization, unlike the case of leaf spring steels, is not so relevant.
- 45 **[0011]** In addition to the aforementioned, there are steels and methods for obtaining them today that are aimed at improving the service features of steels intended for the applications discussed above, in which variable amounts of alloying elements, such as Si, Mn, Cr, Ni, Mo, Cu, V, Ti, Al, Nb or B, for example, are usually added, examples of which are mentioned below.
- [0012]** Patent no. WO-2011/074600-A1 describes a method for obtaining steel for leaf springs with a Ti alloy and Ti/N ratio ≥ 10 which prevents bainite from occurring and, with it and a hot shot peening treatment of the component, improves the fatigue life for leaf springs with a Vickers hardness greater than 510 HV.
- 50 **[0013]** On the other hand, Japanese patent application no. JPH-08295984-A describes a steel with a low Mn content for leaf springs with high toughness and delayed fracture strength for tensile strengths of 1650 MPa.
- [0014]** Chinese patent application no. CN-102586687-A describes a leaf spring steel with a strength of up to 1750 MPa and high-quench hardenability, but having reduced ductility even for tempering treatment at 500°C.
- 55 **[0015]** Other high-strength steel inventions relate to applications of wire rod of small thickness for coil suspensions such as those referred to below as an example.
- [0016]** Chinese patent no. CN-102634735-A describes a high-strength alloy steel, with an addition of Cu between

0.50% and 0.80% and of rare earth elements between 0.02% and 0.07%, reaching a mechanical strength ≥ 2000 MPa for springs having a diameter < 16 mm.

[0017] Patent no. WO-2012/063620-A1 relates to the invention of an Si-Mn spring steel having high corrosion resistance to be applied to cold- or hot-formed coil springs, as well as to the high-strength spring manufactured from this steel.

[0018] Patent no. WO-2010/110041-A1 solves the problem of the lack of ductility of high-strength steels by means of austempering an Si-Mn-Cr steel which generates a high-strength mixed bainite and retained austenite microstructure having good ductility.

[0019] Patent no. WO-2008/102573-A1 improves the toughness of high-strength steel by means of adding high Si and a suitable balance of tempering temperatures and times preventing the transformation of ϵ carbides into cementite.

[0020] The improvement of corrosion fatigue strength of the high-strength steels is solved in patent no. WO-2006/022009-A1 by means of adding anti-corrosive elements such as Cu and Ni, the improvement of the deoxidation process which drastically reduces the content of oxides having a size greater than $10\ \mu\text{m}$ in diameter and a suitable balance of other alloy elements (Si, Mn, Cr).

[0021] The improvement of toughness in high-strength steels is obtained in patent no. WO-1998/051834-A1 by means of refining grain by the microprecipitation effect and decreasing impurities at austenite grain boundaries, with a suitable balance of alloy elements (Si, Ti, B).

[0022] The increase in tensile strength above 2000 MPa and in fatigue strength of steels for coil springs is obtained in the Japanese patents JP 2842579-B2 and JP 3255296-B2 by means of a suitable balance of alloy elements (Si, Ni, Cr, Mo, V) and by restricting, in number and size, the content of oxides in the steel.

[0023] The weight reduction of suspension arms and leaf springs in industrial vehicles requires high mechanical strength (≥ 1800 MPa) steels in parts that are between 10 and 60 mm thick and between 50 and 150 mm wide, with a long fatigue life, good corrosion resistance and corrosion fatigue strength, low hydrogen embrittlement susceptibility and moderate toughness and impact resistance at low temperatures. This challenge has still not been solved in its entirety by the state of the art.

[0024] Therefore, the properties of the parts manufactured with spring steels intended for said applications are susceptible to optimization.

Description of the Invention

[0025] The present invention relates to a leaf spring steel, in which an optimal combination of two opposing mechanical properties, high tensile strength, with strength values of at least 1800 MPa, and high ductility, with elongation values $> 9\%$ and area reduction values $> 30\%$, has been obtained as a result of several investigations.

[0026] The invention allows obtaining leaf spring steel from a novel chemical composition and a specific metallurgical process, having optimized and adjusted resistance to decarburization, high mechanical strength while at the same time having good ductility, in addition to having optimal quench hardenability, which is important, for example, for the complete transformation of austenite into martensite in very thick parts.

[0027] On the other hand, in addition to the chemical composition, the heat treatment applied to the steel has a very important effect on the mechanical features of the end component, i.e., the part with the initial chemical composition is subjected to a specific method of quench hardening and tempering, which must be performed under specific time and temperature conditions.

[0028] To assure a long fatigue life it is necessary to apply during the process of manufacturing this steel a specific inclusion deoxidizing and floating method under certain special conditions.

[0029] The inventors have found a synergistic effect between a novel combination of chemical elements and a method for obtaining said steel which contemplates a specific heat treatment, achieving a high strength and ductility leaf spring steel for quench hardening and tempering, in addition to good hot forming ability and good quench hardenability.

[0030] The investigations resulted in a new grade of SiCrMoV alloy steel, comprising the following chemical composition by weight percentage:

$$0.45\% \leq C \leq 0.58\%$$

$$0.75\% \leq Si \leq 2.25\%$$

$$0.65\% \leq Mn \leq 1.20\%$$

$$0.65\% \leq Cr \leq 1.50\%$$

$$0.01\% \leq Mo \leq 0.40\%$$

$$0.01\% \leq V \leq 0.40\%$$

the remaining elements being impurities resulting from the production thereof.

[0031] These alloy elements are used in alloy steels to improve tensile strength, tempering resistance, toughness or other characteristics, but not with the concentrations by weight indicated, not with the proposed combination of elements,

or for obtaining the properties described above which allow use thereof in the mentioned applications.

[0032] Each of the alloy elements, in the proportions indicated above affects specific parameters and properties of the steel that is finally obtained.

[0033] Carbon is an indispensable element for obtaining high strength and hardness after the quench hardening and tempering treatment. Below 0.45% carbon, the strength that is obtained is insufficient. On the other hand, above 0.58%, the toughness of the steel markedly decreases and hydrogen embrittlement may be favored. The optimal range is between 0.47% and 0.55%

[0034] Silicon is one of the most important hardeners of ferrite by solid solution. Given that it dissolves in ferrite and not in cementite, it tends to inhibit carbide precipitation, and therefore shifts the temperature of the tempering brittleness area to higher temperatures, preventing hydrogen embrittlement and improving corrosion fatigue strength. Furthermore, silicon is a powerful deoxidizer and is used as such in refining processes in iron and steel processes. Likewise it increases quench hardenability and hardens the ferrite matrix of the martensite substituting the iron atoms of the lattice. In order for these effects to translate into a significant increase in strength of at least 0.75% silicon is required, recommending for this application a silicon content over 0.90%. However, excessive silicon content favors decarburization and the intergranular oxidation given its tendency to combine itself with the oxygen from the atmosphere at the forging or rolling temperatures (>1000°C). Furthermore, silicon contributes to shifting the ductile-fragile transition temperature to higher temperatures, such that if the silicon content is very high, the steel can be embrittled to room temperature, such that the upper limit is established at 2.25% to assure an acceptable toughness, 2.00% to assure an acceptable decarburization in quench hardening and tempering treatments and 1.75% to assure acceptable decarburization in rolling and re-rolling process of the leaf spring, depending on the process used. In the case of heating by a gas oven, silicon tends to combine with O₂ and greater decarburization takes place, whereby it would need to be limited to 1.75% or even 1.50%. In the case of heating by induction, decarburization is lower and the upper limit can be left at 2.00%. Silicon improves the mechanical properties of the steel.

[0035] Manganese is an indispensable element for assuring the required quench hardenability in steel for leaf springs. Furthermore, it reduces the transformation temperature, which allows obtaining a fine-grain crystalline structure, which at the same time allows increasing strength and improving toughness. It also prevents the harmful effect of the sulfur, combining with said sulfur to form MnS. On the other hand, an excessive content can favor the occurrence of quench hardening cracks, such that the optimal content is between 0.65% and 1.20%, even being able to be limited between 0.80-1.10%.

[0036] Chromium is an indispensable element for assuring the required quench hardenability in steel for leaf springs. If it is below 0.65%, the quench hardenability may not be enough and unwanted structures may occur in the core of the part. A high chromium content increases the risk of quench hardening cracks. Chromium carbides also act like local electrodes on the surface of the steel by increasing pitting corrosion and reducing the corrosion fatigue strength. The upper limit is therefore established at 1.50%. The best combination of properties is obtained for a range consisting of 0.80% to 1.25%Cr.

[0037] Molybdenum has a strong, quench hardenability-favoring effect, in turn being a strong carbide-forming element, providing a notable effect of secondary hardening during tempering. On the other hand, molybdenum improves pitting corrosion resistance and prevents tempering brittleness by preventing phosphorus precipitation at the grain boundary. Nevertheless, in high contents, the alloy cost is excessive and economically unacceptable, such that the preferred range is between 0.01% and 0.40%. The best ratio between cost and characteristic is obtained between 0.10% and 0.30% of molybdenum.

[0038] Vanadium is a microalloying element that contributes to refining grain size and causes intense precipitation hardening, and it greatly increases quench hardenability when it remains in solid solution. Vanadium precipitates are hydrogen nucleators, such that they fix the hydrogen in corrosive environments and improve the delayed fracture strength induced by hydrogen. However, with a very high vanadium content, precipitates coalesce and their effect can become harmful. Therefore, the vanadium content must be between 0.01% and 0.40%, a content between 0.05% and 0.30% being preferable.

[0039] Furthermore, the steel proposed by the invention may comprise, in addition, at least one of the following elements or a combination thereof, with a weight percentage:

$$P \leq 0.040\%$$

$$S \leq 0.040\%$$

$$Cu \leq 0.50\%$$

$$0.001\% \leq Al \leq 0.050\%$$

$$0.001\% \leq Nb \leq 0.100\%$$

$$0.001\% \leq Ti \leq 0.050\%$$

$$0.004\% \leq N \leq 0.020\%$$

the remaining elements being residual elements that result from obtaining the steel.

[0040] Phosphorus hardens steel and segregates at austenite grain boundaries, drastically reducing the toughness of the steel. Furthermore, it favors hydrogen embrittlement and delayed fracture. The phosphorus content is limited to less than 0.040% in order to limit its adverse effect, a content less than 0.020% being desirable.

[0041] Sulfur embrittles steel in a manner similar to phosphorus. Despite this effect being counteracted by combining with manganese, manganese sulfides form inclusions that deform longitudinally in the forging or rolling direction and considerably deteriorate the transverse mechanical properties and the fatigue behavior. Nevertheless, sometimes a minimum amount of sulfur is required to improve the machinability of the steel and the forming thereof by machining. Therefore, the sulfur content is restricted to less than 0.040%, a content less than 0.015% being preferable.

[0042] Adding copper prevents decarburization of steel and improves corrosion resistance in a manner similar to nickel by inhibiting the growth of corrosion-induced pitting. However, a high copper content impairs hot ductility of steel, such that the upper limit of copper is established at 0.50%. For optimal hot processing, the maximum copper content must be limited to 0.30%.

[0043] Aluminum is an element that acts as a powerful deoxidizer during the steel manufacturing process. Aluminum forms aluminum nitrides which contribute to controlling the austenitic grain size during heat treatments and heating prior to hot forming processes. Nevertheless, it forms very hard oxides which are very prejudicial for fatigue life, such that the upper limit thereof is established at less than 0.050%.

[0044] Niobium is a microalloying element having effects that are similar to those of vanadium in controlling grain size and in precipitation-induced hardening of steel, such that it contributes to increasing mechanical strength and to improving toughness. Furthermore, niobium precipitates fix the hydrogen attacking the steel in corrosive environments, improving delayed fracture strength. Content above 0.100%, nevertheless, causes coarsening of the precipitates, which is prejudicial for the mechanical properties. The optimal niobium content is established between 0.001% and 0.100%.

[0045] The titanium is an effective austenitic grain size controller at a high temperature, typically at hot forging temperatures. However, given its affinity for nitrogen, it forms titanium nitrides at temperatures close to those of liquid steel, which transforms its precipitates into extremely hard inclusions that are harmful for fatigue life. The titanium content in the steel is limited to a maximum of 0.050% to limit excessive titanium nitride coarsening.

[0046] Nitrogen combines with Ti, Nb, Al and V to form nitrides, the precipitation temperatures of which depend on the respective content of the different elements and on constant characteristics. With a suitable size, those nitrides exert a pinning effect on the austenitic grain, controlling its size at high temperature and preventing the coalescence and growth thereof. However, if the nitrogen content or the microalloying element content is very high, precipitation occurs at a high temperature, and the precipitates become coarse, becoming ineffective for controlling the grain and prejudicial for fatigue life. Therefore, the nitrogen content in the steel is limited to 0.004% to 0.020%.

[0047] It has previously been found that spring steels having a standard composition and process for truck leaf spring applications which have been subjected to a conventional quench hardening and tempering process did not come to have the required and previously discussed mechanical properties due to fact that the degree of inclusion cleanliness was lower and the balance of microalloying elements was inadequate with respect to the optimized process that the steel of the invention has.

[0048] A preferred composition of the steel proposed by the invention comprises a weight percentage:

$$\begin{aligned} 0.47\% &\leq C \leq 0.55\% \\ 0.90\% &\leq Si \leq 2.00\% \\ 0.75\% &\leq Mn \leq 1.20\% \\ 0.80\% &\leq Cr \leq 1.25\% \\ 0.10\% &\leq Mo \leq 0.30\% \\ 0.05\% &\leq V \leq 0.30\%. \end{aligned}$$

[0049] For this preferred composition, the steel can additionally comprise at least one of the following elements, or a combination thereof, by weight:

$$\begin{aligned} P &\leq 0.020\% \\ S &\leq 0.015\% \\ Cu &\leq 0.50\% \\ 0.001\% &\leq Al \leq 0.050\% \\ 0.001\% &\leq Nb \leq 0.060\% \\ 0.001\% &\leq Ti \leq 0.030\% \\ 0.004\% &\leq N \leq 0.020\%. \end{aligned}$$

[0050] Therefore, after various experiments a rigorous method has been developed for obtaining steel according to

the following steps:

- Rigorously controlling the raw materials of the furnace, i.e., coke and lime and especially scrap.
- Using between 30% and 50% top-quality scrap.
- Performing an oxidizing period in an electric furnace, which is important for dephosphorization of the steel, prior to the foamed slag.
- Once the foamed slag has ended, deslagging until virtually leaving the furnace with no slag, the objective being a presence of phosphorus in this step less than 0.010% by weight.
- Tilting with standard temperature and parts per million (ppm) of oxygen, according to a clean steel standard, assuring that slag does not pass from the furnace to the ladle.
- Deoxidizing with Si to obtain very fluid white slag with a lime-spar base.
- Rigorously controlling the refining raw materials, i.e., ferroalloys and other metallic and slag forming additions.
- Establishing a prolonged vacuum, considering as a vacuum time that which is below 1 mbar, and being 50% greater than the conventional vacuum time.
- Ending the vacuum treatment with a high enough temperature to perform an inclusion decanting process after said process of at least fifteen minutes, without performing any type of addition or heating.
- Finally, a meticulous casting process with special protection for the liquid steel stream must be followed.
- If the solidification process is during continuous casting, casting, cooling and stirring speed conditions will be adjusted to obtain a homogeneously solidified microstructure.

[0051] This entire method of manufacturing steel allows achieving low sulfur levels, below 0.015% by weight, and low phosphorus levels, below 0.020% by weight, in addition to a low inclusion level.

[0052] CCT (Continuous Cooling Transformation) diagrams allow representing heat treatments for a certain chemical composition when the phase transformations occur in non-equilibrium conditions.

[0053] The solidification products are subsequently transformed when hot by means of a process consisting of heating at a temperature greater than 1100°C and a series of consecutive deformations by means of hot forging or rolling until obtaining an intermediate product having the suitable section, shape and microstructure.

[0054] After various experimental tests, it has been verified that after the process of manufacturing steel proposed by the invention, with the chemical composition indicated above, adjusting the temperatures and the maintenance times of the quench hardening and tempering, a steel with tensile strength above 1800 MPa and high ductility, with reduction of area >30%, is obtained. Furthermore, said steel has high-quench hardenability, which is suitable for obtaining 100% martensite in thick sections, such as those of leaf springs for industrial vehicles.

[0055] To obtain a part of the previously obtained steel having the mentioned features, the invention contemplates performing a method whereby said part of steel is obtainable.

[0056] The method for obtaining parts of said steel comprises a hot forming process, with prior heating at a temperature greater than 950°C which allows providing the steel with sufficient ductility when hot, to confer to the part of steel a shape similar to that of the end component. After being shaped, the part is left to be air cooled.

[0057] The method subsequently contemplates a quench hardening process which is performed with austenization at a temperature greater than 800°C, followed by final forming operations and then subsequent cooling, for example, in oil. The steel of the invention has a balance of alloy elements that allows obtaining 100% martensite, even in the thicker sections, without increasing the risk of cracks resulting from quench hardening appearing due to the stress produced during cooling.

[0058] The method then comprises a tempering process, which is carried out at a temperature greater than 300°C for at least one hour, thus achieving the adjustment of the hardness and toughness of the material, in addition to preventing decreases in resilience, which are associated with the brittleness phenomenon of tempering.

[0059] Finally, the method comprises carrying out a shot peening process by applying or not applying stress to the component at a temperature between 0°C and 400°C, usually at room temperature, to generate in surface regions of the component residual compressive stresses improving its fatigue behavior. A surface coating or painting that improves the corrosion behavior of the component can additionally be applied.

[0060] Therefore, the method for obtaining parts of steel comprises the following steps:

- Obtaining the previously described steel of the invention, in which the selected steel comprises the previously defined general composition or preferred composition
- Manufacturing a part of said steel, for example by means of rolling or another forming process.
- Performing the previously defined quench hardening treatment in the part.
- Performing the previously defined tempering treatment in the part.
- Performing a shot peening treatment in the part.
- Painting or coating the part with an anticorrosion treatment.

Description of the Drawings

[0061] To complement the description that is being made and for the purpose of aiding to better understand the features of the invention according to a preferred practical embodiment thereof, a set of drawings is attached as an integral part of said description in which the following is depicted with an illustrative and non-limiting manner:

Figure 1 shows a Jominy quench hardenability curve diagram obtained for each of the steels A-H. Steels C, D and H show virtually flat curves, whereas drops in hardness occur in steels A, B, E, F and G at distances from the quench hardened end equal to or less than 40 mm.

Figures 2-4 show the microscopy of the surface of steels B, H and A, respectively, after heating at 960°C for 110 minutes.

Figures 5-7 show the microscopy in which the decarburized layer of the same steels B, H, and A after heating at 1030°C for 35 minutes, followed by heating at 960°C for 45 minutes.

Embodiments of the Invention

Example 1

[0062] The tests performed with steel specimens with other compositions different from the chemical composition of the steel of the invention are described below by way of example. Said specimens are steels A-G, steel H is the steel of the invention. Table 1 shows the chemical compositions by weight percentage, the rest being Fe and impurities:

Table 1

	C	Mn	Si	P	S	Cr	Ni	Mo	V	Cu	Al	N
A	.55	.79	1.94	.008	.013	.95	.14	.004	.12	.15	.005	.0092
B	.50	.78	.28	.009	.013	1.03	.15	.18	.12	.15	.007	.0144
C	.55	.79	.34	.011	.004	1.03	1.60	.003	.12	.15	.008	.0131
D	.50	.79	.99	.013	.004	.96	.15	.18	.003	.15	.008	.0082
E	.51	.78	.31	.013	.003	1.05	.15	.003	.12	.15	.009	.0083
F	.53	.84	1.04	.013	.003	1.12	.15	.003	.13	.16	.011	.0091
G	.52	.80	.33	.013	.003	1.07	.15	.004	.26	.15	.005	.0089
H	.50	.79	1.02	.012	.003	1.07	.14	.18	.12	.15	.007	.0080

[0063] Table 2 includes the ideal critical diameter values according to data tabulated in the ASTM A255-02 standard for each of the compositions and steels described in Table 1.

Table 2

	A	B	C	D	E	F	G	H
DI (mm)	227	175	191	197	120	193	155	259

[0064] Illustration 1 shows the Jominy quench hardenability curve diagram obtained for each of steels A-H. Steels C, D and H show virtually flat curves, whereas drops in hardness occur in steels A, B, E, F and G at distances from the quench hardened end equal to or less than 40 mm. [/*/*]

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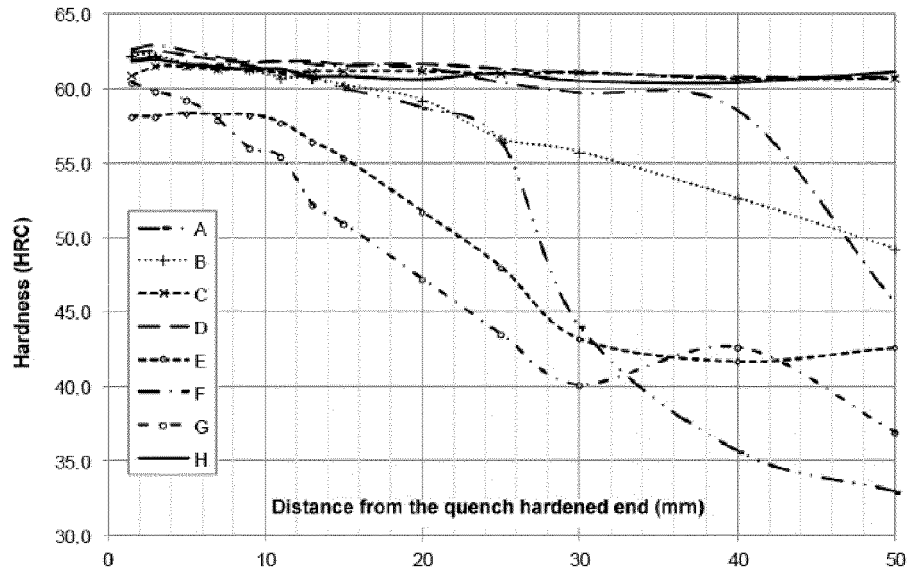


Illustration 1

[0065] All these steels were subjected to quench hardening and tempering treatments under different conditions for the purpose of achieving for each of them the most optimal mechanical strength and toughness combination.

[0066] Therefore, the mechanical strength for each steel and each tempering temperature is shown in Table 3.

Table 3

	Strength (MPa) vs. Tempering Temperature			
	300°C	350°C	400°C	450°C
A	2075	2099	1938	1736
B	1932	1845	1695	1554
C	1965	1796	1650	1500
D	2144	1992	1838	1656
E	1653	1615	1536	1319
F	2138	2046	1814	1658
G	1731	1569	1562	1352
H	2050	2028	1874	1691

[0067] The reduction of area results for each steel and temperature are shown in Table 4.

Table 4

	Reduction of Area (%) vs. Tempering Temperature			
	300°C	350°C	400°C	450°C
A	13	14	14	15
B	25	19	27	32
C	20	4	33	30
D	-	6	11	15
E	11	26	19	32
F	19	7	22	36

(continued)

	Reduction of Area (%) vs. Tempering Temperature			
	300°C	350°C	400°C	450°C
G	34	41	41	47
H	10	11	33	38

[0068] As shown in Tables 3 and 4, steels A, B, C, D, E, F and G do not attain strength of 1800 MPa, maintaining a minimum area reduction $\geq 30\%$.

[0069] Steels B, C and E have low silicon contents, such that they do not attain 2000 MPa for any tempering temperature.

[0070] In turn, steels A, D and F do not achieve desired ductility levels despite having a high silicon content and exceeding 1800 MPa for tempering temperatures equal to or less than 400°C, because the alloying element combination is not the suitable combination for attaining the required mechanical features.

[0071] However, for steel H, which has a chemical composition within the limits object of the invention, i.e., it is the steel proposed by the invention, it has been found that after being subjected to a quench hardening and tempering treatment, consisting of quench hardening plus tempering, said steel attains the required mechanical features and its quench hardenability is high.

[0072] Furthermore, the steel of the invention has a moderate decarburization similar to steels commonly used in leaf spring, which allows the processing thereof by hot forming without deteriorating the surface quality of the steel bar.

[0073] Figures 2, 3 and 4 show the surface of steels B, H and A, respectively, after heating at 960°C for 110 minutes. The steel A, with 1.94% Si, shows total surface decarburization, which is unacceptable for a leaf spring application given the lower resistance of the area subjected to greater stress in service.

[0074] Figures 5, 6 and 7 show the decarburized layer of the same steels B, H and A after heating at 1030°C for 35 minutes, followed up by heating at 960°C for 45 minutes. The first treatment is similar to the heating prior to the re-rolling of the leaf spring and the second treatment is similar to the austenization process prior to quench hardening.

[0075] Steel A, with 1.94% Si, as can be seen in Figure 7, shows a very thick decarburized layer (0.20-0.25 mm) that negatively influences the performances of the part. Steels B and H, with 0.28% Si and 1.02% Si, respectively, depicted in Figures 5 and 6, show much less partial decarburization and total decarburization is not observed.

[0076] Steel H, located within the limits of the invention, has the quench hardening necessary to assure 100% martensite in thick sections, without generating excessive stress during quench hardening giving rise to cracks. Likewise, it acquires a resistance of 1800 MPa through thermal quench hardening and tempering treatment, maintaining a minimal area reduction $\geq 30\%$. All this by maintaining a resistance to decarburization that is sufficient so as not to lose surface mechanical properties.

[0077] The invention is described according to some preferred embodiments thereof, but for the person skilled in the art it will be obvious that multiple variations can be introduced in said preferred embodiments without exceeding the object of the claimed invention.

Claims

1. Leaf spring steel, with high tensile strength, high-quench hardenability and high ductility, **characterized in that** it comprises the following elements with a weight percentage:

$$0.45\% \leq C \leq 0.58\%$$

$$0.75\% \leq Si \leq 2.25\%$$

$$0.65\% \leq Mn \leq 1.20\%$$

$$0.65\% \leq Cr \leq 1.50\%$$

$$0.01\% \leq Mo \leq 0.40\%$$

$$0.01\% \leq V \leq 0.40\%, \text{ the rest being iron and impurities.}$$

2. Leaf spring steel according to claim 1, **characterized in that** it comprises at least one of the following elements with a weight percentage:

$$P \leq 0.040\%$$

$$S \leq 0.040\%$$

$$Cu \leq 0.50\%$$

$0.001\% \leq \text{Al} \leq 0.050\%$
 $0.001\% \leq \text{Nb} \leq 0.100\%$
 $0.001\% \leq \text{Ti} \leq 0.050\%$
 $0.004\% \leq \text{N} \leq 0.020\%$.

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3. Leaf spring steel according to claim 1, **characterized in that** it comprises the following elements with a weight percentage:

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$0.47\% \leq \text{C} \leq 0.55\%$
 $0.90\% \leq \text{Si} \leq 2.00\%$
 $0.75\% \leq \text{Mn} \leq 1.20\%$
 $0.80\% \leq \text{Cr} \leq 1.25\%$
 $0.10\% \leq \text{Mo} \leq 0.30\%$
 $0.05\% \leq \text{V} \leq 0.30\%$.

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4. Leaf spring steel according to any of claims 2 and 4, **characterized in that** it comprises at least one of the following elements with a weight percentage:

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$\text{P} \leq 0.020\%$
 $\text{S} \leq 0.015\%$
 $\text{Cu} \leq 0.50\%$
 $0.001\% \leq \text{Al} \leq 0.050\%$
 $0.001\% \leq \text{Nb} \leq 0.060\%$
 $0.001\% \leq \text{Ti} \leq 0.030\%$
 $0.004\% \leq \text{N} \leq 0.020\%$.

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5. Leaf spring steel according to any of the preceding claims, **characterized in that** it has mechanical tensile strength greater than or equal to about 1800 MPa and reduction of area greater than or equal to 30%.

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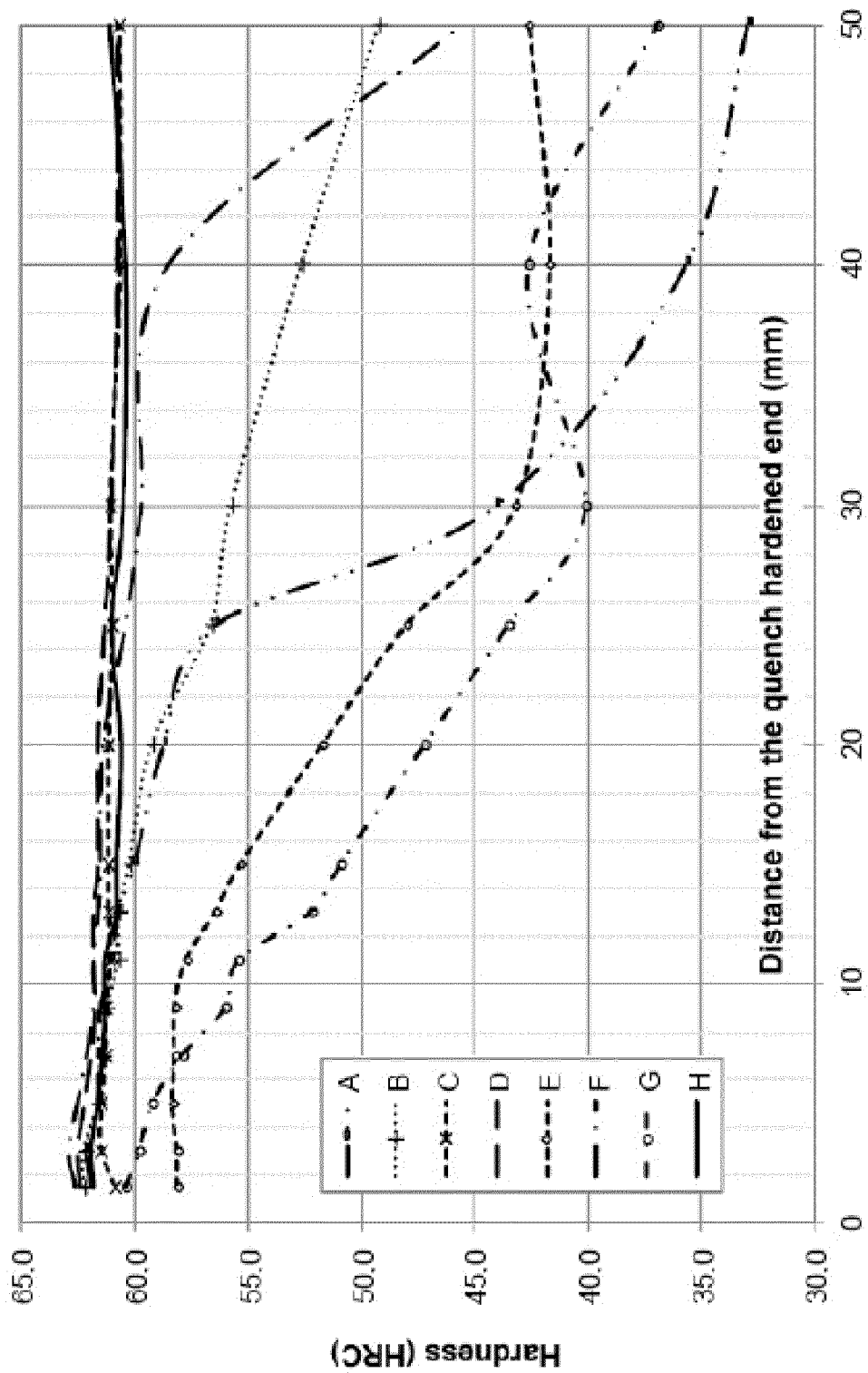


FIGURE 1

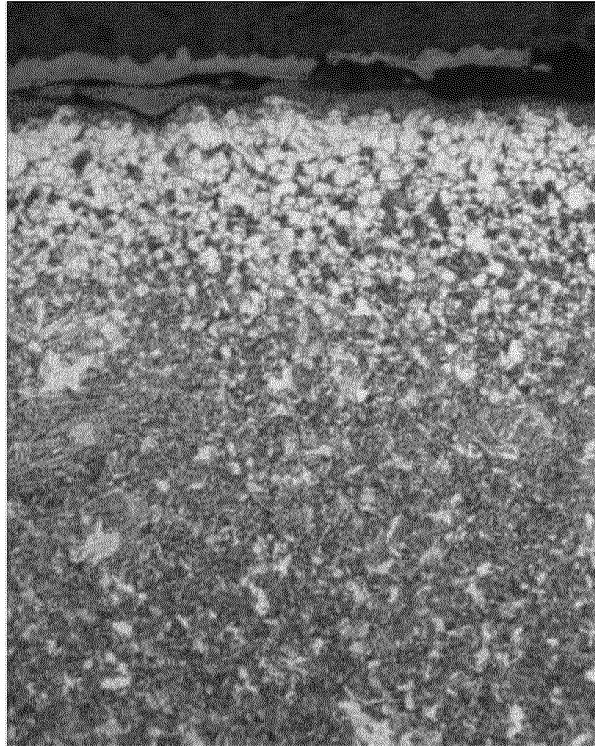


FIG. 2

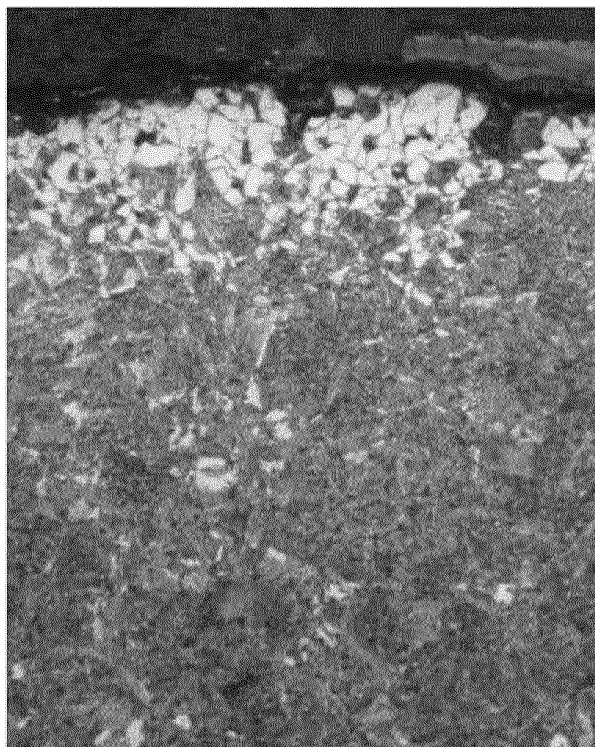


FIG. 3

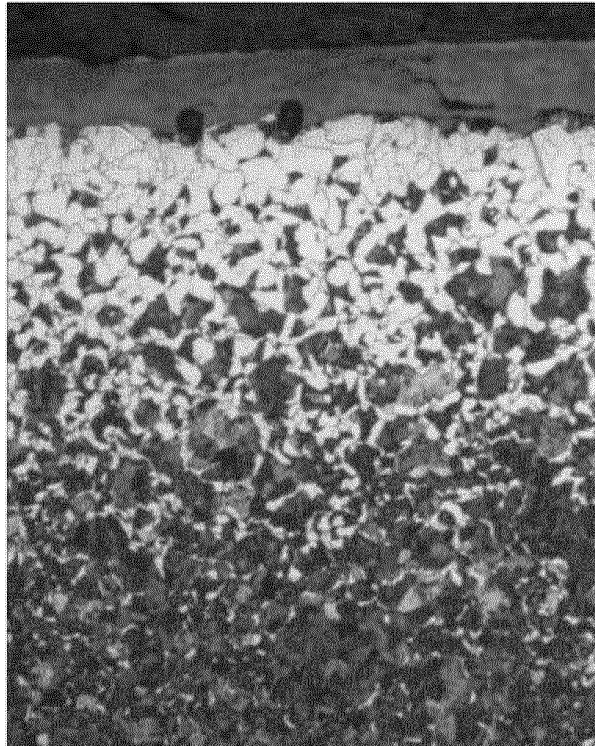


FIG. 4

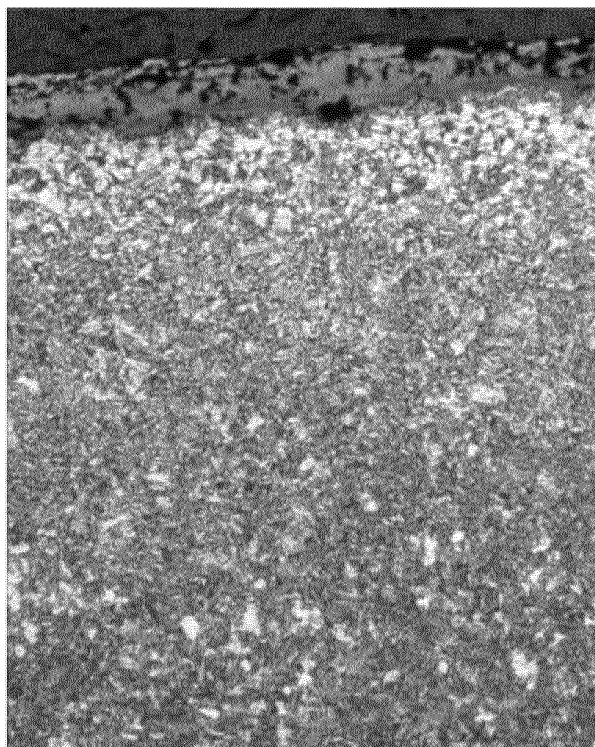


FIG. 5

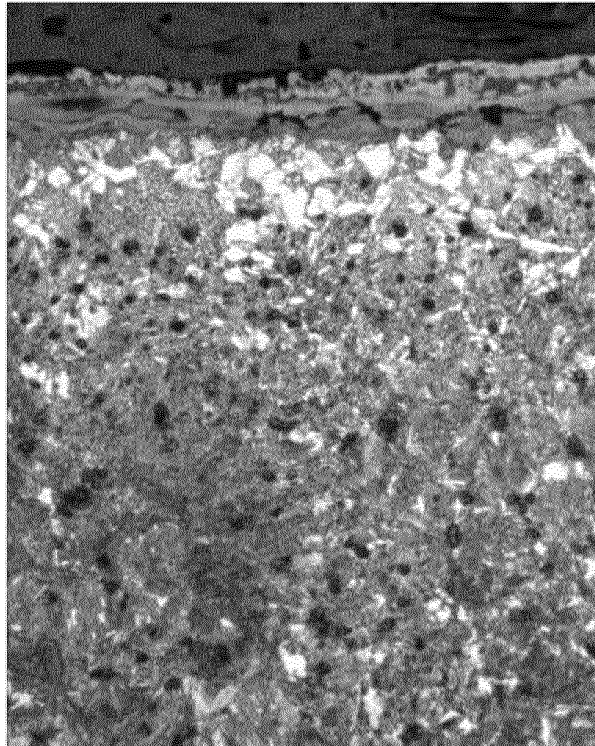


FIG. 6

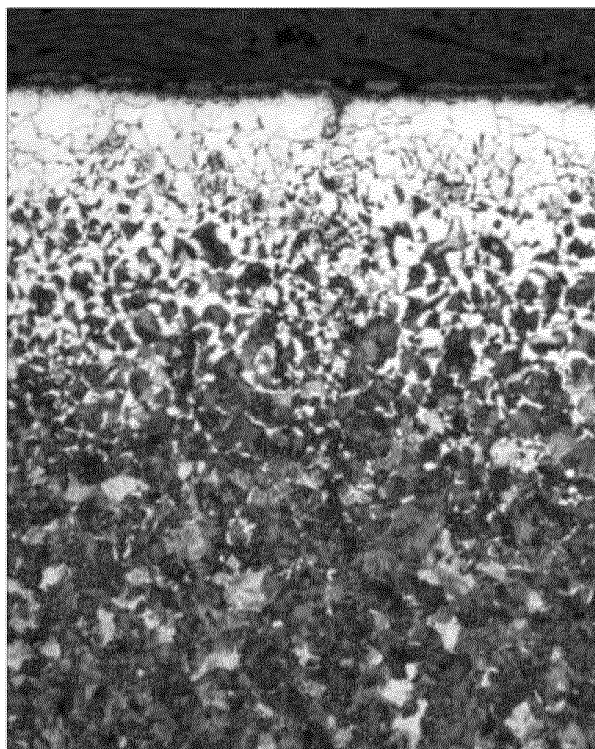


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/ES2015/070582

A. CLASSIFICATION OF SUBJECT MATTER	INV. C22C38/02 C22C38/04 C22C38/12 C22C38/18 C22C38/22 C21D8/06 C21D9/02 ADD.	
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols)	C22C C21D	
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)	EPO-Internal, WPI Data, INSPEC	
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	
	Relevant to claim No.	
X	JP H08 170152 A (KOBE STEEL LTD) 2 July 1996 (1996-07-02) abstract; tables 1, A5	1-5
X	EP 0 676 482 A1 (MITSUBISHI STEEL MFG [JP]) 11 October 1995 (1995-10-11) page 1, lines 10-11; tables 1, ex. 8	1-5
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A	JP S60 86245 A (DAIDO STEEL CO LTD) 15 May 1985 (1985-05-15) abstract; tables 1, ex. 6	1-5
☐ Further documents are listed in the continuation of Box C.	☒ See patent family annex.	
* Special categories of cited documents :		
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention	
"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone	
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"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family	
"P" document published prior to the international filing date but later than the priority date claimed		
Date of the actual completion of the international search	Date of mailing of the international search report	
13 April 2016	21/04/2016	
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer	
	Chebeleu, Alice	

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/ES2015/070582

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JP S6086245 A	15-05-1985	NONE	

REFERENCES CITED IN THE DESCRIPTION

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