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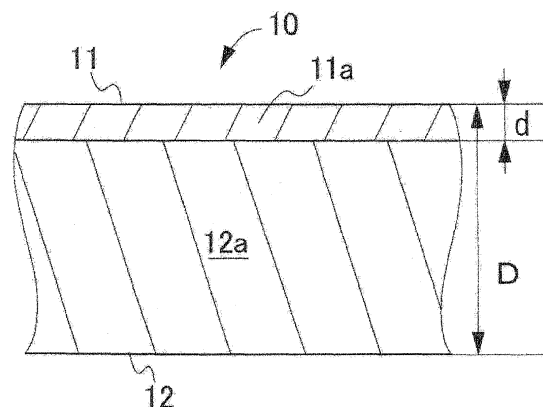
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(54) **Leaf spring material and manufacturing method thereof**

(57) The present invention provides a leaf spring material superior in mechanical characteristics and a manufacturing method of the leaf spring material capable of reliably achieving the same, utilizing induction hardening. The manufacturing method of the leaf spring material comprises the steps of imparting tensile stress on a first surface along the longitudinal direction of the first surface and compressive stress on a second surface along the longitudinal direction of the second surface of a substantially strip-shaped steel plate, and subjecting the first surface to induction hardening. With this induction hardening, an induction-hardened structure having a higher average hardness than that of a parent material structure in the vicinity of the second surface and comprising martensite and finely and evenly dispersed austenite is imparted on a surface layer in the vicinity of the first surface.

Fig. 2



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Description**BACKGROUND OF THE INVENTION****Field of the Invention**

[0001] The present invention relates to a leaf spring material and a manufacturing method thereof, and more specifically to a leaf spring material and a manufacturing method thereof that utilizes heat treatment based on induction hardening so as to improve the service life of the spring.

Description of the Background Art

[0002] The spring material used for "springs" is provided by cold or hot forming a metal material made of spring steel so as to impart a "spring" shape to the material, and heat treating the material by quenching and tempering. Additionally, in order to improve fatigue strength, shot peening is also widely performed on the surface of the spring material so as to impart compressive residual stress in the material. In recent years, spring materials in which the fatigue strength is improved by performing quenching using a high frequency induction heating apparatus have also been known.

[0003] For example, in JP, A, 2004-323912 is disclosed a coil spring material in which a cold-formed coil is subjected to heat treatment using a high frequency induction heating apparatus so as to improve the fatigue strength. In general, however, when austenite remains after the quenching and tempering of the spring material, the fatigue strength of the "spring" decreases, making such retained austenite unpreferable. Here, the publication of unexamined application states that the high frequency induction heating apparatus makes it possible to heat the coil and perform quenching with high accuracy and at high speed, thereby achieving a heat treatment that takes into sufficient consideration the metal material components of the coil and suppressing the amount of retained austenite to 3% or less. That is, the publication of unexamined application states that heat treatment conditions are optimized in order to reduce the retained austenite, thereby improving the fatigue strength of the spring.

[0004] Additionally, a spring material that is partially subjected to heat treatment using a high frequency induction heating apparatus so as to improve fatigue strength is also known.

[0005] For example, in JP, A, 2006-71082 is disclosed a manufacturing method of a spring material in which induction hardening is performed only on one surface of the leaf spring material. Specifically, a substantially strip-shaped leaf spring material made of spring steel is hot formed and subjected to quenching and tempering. That is, a normal leaf spring material is achieved. Subsequently, since the leaf spring material is provided with thickness, load is added in the same direction as the state of usage of the leaf spring, generating tensile stress on a first surface and compressive stress on a second surface. When heat is applied in the vicinity of the first surface on which the tensile stress acts using a high frequency induction heating apparatus, stress relaxation occurs in that surface vicinity, thereby alleviating the tensile stress. Then when the load is released after cooling, the first surface is imparted with compressive stress, making it possible to achieve a spring material with high fatigue strength.

[0006] As in the disclosure of the first publication of unexamined application, the high frequency induction heating apparatus makes it possible to subject the spring material to heat treatment with high accuracy, thereby reliably imparting a metal structure of high fatigue strength to the spring material. Additionally, as in the disclosure of the second publication of unexamined application, a composite structure can be achieved by partially subjecting the spring material to heat treatment, resulting in a promising spring material superior in "spring" mechanical characteristics. Recently, however, an even higher fatigue strength is in demand.

[0007] The present invention has been made in view of the above circumstances, and it is an object of the present invention to provide a leaf spring material superior in mechanical characteristics, and a manufacturing method of the leaf spring material capable of reliably achieving the same, utilizing high frequency induction heating.

SUMMARY OF THE INVENTION

[0008] The manufacturing method of a leaf spring material according to the present invention comprises the steps of: imparting tensile stress on a first surface along the longitudinal direction of the first surface and compressive stress on a second surface along the longitudinal direction of the second surface of a substantially strip-shaped steel plate, and subjecting the first surface to induction hardening. The induction hardening imparts in the vicinity of the first surface an induction-hardened structure having a higher average hardness than that of the parent material in the vicinity of the second surface and comprising martensite and finely dispersed austenite.

[0009] According to the manufacturing method of the leaf spring material of the present invention, it is possible to achieve an induction-hardened structure having a higher average hardness than that of the parent material structure and comprising martensite and finely dispersed austenite. While this induction-hardened structure includes austenite,

the austenite is finely and evenly dispersed, significantly preventing a decrease in quenched hardness. The achieved high average hardness enhances the fatigue strength of the spring, improving the spring service life.

[0010] The finely and evenly dispersed austenite in the induction-hardened structure generates stress induced transformation when used as a leaf spring, breaking down into fine martensite. With use as a "spring," the compressive stress in the vicinity of the first surface is further increased, imparting high fatigue strength to the leaf spring material. That is, an improved spring service life is achieved.

[0011] The quenching conditions of the leaf spring material having such a long spring service life are optimized by so-called stress-induced hardening which performs induction hardening while imparting tensile stress. The structure unique to induction hardening can be achieved by using simple high frequency induction heating with stable temperature control. Therefore, the structure makes it possible to provide a leaf spring material having a stable and long spring service life.

[0012] Furthermore, the leaf spring material according to the present invention comprises a substantially strip-shaped steel plate having a first surface and a second surface. Such a leaf spring material has in the vicinity of the first surface an induction-hardened structure having an average hardness higher than that of the parent material structure in the vicinity of the second surface and comprising martensite and finely and evenly dispersed austenite.

[0013] Such an induction-hardened structure includes austenite. Nevertheless, because the structure is a unique induction-hardened structure wherein the austenite is finely and evenly dispersed, the quenched hardness is not significantly reduced. That is, the high hardness resulting from the induction-hardened structure makes it possible to enhance the fatigue strength of the spring and improve the spring service life.

[0014] Further, the finely and evenly dispersed austenite of the induction-hardened structure produces stress-induced transformation when used as a leaf spring, breaking down into fine martensite. With use as a "spring," the compressive stress in the vicinity of the first surface is further increased, imparting high fatigue strength to the leaf spring material. That is, an improved spring service life is achieved.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015]

FIG. 1 is a diagram showing the manufacturing method of a leaf spring material according to the present invention.

FIG. 2 is a partial cross-sectional view of the leaf spring material according to the present invention.

FIG. 3 is a graph showing the relationship between heat treatment temperature, hardness distribution, and residual stress distribution.

FIG. 4 is an etched photograph of a typical induction-hardened structure.

FIG. 5 is an etched photograph of a typical parent material structure.

FIG. 6 is a graph showing the relationship between the depth direction distribution of retained austenite before and after a fatigue test.

FIG. 7 is a graph showing the relationship between retained austenite and heat treatment temperature.

FIG. 8 is a graph showing the relationship between the X-ray based half value breadth $\Delta 2\theta$ and heat treatment temperature.

FIG. 9 is a graph showing the comparison of retained austenite distribution in the depth direction with respect to the applied stress at the present invention.

FIG. 10 is a graph showing the relationship between mean stress and number of cycles to failure in fatigue tests of the leaf spring materials of the present invention and comparison examples.

FIG. 11 is a graph showing the relationship between the X-ray based half value breadth $\Delta 2\theta$ and number of cycles to failure.

FIG. 12 is a diagram showing the results of fatigue tests with respect to heat treatment temperature and hardened layer thickness.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0016] An embodiment of a leaf spring material and the manufacturing method thereof according to the present invention will now be described.

[0017] A metal material made of spring steel or the like is cool or heat formed so as to prepare the leaf spring material imparted with a "leaf spring" shape. That is, a normal leaf spring material is prepared. Under ambient temperature, a load is added to such a leaf spring material made of a steel plate bent into a substantially strip shape, in the same direction as when used as a "spring." That is, the leaf spring material of a bent shape is straightened out and fixed as a substantially flat plate. At this time, because the leaf spring material is provided with thickness, tensile stress is generated along the longitudinal direction on the first surface thereof, and compressive stress is generated along the longitudinal direction of the second surface on the opposite side. To achieve a typical induction hardened structure described later,

a higher tensile stress on the first surface is preferred. Such tensile stress is 1000MPa or higher at ambient temperature. This tensile stress can be changed by the leaf spring material shape, thickness, fixed shape, and the like.

[0018] When induction hardening is performed on the first surface with the leaf spring material straightened out and fixed as a flat plate, the tensile stress of that surface is quickly alleviated by heat. When the fixed state and the load are released after cooling, compressive residual stress is imparted on the first surface of the leaf spring material. Subsequently, heat treatment at 80°C to 160°C for a duration shorter than 120 minutes is preferably performed. The structure, thickness, and the like of the induction-hardened structure described later can be controlled by high frequency induction heating source output and cooling conditions.

[0019] With the leaf spring material obtained after heat treatment such as the above-described stress-induced hardening and arbitrarily performed low-temperature tempering, however, the vicinity of the second surface located on the side opposite the first surface subjected to induction hardening has the structure of the parent material. That is, the second surface vicinity has the same structure as that of the leaf spring material initially prepared, which is the parent material structure comprising one or more of martensite, a tempered martensite structure, troostite, sorbite, bainite, ferrite, and pearlite. Furthermore, the first surface vicinity also has the same structure as the parent material structure prior to induction hardening. Nevertheless, stress-induced hardening is performed so as to obtain in the vicinity of the first surface an induction-hardened structure having a higher average hardness than that of the parent material structure of 650HV or higher and comprising martensite and finely and evenly dispersed austenite. Such high hardness enhances the fatigue strength of the "spring" and improves the spring service life. Here, the thickness of the induction-hardened structure is preferably 5 to 10 percent of the thickness of the leaf spring material.

[0020] Further, stress-induced hardening is performed so as to increase the volumetric content of austenite, and this volumetric content is preferably 15% or higher. Such austenite is preferably made into an equally and evenly dispersed fine grain having an average grain size of 500nm or less, preferably 100nm or less, by performing stress-induced hardening while imparting high tensile stress. Such unique austenite having an induction-hardened structure generates stress-induced transformation when used as a leaf spring, breaks down into fine martensite and, with use as a "spring," further increases the compressive stress in the vicinity of the first surface. Thus, a higher fatigue strength is imparted on the leaf spring material, making it possible to improve the spring service life.

[0021] Furthermore, when induction hardening is performed while imparting a large tensile stress as described above on the first surface, the grain size of the induction-hardened structure is refined more than that of the parent material structure, making it possible to vastly improve spring service life. Preferably, the grain size number of the parent material structure is 8 to 10, and the grain size number of the induction-hardened structure is 11 to 13.

[0022] Furthermore, a compressive residual stress of 650MPa or higher of the induction-hardened structure is preferably imparted on the spring plate, thereby vastly improving spring service life.

[0023] The strain state of such an induction-hardened structure can be measured when the half value breadth of an Fe (200)_α diffraction peak is measured using a CrKα beam diffractometer, making it possible to simply estimate spring service life. A half value breadth of 8° or higher is preferred since such a value vastly improves spring service life.

[0024] As described above, according to the leaf spring material of the present invention based on the manufacturing method of the present invention, a fatigue life equivalent to three times that of a leaf spring material comprising conventional and a typical modified-ausformed material is reliably obtained when evaluated at a B₁₀ life, which is the fatigue life based on Weibull statistics and probability, for example.

[0025] An embodiment of the leaf spring material and the manufacturing method thereof according to the present invention will now be described in detail, with reference to FIG. 1 and FIG. 2.

[0026] While in the following an embodiment employing JIS SUP11A steel is described in detail, the steel type is not limited thereto. Particularly, similar implementation is possible using a general spring steel (JIS4801) or its equivalent.

[0027] As shown in FIG. 1, a steel plate comprising a spring steel of a ferrite and pearlite dual phase structure is cut into a strip shape of predetermined dimensions. This steel is then shaped while heated and subjected to the heat treatment of quenching and tempering, resulting in a bent-shaped pre-treated leaf spring material 10-1 of the present invention. This process is publicly known and will therefore not be described. Such a pre-treated leaf spring material 10-1 has a tempered martensite structure. Materials such as an as-is leaf spring material of the ferrite and pearlite dual phase structure not subjected to tempering, or a leaf spring material having a bainite structure may also be suitably used.

[0028] As shown in FIG. 1(a), the pre-treated leaf spring material 10-1 is arranged on a fixed base 1 so that both upward warped end portions are on the top and the center portion is on the bottom.

[0029] As shown in FIG. 1(b), the pre-treated leaf spring material 10-1 is pressed down onto the fixed base 1 and fixed as a substantially flat plate using a clamp 2. At this time, due to the thickness of the pre-treated leaf spring material 10-1, a tensile stress TMPa is generated on a first surface (upper surface) 11, and a compressive stress is generated on a second surface (lower surface) 12.

[0030] As shown in FIG. 1(c), the first surface 11 is then heated at a predetermined output while moving high frequency induction heating means 3 along a longitudinal direction A of the pre-treated leaf spring material 10-1. As a result, the tensile stress of the first surface 11 is alleviated. With this, a surface layer 1 1a in the vicinity of the first surface 11

changes from a tempered martensite structure (or a ferrite + pearlite dual phase structure, a bainite structure, or the like) to a substantially single phase structure of austenite of a high-temperature phase.

[0031] On the other hand, the heated section of the first surface 11 is sequentially cooled while moving cooling means 4 in the direction A following the high frequency induction heating means 3. With this arrangement, the surface layer 11 a in the vicinity of the first surface 11 that changed to an austenite phase in the above-described heating process is quenched so as to change to a martensite + finely dispersed austenite dual phase structure.

[0032] Furthermore, the temperature distribution, quenched structure, and the like in the vicinity of the first surface of the pre-treated leaf spring material 10-1 can be adjusted by adjusting the tensile stress T, high frequency induction heating conditions (output, movement speed, and the like), and cooling conditions (cooling ability, movement speed, and the like). That is, factors such as the thickness of the surface layer 11 a, the austenite content of the surface layer 11 a, and the residual stress in the vicinity of the first surface 11 can be adjusted.

[0033] As shown in FIG. 1(d), the above-described high frequency induction heating and quenching is performed on a predetermined section, such as the center section only or from one end portion to the other end portion, for example, of the pre-treated leaf spring material 10-1, as suitably required.

[0034] As shown in FIG. 1(e), the clamp 2 is then released, thereby releasing the compressive stress of the second surface so that the leaf spring material 10 returns once again to a shape wherein both end portions are warped upward. At this time, compressive stress is generated in the vicinity of the first surface 11.

[0035] As shown in FIG. 2, the leaf spring material 10 (given a thickness D) according to the embodiment comprises a parent material layer 12a having a parent material structure comprising a tempered martensite structure (or, ferrite + pearlite dual phase structure, bainite structure, or the like), and the surface layer 11 a having a martensite + finely dispersed austenite dual phase structure (quenched structure) of a thickness d. Here, the parent material structure is preferably subjected to treatment that causes carbide to be evenly distributed.

[0036] Several advance experiments were conducted when preparing the embodiment and the comparison example samples described later.

[0037] FIG. 3 shows the measurement results of a hardness distribution 31 and a residual stress distribution 34 in the depth direction of the leaf spring material 10 wherein the substantially strip-shaped spring material 10-1 of an 18mm plate thickness comprising steel plate SUP11A was subjected to stress-induced hardening such as described above. The hardness distribution 31 was substantially constant in the depth direction from the first surface 11 at about 750HV, and suddenly decreased at the position at a depth of 1.5mm. Further, the compressive residual stress distribution 34 was 750MPa on the first surface 11 (depth: 0mm), but reached a maximum of 1200MPa or higher at the position at a depth of 1.5mm while the absolute value was increased, and then suddenly decreased.

[0038] Next, FIG. 3 shows a hardness distribution 32 and a compressive residual stress distribution 35 of the leaf spring material (hereinafter denoted 10') wherein the above-described leaf spring material 10 was subjected to heat treatment for one hour at 150°C. From the effect of the heat treatment, the hardness distribution 32 was at a level of approximately 650HV, a value lower than the hardness distribution 31 by about nearly 100. Further, the compressive residual stress distribution 35 was 650MPa on the first surface 11 (depth: 0mm), but reached a maximum of 1000MPa or higher at the position at a depth of 1.5mm while the absolute value was slightly increased. Subsequently, the value suddenly decreased.

[0039] Furthermore, FIG. 3 shows a hardness distribution 33 and a compressive residual stress 36 of the leaf spring material wherein the above-described leaf spring material 10 was subjected to heat treatment of one hour at 250°C. From the effect of the heat treatment, the hardness distribution 33 was at a level of approximately 500HV, a value lower than the hardness distributions 31 and 32. Further, the compressive residual stress distribution 36 was 400MPa on the first surface 11, and the absolute value was lower than those of the compressive stress residual stress distributions 34 and 35. The compressive residual stress distribution 36 reached a maximum of 750MPa at the position at a depth of 1.5mm while the absolute value was slightly increased, but then suddenly decreased.

[0040] Lastly, FIG. 3 shows a compressive residual stress distribution 37 of the leaf spring material 10-1 wherein induction hardening was performed without tempering and without a stress load applied. Since the distribution was substantially the same as the compressive residual stress distribution 36, it is understood from the figure that the effect resulting from loaded stress is lost when heat treatment is performed for one hour at 250°C.

[0041] Further, the cross-sectional structure of the leaf spring material 10' wherein the above-described leaf spring material 10 was subjected to heat treatment for one hour at 150°C was observed.

[0042] As shown in FIG. 4, a typical induction-hardened structure of the surface layer 11a of the leaf spring material 10' is a dual-phase mixed structure of retained austenite and a fine tempered martensite structure having an old austenite grain boundary of a grain size number of 12 or higher, and the retained austenite existed finely and evenly in a granular shape in the sub-micron order as if evenly dispersed on the old austenite grain boundary. According to EBSD analysis (measurement at an acceleration voltage of 25kV using a TSL manufactured OIM EBSD detector), the retained austenite was approximately 15% by volume based on the volumetric content converted from surface area, and was finely and evenly dispersed in a granular shape in the sub-micron order. As described later, this amount matches the retained

austenite found from X-ray analysis. On the other hand, as shown in FIG. 5, the parent material structure is typically a tempered martensite structure, and the retained austenite was substantially not detected.

[0043] Next, the retained austenite distribution in the induction-hardened structure of the leaf spring material 10 wherein the substantially strip-shaped spring material 10-1 of an 18mm plate thickness comprising SUP11A steel plate was subjected to stress-induced hardening so as to impart the surface layer 11a of 1.5mm was examined before and after a fatigue test. Furthermore, the retained austenite was calculated in X-ray analysis from the diffraction intensity (integrated value) ratios of $(200)_\alpha$ and $(211)_\alpha$, $(200)_\gamma$ and $(220)_\gamma$ at a tube voltage of 40kV and a tube current of 200mA using a Co tube.

[0044] As indicated by a curve 41 of FIG. 6, the retained austenite in the surface 11 (depth: 0 mm) of the leaf spring material 10 was approximately 25% by volume and then suddenly decreased at a depth of approximately 1mm from the surface 11, decreasing to approximately 15% by volume or higher at a depth of approximately 1.2mm and to substantially 0 at a depth of approximately 1.5mm. When a fatigue test was conducted on this leaf spring material 10, the retained austenite of the surface 11, as indicated by a curve 42, decreased to approximately 13% by volume, with substantially no change at the position approximately 0.5mm deeper. That is, the finely and evenly distributed austenite unique to the induction-hardened structure changes to fine martensite as a result of stress induced transformation. At this time, the ductility of the spring material surface improves due to the transformation-induced plasticity, improving the fatigue strength of the "spring" as well. To obtain such an effect, as further described later, an austenite content that is greater than a predetermined amount is required, preferably a content that is greater than or equal to 15% by volume. On the other hand, the non-transformed austenite after stress-induced transformation suppresses strength. That is, to impart strength that will result in a hardness of 650HV or higher, the austenite content is preferably less than or equal to 30% by volume.

[0045] Next, the heat treatment temperature and retained austenite of the leaf spring material 10 wherein the substantially strip-shaped spring material 10-1 of an 18mm plate thickness comprising SUP11A steel plate was subjected to stress-induced hardening so as to impart the surface layer 11a of 1.5mm were measured.

[0046] As indicated by a curve 51 of FIG. 7, when the heat treatment temperature increases, the retained austenite breaks down into low carbon martensite and ϵ carbide, thereby decreasing in content. Further, in the course of this breakdown, contraction occurs, causing tensile stress to act and, as a result, a decrease in fatigue strength. In consequence, to improve the fatigue strength of the spring material by transformation-induced plasticity, it is necessary to limit the heat treatment temperature under a predetermined temperature.

[0047] Furthermore, as shown in FIG. 8, the half value breadth $\Delta 2\theta$ of $\text{Fe } (200)_\alpha$ decreases as the heat treatment temperature rises. That is, because the martensite also breaks down into low carbon martensite and ϵ carbide by heat treatment, resulting in a decrease in average hardness and residual stress, to maintain a hardness of a predetermined level or higher, action should be taken to ensure that the heat treatment temperature is not too high. This experiment will be further described later. [Measurement of the half value breadth of $(200)_\alpha$ in X-ray analysis was conducted under conditions including a Cr tube, a tube voltage of 30kV, and a tube current of 10mA.]

[0048] Next, the relationship between a tensile stress T and the depth direction distribution of the retained austenite of the leaf spring material 10 wherein the substantially strip-shaped spring material 10-1 of an 18mm plate thickness comprising SUP11A steel plate was subjected to stress-induced hardening so as to impart the surface layer 11a of 1.5mm was measured.

[0049] As shown in FIG. 9, compared to a retained austenite 71 of the leaf spring material 10 at the tensile stress $T = 1000\text{MPa}$, a retained austenite 72 of the leaf spring material 10 to which a tensile stress is not loaded is low in the vicinity of the surface. That is, retained austenite can be increased by increasing tensile stress. The reason for this is conceivably as follows. That is, when the tensile stress T acts during induction hardening, many transformed nuclei are generated and the growth of each is suppressed by the interference with neighboring nuclei. For this reason, the amount of austenite retained increases without transformation completed.

[0050] Based on the above experiment results, quenching conditions were changed to the substantially strip-shaped pre-treated leaf spring material 10-1 of an 18mm plate thickness comprising SUP11A steel plate and, as shown in Table 1, 18 samples for embodiments 1 to 5 and comparison examples 1 to 13 were prepared.

Table 1

Sample Name	Tensile Stress (MPa)	Induction Hardened Thickness (%)	Heat Treatment Temperature (°C)	Reference Code
Embodiment 1	1000	8.1	none	-
Embodiment 2	1000	8.1	150	81
Embodiment 3	1200	7.4	150	101
Embodiment 4	1000	7.4	none	82

(continued)

Sample Name	Tensile Stress (MPa)	Induction Hardened Thickness (%)	Heat Treatment Temperature (°C)	Reference Code
Embodiment 5	1000	7.4	150	83
Comparison example 1	1000	8.1	250	-
Comparison example 2	0	8.1	none	-
Comparison example 3	1000	10.4	150	84
Comparison example 4	1000	10.4	300	85
Comparison example 5	500	10.4	150	91
Comparison example 6	500	10.4	300	92
Comparison example 7	0	10.4	150	102
Comparison example 8	0	10.4	300	103
Comparison example 9	1000	8.1	300	86
Comparison example 10	500	8.1	150	93
Comparison example 11	500	8.1	300	94
Comparison example 12	0	8.1	150	104
Comparison example 13	0	8.1	300	105

[0051] First, fatigue tests were conducted with each sample, that is, with embodiment 2 (reference code 81), embodiment 4 (reference code 82), embodiment 5 (reference code 83), comparison example 3 (reference code 84), comparison example 4 (reference code 85), and comparison example 9 (reference code 86) of Table 1, given 1000MPa as the tensile stress T. FIG. 10 shows the number of cycles to failure for each of these samples. The stress amplitudes were 0.8 times of the mean stress shown on the vertical axis of FIG. 10, that is, 0.8 times 650, 700, and 750MPa, respectively. The dashed line M in the figure shows the fatigue life equivalent to three times of a known and typical modified-ausformed material at the B₁₀ life.

[0052] Embodiment 2 (reference code 81), embodiment 4 (reference code 82), and embodiment 5 (reference code 83) are located on the greater number of cycles to failure than the dashed line M. On the other hand, comparison example 3 (reference code 84), comparison example 4 (reference code 85), and comparison example 9 (reference code 86) are located less than the dashed line M. That is, the spring material in which the induction hardening depth is 10% or less and the heat treatment temperature is 150°C or less reliably exhibits a fatigue life equivalent to three times of the known and typical modified-ausformed material at the B₁₀ life or higher.

[0053] Next, FIG. 11 shows the relationship between the half value breadth of Fe (200)_α when X-ray analysis is conducted under conditions including a Cr tube, a tube voltage of 30kV, and a tube current of 10mA, and the number of cycles to failure based on a fatigue test, for the above-described leaf spring material 10. In the relationship between half value breadth Δ2θ and number of cycles to failure, the number of cycles to failure of the leaf spring material is 4 x 10⁵ or higher for a half value breadth of more than 8°, and 2 x 10⁵ or less for a half value breadth of less than 8°. Furthermore, reference codes 111, 112, and 113 indicate the respective results at a mean stress of 650MPa, 700MPa,

and 750MPa, respectively. On reflection, in FIG. 8, the half value breadth $\Delta 2\theta$ was smaller than 8° at heat treatment temperatures higher than 160°C . That is, when viewed together with FIG. 11, fatigue life decreases when the heat treatment temperature is higher than 160°C . This decrease is in response to the advances in the breakdown of quenched martensite to low carbon martensite and ϵ carbide ($\text{Fe}_{2.4}\text{C}$) in the vicinity of 160°C .

[0054] Furthermore, FIG. 12 shows the number of cycles to failure (k) based on a fatigue test of the above-described leaf spring material 10 when the depth of the surface layer 11a having high hardness is changed. According to this figure, a predetermined fatigue life is obtained with heat treatment of lower temperatures, preferably temperatures lower than 160°C . With such a preferred heat treatment temperature, fatigue life increases to the extent that the thickness (depth) d of the surface layer 11 a increases. On the other hand, a larger thickness d of the surface layer 11 a results in a relative decrease in the stress (restoring force) imparted from the parent material layer 12a, thereby decreasing the compressive residual stress of the surface 11. Thus, the thickness d of the surface layer 11 a is preferably 10% of the thickness D of the spring material 10 or lower. On the other hand, if the thickness d of the surface layer 11a is too small, the effects such as described above of the surface layer 11a decreases. Thus, the thickness d of the surface layer 11a is preferably 5% of the thickness D of the spring material 10 or higher.

[0055] With the above, according to the spring material of the present embodiment, a fatigue life equivalent to three times of a known and typical modified-ausformed material at the B_{10} life or higher is reliably achieved.

[0056] Furthermore, while representative embodiments according to the present invention and modifications based thereon have been described, the present invention is not limited thereto. It will be apparent to those skilled in the art that various modifications and variations can be made in the present invention without departing from the spirit or scope of the present invention.

[0057] In summary an embodiment of the invention can be described as follows:

[0058] The present invention provides a leaf spring material superior in mechanical characteristics and a manufacturing method of the leaf spring material capable of reliably achieving the same, utilizing induction hardening. The manufacturing method of the leaf spring material comprises the steps of imparting tensile stress on a first surface along the longitudinal direction of the first surface and compressive stress on a second surface along the longitudinal direction of the second surface of a substantially strip-shaped steel plate, and subjecting the first surface to induction hardening. With this induction hardening, an induction-hardened structure having a higher average hardness than that of a parent material structure in the vicinity of the second surface and comprising martensite and finely and evenly dispersed austenite is imparted on a surface layer in the vicinity of the first surface.

Claims

1. A manufacturing method of a leaf spring material that comprises the steps of:

imparting tensile stress on a first surface along the longitudinal direction of said first surface and compressive stress on a second surface along the longitudinal direction of said second surface of a substantially strip-shaped steel plate; and subjecting said first surface to induction hardening, wherein:

said induction hardening imparts in the vicinity of said first surface an induction-hardened structure having a higher average hardness than a parent material structure in the vicinity of said second surface and comprising martensite and finely dispersed austenite.

2. The manufacturing method of a leaf spring material according to claim 1, wherein said parent material structure comprises one or more of martensite, tempered martensite structure, troostite, sorbite, bainite, ferrite, and pearlite.

3. The manufacturing method of a leaf spring material according to claim 1 or 2, wherein said induction-hardened structure has a grain size smaller than that of said parent material structure.

4. The manufacturing method of a leaf spring material according to claim 3, wherein the grain size number of said parent material structure is 8 to 10, and the grain size number of said induction-hardened structure is 11 to 13.

5. The manufacturing method of a leaf spring material according to any of the preceding claims, comprising the step of:

releasing the load of said tensile stress after said induction hardening, wherein said tensile stress is 1000MPa or higher at ambient temperature.

6. The manufacturing method of a leaf spring material according to claim 5, comprising the step of low temperature tempering at the temperature of 80°C to 160°C for a duration shorter than 120 minutes after said induction hardening.

7. A leaf spring material that comprises a substantially strip-shaped steel plate having a first surface and a second surface, comprising:

in the vicinity of said first surface an induction-hardened structure having a higher average hardness than that of a parent material structure in the vicinity of said second surface and comprising martensite and finely dispersed austenite.

8. The leaf spring material according to claim 7, wherein said parent material structure comprises one or more of martensite, tempered martensite structure, troostite, sorbite, bainite, ferrite, and pearlite.

9. The leaf spring material according to claim 7 or 8, wherein the grain size number of said parent material structure is 8 to 10, and the grain size number of said induction-hardened structure is 11 to 13.

10. The leaf spring material according to any of claims 7 to 9, wherein said induction-hardened structure has a hardness of 650HV or higher.

11. The leaf spring material according to claim 10, wherein the volumetric content of said austenite of said induction-hardened structure is 15% or higher.

12. The leaf spring material according to one of claims 7 to 11, wherein said austenite has an average grain size of 500nm or less.

13. The leaf spring material according to one of claims 7 to 12, wherein said induction-hardened structure is distributed at a thickness of 5 to 10% of the thickness of said steel plate.

14. The leaf spring material according to one of claims 7 to 13, wherein said induction-hardened structure has a compressive residual stress of 650MPa or higher.

15. The leaf spring material according to one of claims 7 to 14, wherein a half value breadth of an Fe (200) α diffraction peak of said induction-hardened structure based on a CrKa beam diffractometer is 8° or higher.

Fig. 1

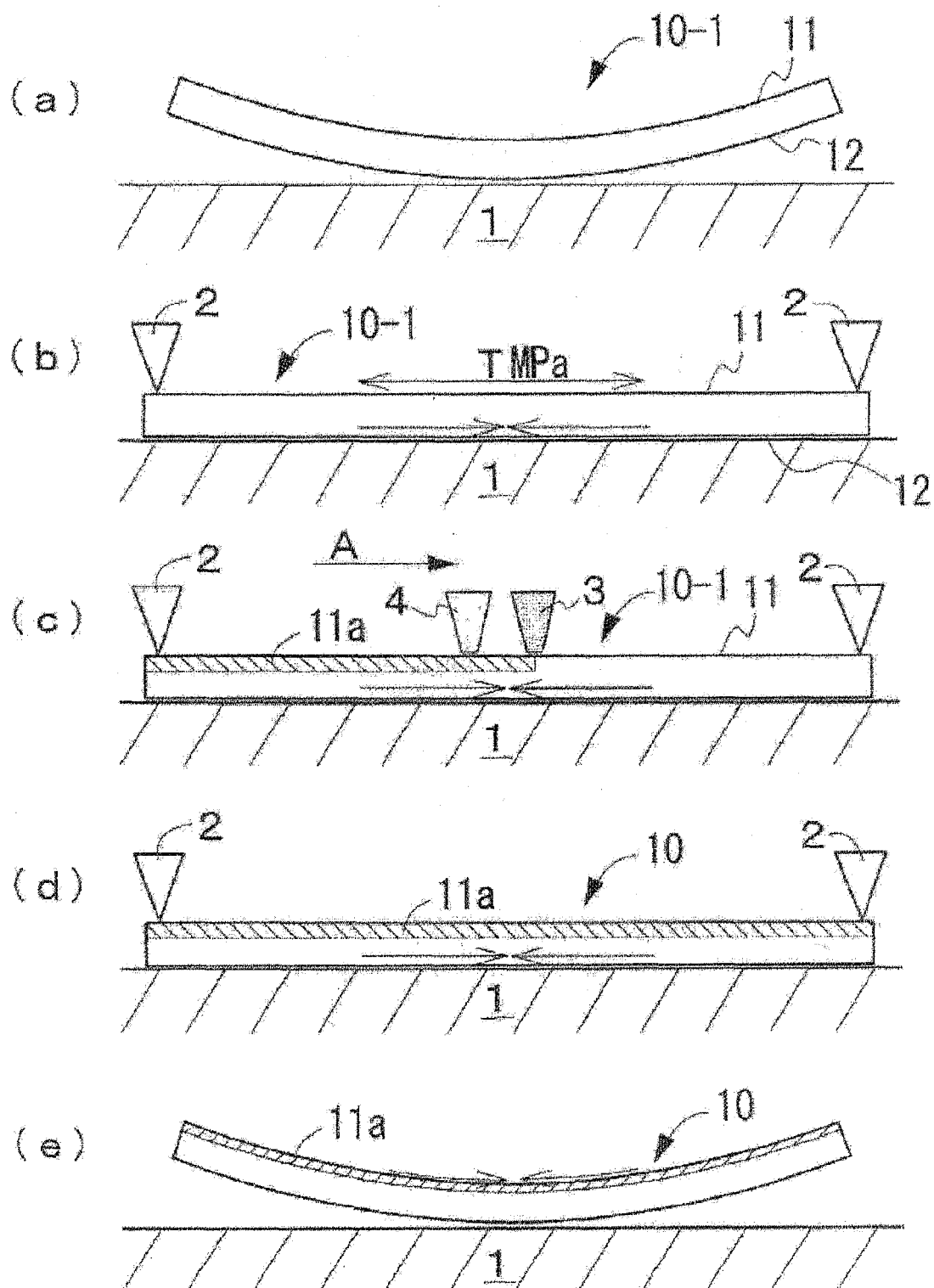


Fig. 2

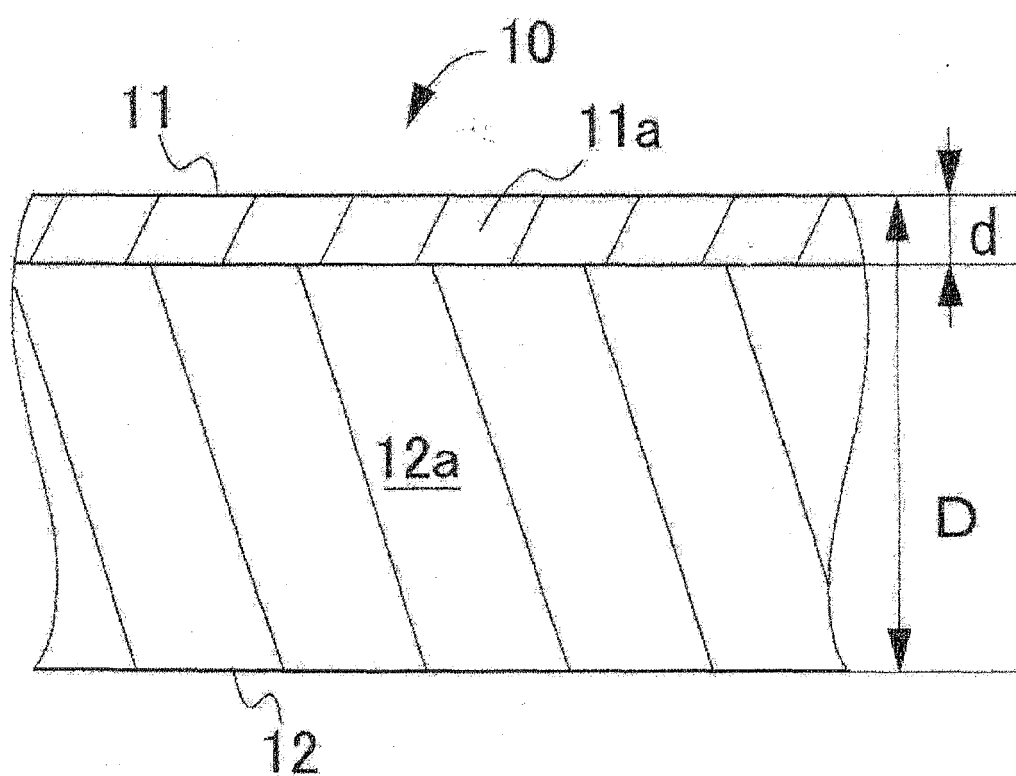


Fig. 3

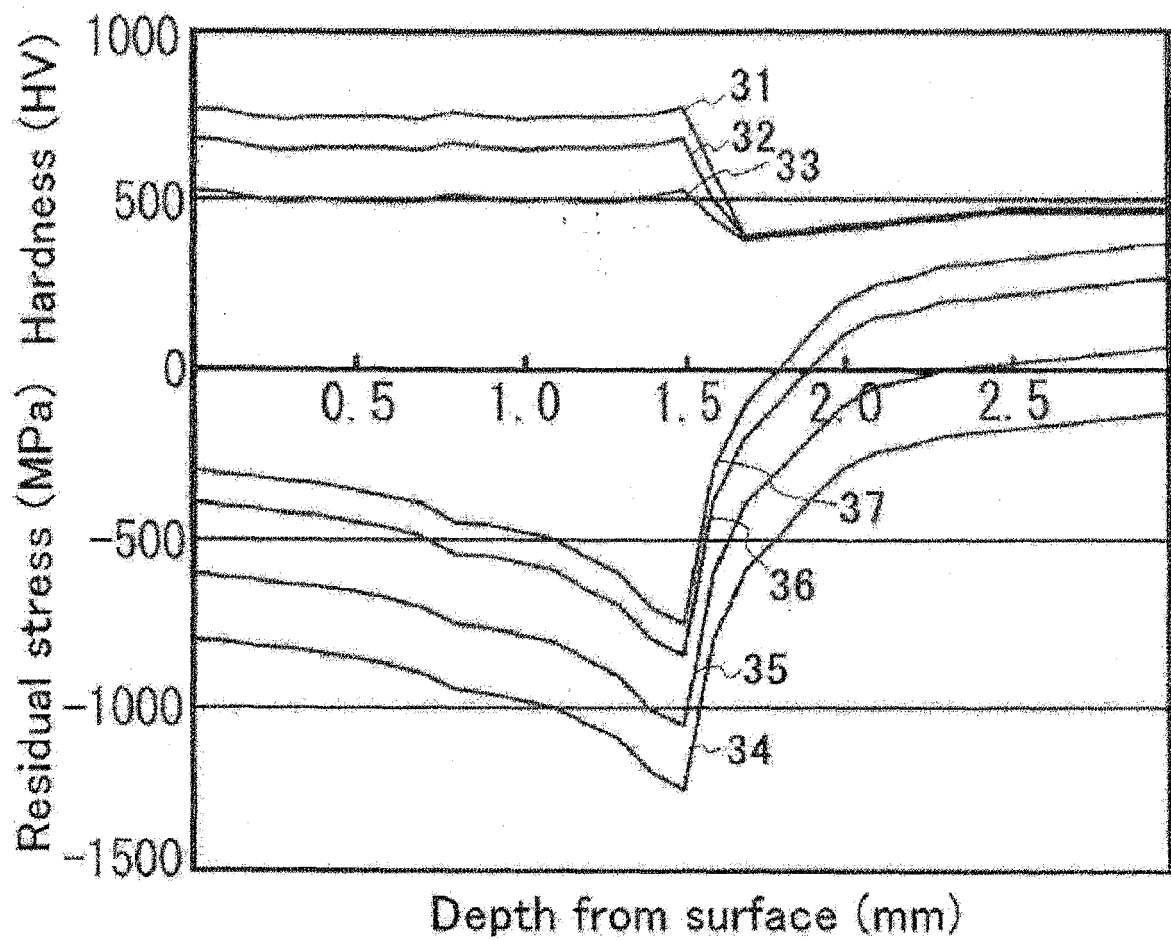


Fig. 4

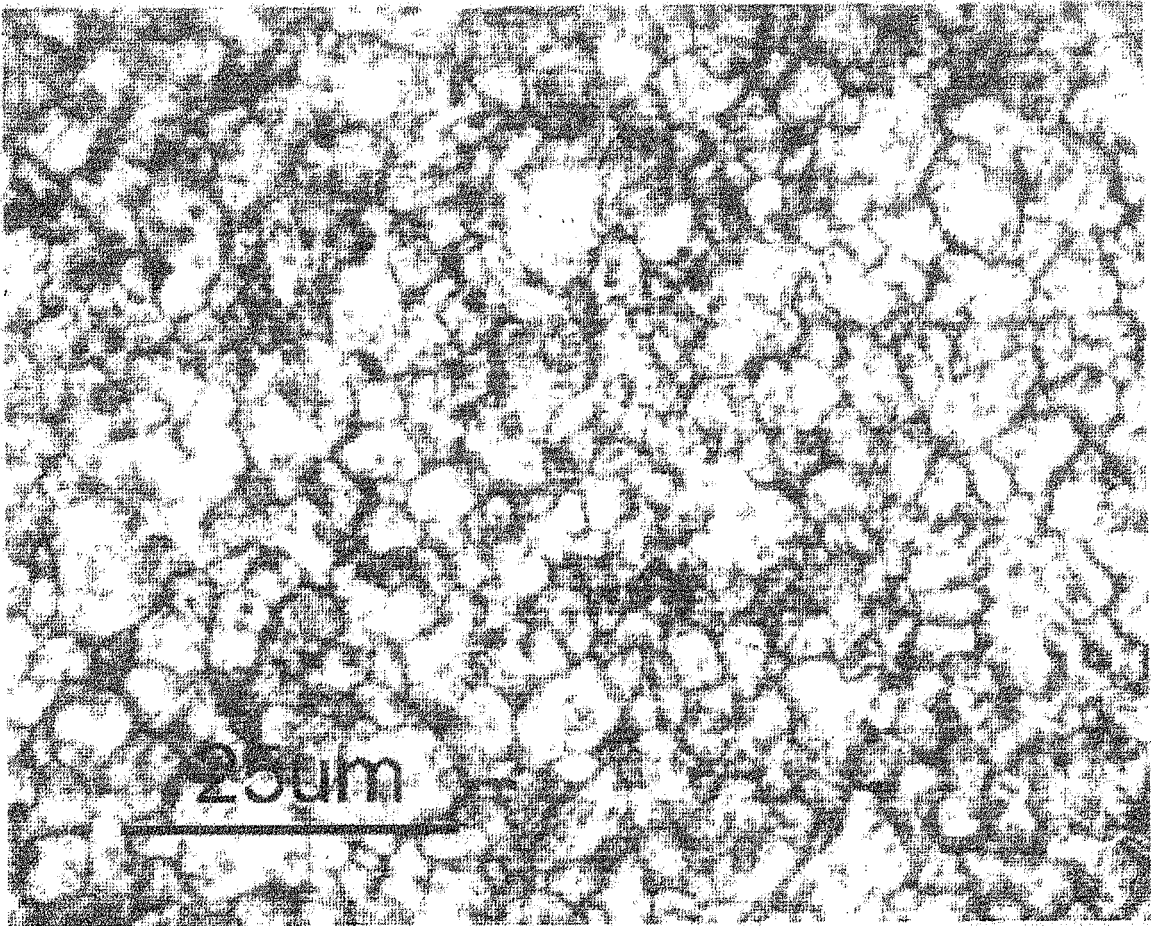


Fig. 5

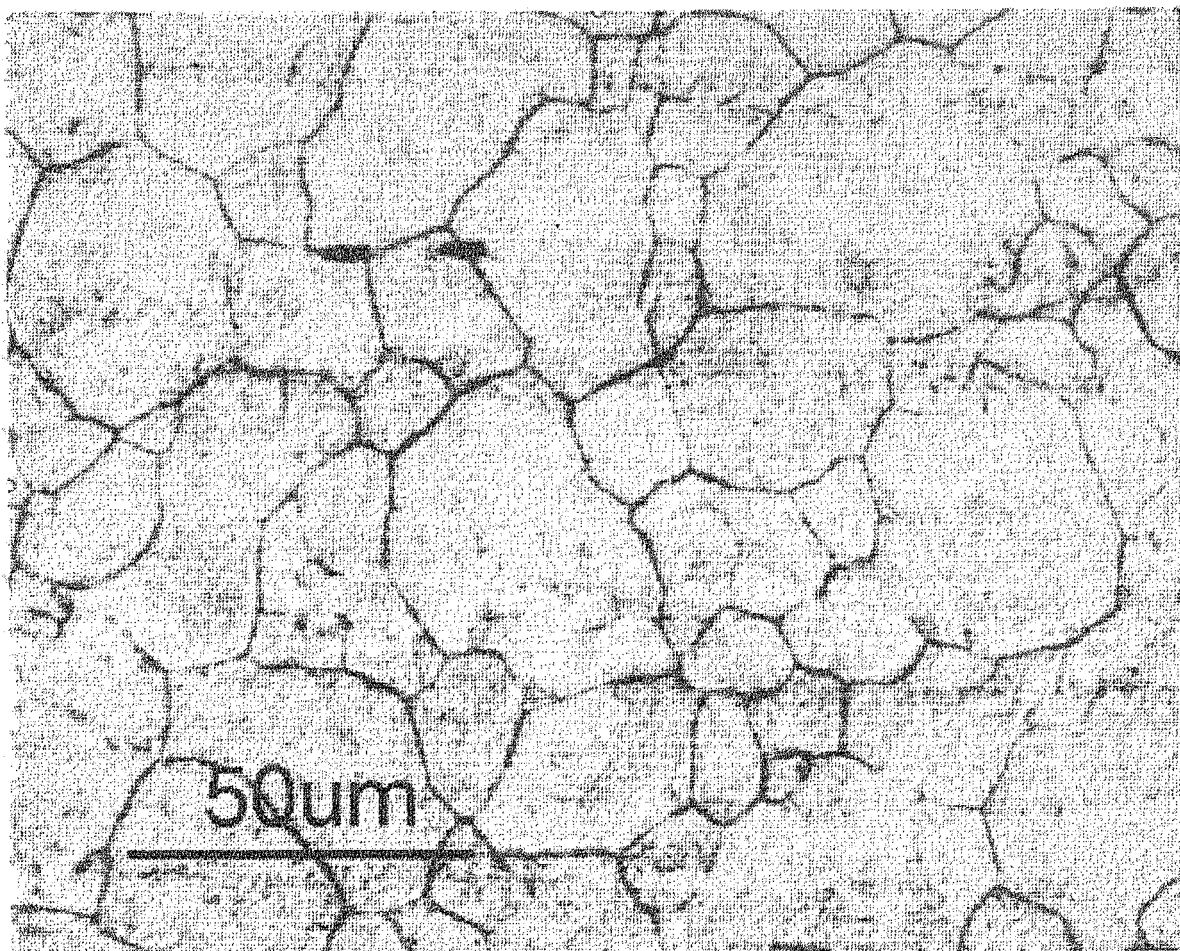


Fig. 6

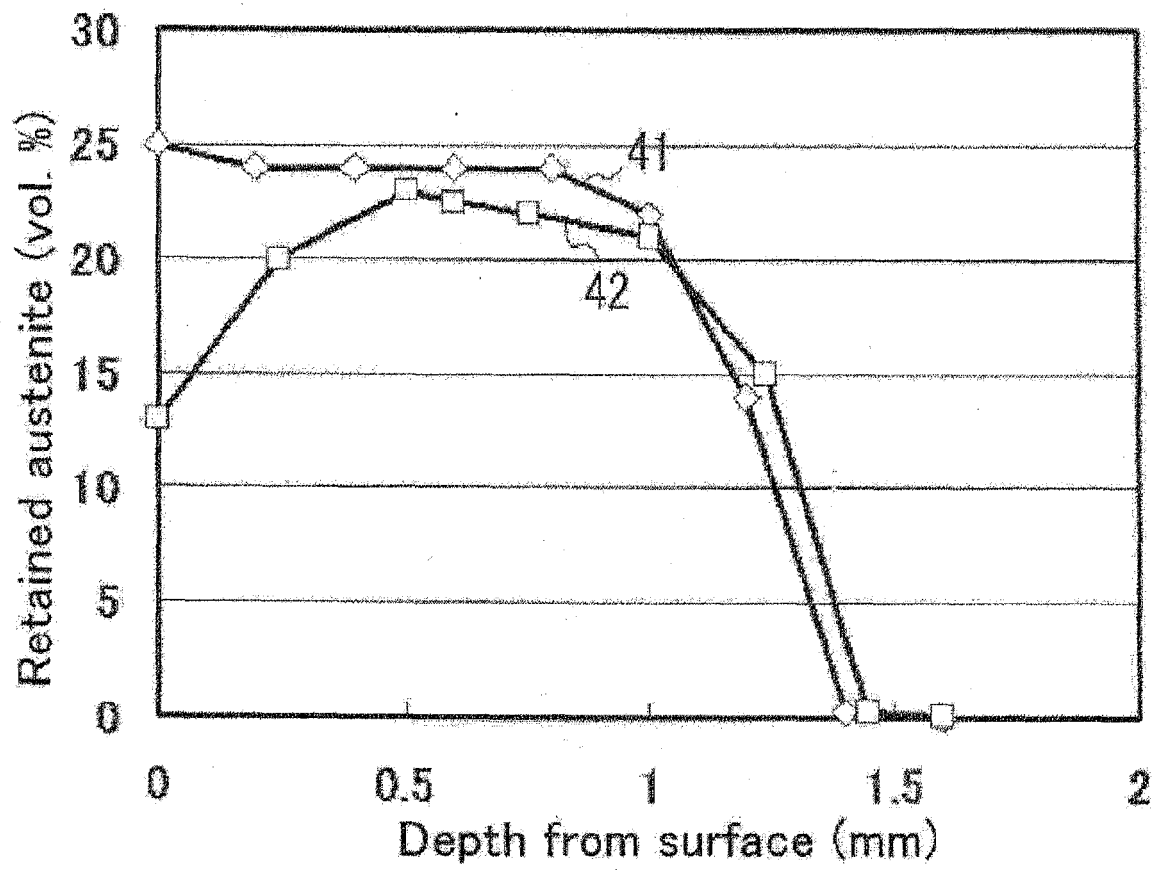


Fig. 7

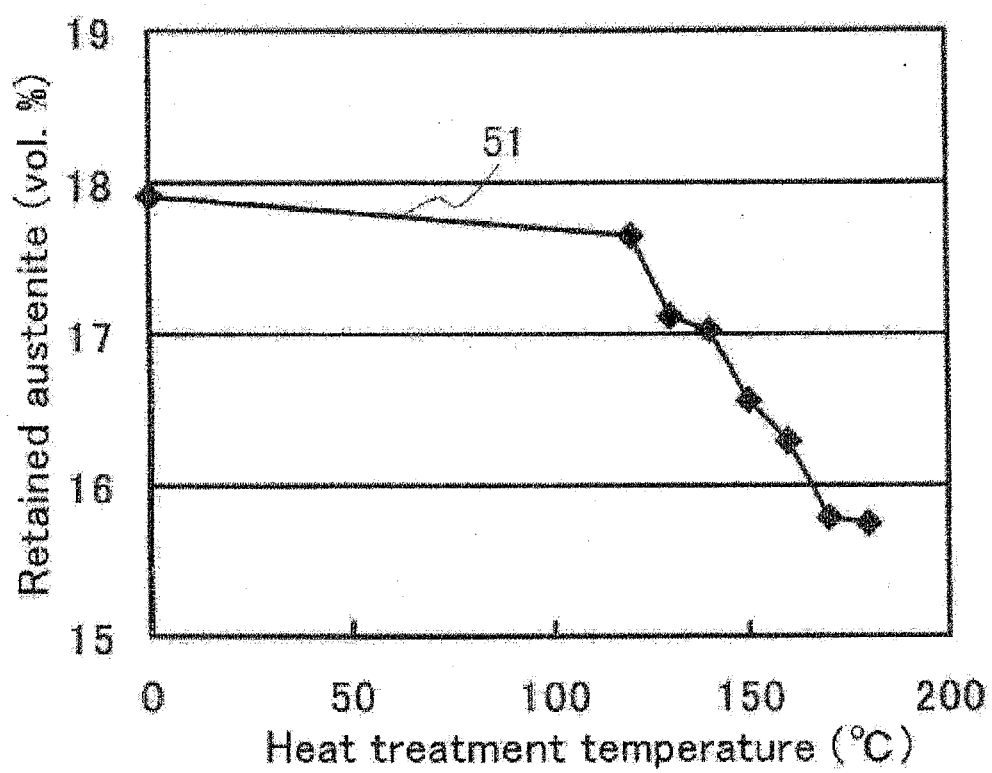


Fig. 8

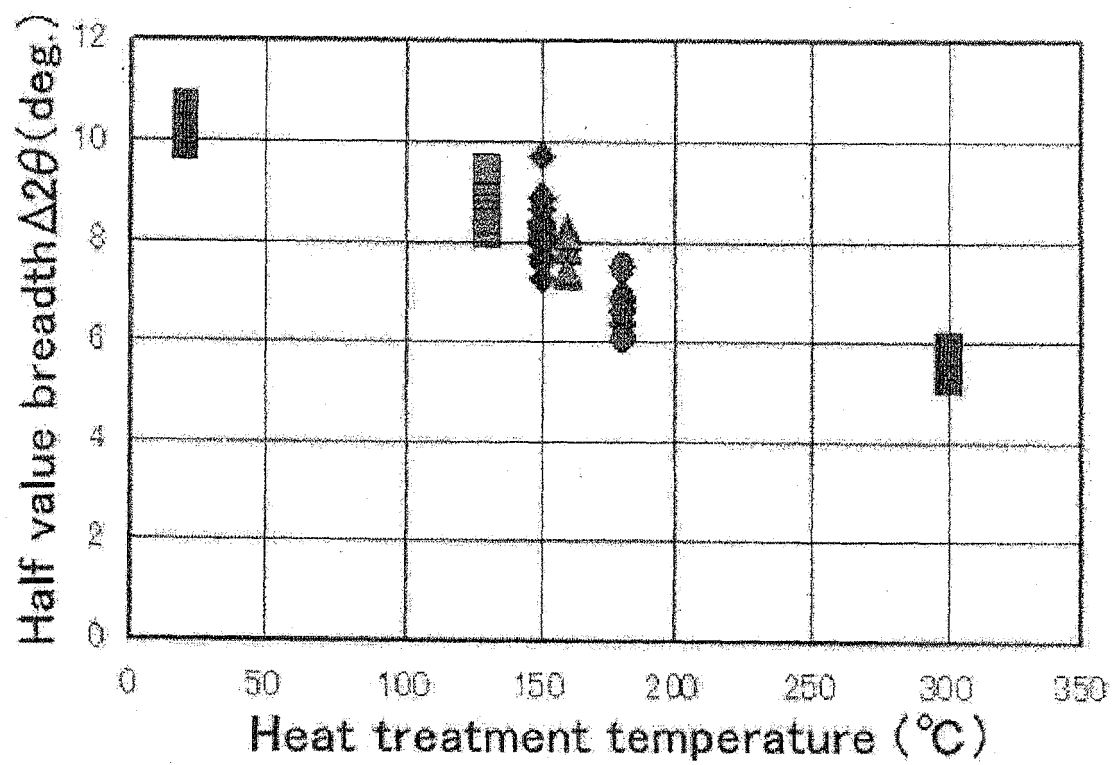


Fig. 9

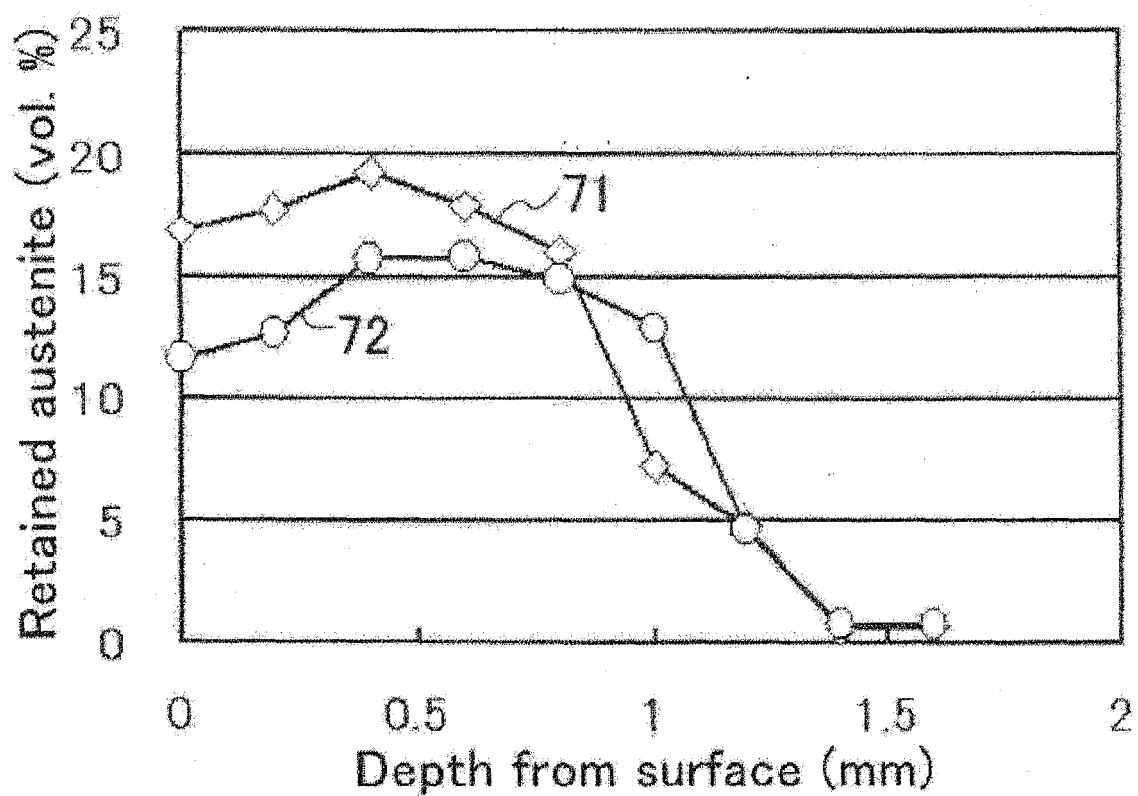


Fig. 10

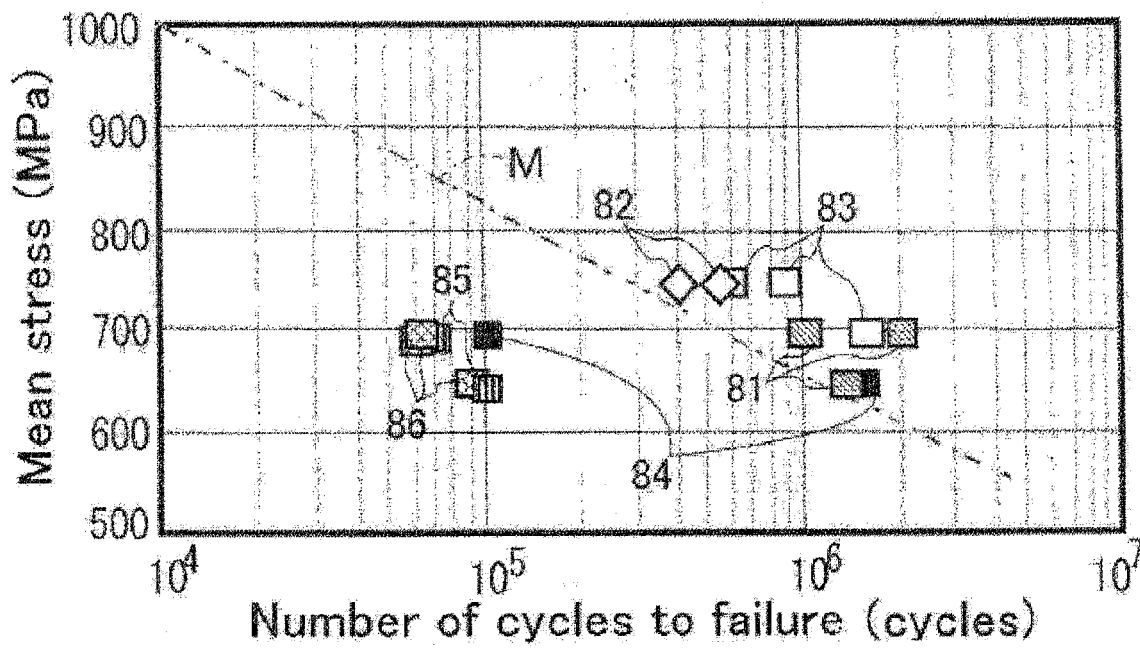


Fig. 11

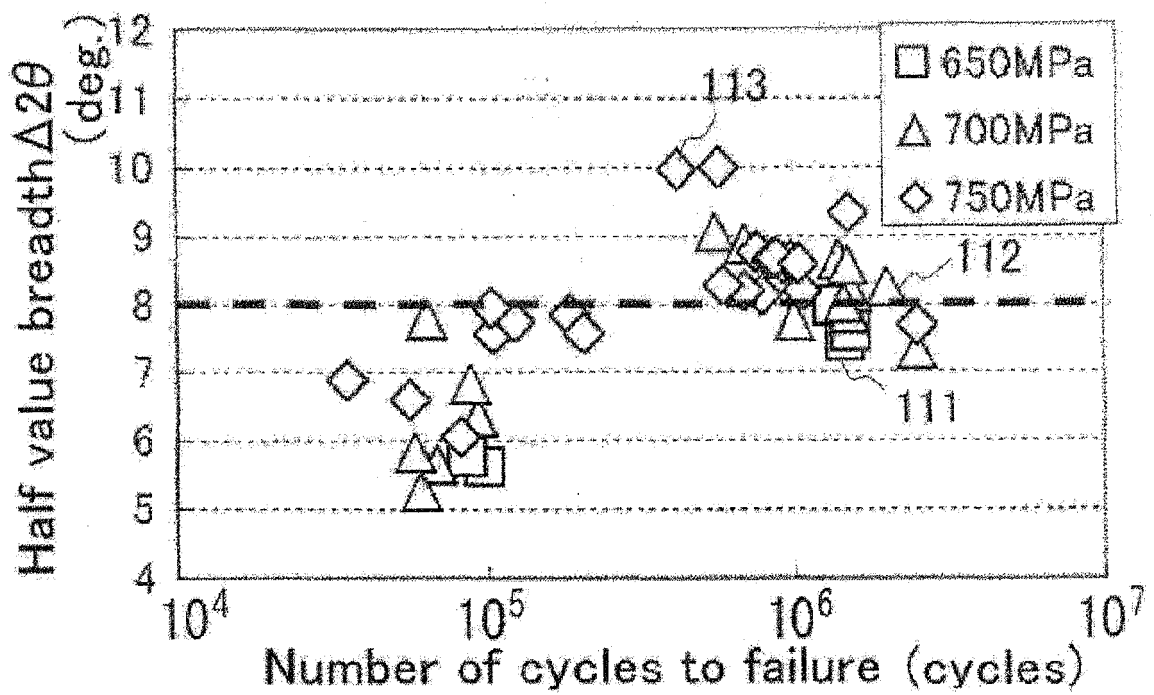


Fig. 12

Heat treatment temperature (°C)	Hardened layer thickness $\frac{d}{\text{Steel plate thickness } D} \times 100 (\%)$		
	Steel plate thickness D		
	8.7~8.4	7.1~8.1	4.9~8.1
130	○	○	○
160	○	○	107
180	87	92	88

Note 1: A circle indicates high number of cycles to failure of 10000k or high.

Note 2: Fatigue test condition : $750 \pm 600 \text{ MPa}$

Note 3: The heat treatment time is one hour.



EUROPEAN SEARCH REPORT

Application Number
EP 08 16 9952

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Place of search		Date of completion of the search	Examiner
Munich		20 February 2009	Prussen, Jean
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