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(54) **ELECTRIC-RESISTANCE-WELDED STEEL PIPE**
WIDERSTANDSGESCHWEISSTES STAHLROHR
TUBE D’ACIER SOUDÉ PAR RÉSISTANCE ÉLECTRIQUE

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Description

[Technical Field]

[0001] The present invention relates to an electric resistance welded steel pipe excellent in terms of fatigue characteristic.

[Background Art]

[0002] In the automotive industry, in order to achieve weight saving and satisfactory stiffness property at the same time, there is a trend toward hollowing driving parts such as a drive shaft which have been manufactured using bar steel to date. As an example of raw materials used for such hollow parts, it is proposed to use a seamless steel pipe, and, for example, Patent Literature 1 discloses a hollow drive axis which is made from a seamless steel pipe as a raw material, having a steel chemical composition controlled to be within a specified range, which is excellent not only in terms of cold workability as indicated by an austenite grain size number of 9 or more after a quenching treatment has been performed but also in terms of hardenability, toughness, and torsion fatigue strength (hereinafter, also simply referred to as fatigue strength), and which realizes a stable fatigue life.

[0003] However, in the case of a seamless steel pipe, there is a problem in that, since surface decarburization and surface defects tend to occur due to the method for manufacturing a seamless steel pipe, it is necessary to grind or polish the surface of the pipe in order to achieve satisfactory fatigue resistance, and in that, since a seamless pipe has unevenness and eccentricity in thickness, a seamless pipe is not always suitable for a rotated object.

[0004] On the other hand, consideration has been given to using an electric resistance welded steel pipe for a drive shaft, because the problems described above are less likely to occur. For example, Patent Literature 2 discloses a technique for increasing the strength of a steel pipe by using an electric resistance welded steel pipe having a steel chemical composition controlled to be within a specified range as a raw material and by performing a quenching-tempering treatment on a weld of ERW and a portion around the weld as a hardening treatment. JPH08295989 discloses an electric resistance welded tube wherein the austenite crystal grain are suppressed in the time of subsequent heat processing by annealing, wherein the steel composition includes (wt.%) 0.41 C, 0.23 Si, 1.05 Mn, 0.001 S, 0.010 P, Al 0.008 and at least one of 0.1 Cu 0.1 Ni, 0.1 Cr and 0.1 Mo.

[Citation List]

[Patent Literature]

[0005]

[PTL 1] International Publication No. WO2006/104023
[PTL 2] Japanese Unexamined Patent Application Publication No. 2002-356742

[Summary of Invention]

[Technical Problem]

[0006] However, although an electric resistance welded steel pipe is superior to a seamless steel pipe in terms of dimension accuracy, it is necessary to improve dimension accuracy by performing cold drawing in order to use an electric resistance welded steel pipe for applications such as a drive shaft for which very high dimension accuracy is required. In this case, it is necessary to perform normalizing after cold drawing has been performed. The reasons for that is because it is necessary to solve, for example, the following problems by performing normalizing: (1) a deterioration in toughness due to processing strain in the cold-drawn state, (2) a local increase in hardness in a weld of ERW due to a quenching effect caused by a thermal history in which rapid heating and rapid cooling occur when the welding is performed, and (3) a thin layer called a white layer, in which carbon concentration is low, in the bonded surface of a weld of ERW.

[0007] In the case where normalizing is not performed, there is a risk in that, since an electric resistance welded steel pipe has low toughness, brittle failure may occur in a practical use environment. In addition, in the case of a drive shaft, since local stress concentration occurs in a weld of ERW and in the vicinity of the weld due to cyclic shearing stress and bending stress being applied, there is a risk in that fatigue breaking may occur in a short time. Therefore, normalizing is a treatment which is very important in order to use an electric resistance welded steel pipe for a drive shaft and which significantly influences the properties of a steel pipe as a final product.

[0008] In the case where high-carbon steel is used as a raw material of an electric resistance welded steel pipe, the metallic microstructure widely varies from ferrite and pearlite to martensite due to a variation in cooling rate after normalizing has been performed. Therefore, since martensite microstructure may be formed, a tempering treatment becomes an indispensable process in order to achieve satisfactory toughness as disclosed in Patent Literature 1 and Patent Literature 2 in the case where high-carbon steel is used as a raw material of an electric resistance welded steel pipe, which results in a problem of an increase in manufacturing cost.

[0009] An object of the present invention is, in order to solve the problems described above, to provide an electric resistance welded steel pipe whose metallic microstructure and tensile strength after normalizing has been performed are less likely to be influenced by a cooling rate when normalizing is performed even in the case where high-carbon steel is used as a raw material of an electric resistance welded steel pipe and with which stable fatigue strength can be achieved.

[Solution to Problem]

[0010] The present inventors diligently conducted investigations in order to solve the problems described above, and as a result, found that, by controlling Al content in steel to be within an appropriate range, the metallic microstructure and tensile strength after normalizing has been performed become less likely to be influenced by a cooling rate after normalizing has been performed and that stable fatigue strength can be achieved. Moreover, it was found that, by controlling the prior austenite grain size to be within an appropriate range, it is possible to increase (1) the strength of pearlite and (2) fatigue crack propagation resistance of ferrite-pearlite steel without changing the tensile strength, which results in an increase in fatigue strength.

[0011] The present inventors manufactured hot-reduced steel pipes (having an outer diameter of 45 mm and a wall thickness of 4.5 mm), by using a hot-rolled steel sheets (coiled at a coiling temperature of 650°C) having a basic chemical composition in accordance with the steel specification SAE1541 (containing 0.42%C,1.5%Mn,0.0035%N) and Al in various amounts as a raw material, by performing roll forming and high-frequency resistance welding on the raw material in order to manufacture electric resistance welded steel pipes (having an outer diameter of 89 mm and a wall thickness of 4.7 mm), and by thereafter performing hot reducing on the formed and welded pipes. Subsequently, by performing cold drawing in order to make cold-drawn pipes (having an outer diameter of 40 mm and a wall thickness of 4.0 mm), and by thereafter performing normalizing (at a temperature of 920°C for a holding time of 10 minutes and with a cooling rate of 0.5°C/sec. to 3.0°C/sec. after soaking had been performed), product steel pipes were manufactured.

[0012] Fig. 1 illustrates the relationship between a cooling rate for normalizing and HV hardness (Vickers hardness). It is clarified that, in the case where the Al content is 0.005% or less, almost constant HV hardness is achieved for a wide cooling rate range, that, in the case where the Al content is 0.007% or more, HV hardness is strongly influenced by the cooling rate, and that, in the case where the cooling rate is low, there is a sharp decrease in HV hardness.

[0013] Fig. 2 illustrates the relationship between the Al content and a lamellar spacing, Fig. 3 illustrates the relationship between the Al content and a prior austenite grain size, and Fig. 4 illustrates the relationship between the Al content and torsion fatigue strength. Here, the cooling rate for normalizing was 1°C/sec. The prior austenite grain size increases with decreasing Al content, and the torsion fatigue strength increases along with the prior austenite grain size. It is clarified that, in the case where the Al content is 0.005% or less, such an effect becomes saturated and that the torsion fatigue strength also becomes stable.

[0014] Fig. 5 illustrates the results of the cross-section observation of the fracture portion after a fatigue test had been performed, and Fig. 5(a) and Fig. 5(b) respectively illustrate the fatigue crack propagation situations for a material containing 0.03%-Al and a material containing 0.003%-Al. The crack propagation route is indicated with a white line. It was found that fatigue crack starts from the outer surface side of a pipe and then propagates through a winding path made of soft pro-eutectoid ferrite. In addition, it is presumed that, since the crack meanders in a zig-zag manner, and since the degree of a change in direction increases with increasing apparent pearlite grain size (corresponding to a prior austenite grain), which is surrounded by the pro-eutectoid ferrite, there is an improvement in crack propagation resistance, which results in an increase in fatigue strength.

[0015] The reason why the results illustrated in Fig. 1, Fig. 2, and Fig. 3 were obtained is thought to be as follows. That is, since the amount of aluminum nitride, which has been precipitated before normalizing is performed, decreases with decreasing Al content, there is a decrease in the pinning effect of aluminum nitride, which results in a tendency for an austenite grain size to increase in a normalizing process. Since pearlite and ferrite use prior austenite grain boundaries as their transformation sites, in the case where there is a decrease in grain boundary area due to an increase in prior austenite grain size, there is a decrease in the number of transformation sites, which results in a decrease in the fraction of ferrite. In particular, the reason why hardness varies depending on the Al content in a low cooling rate region in Fig. 1 is because, in the case where the Al content is high, since the growth of austenite grains is suppressed in a normalizing process due to the pinning effect of aluminum nitride (AlN) which has been precipitated before normalizing is performed, and, at the same time, since there is an increase in the lamellar spacing of pearlite which is finally formed, there is a decrease in hardness. A decrease in hardness is significant particularly in a low cooling rate region, in which quenching effect is less likely to be realized, and significantly depends on the Al content (the amount of AlN precipitated) in steel. In the case where the Al content is 0.005% or less, since there is a decrease in the amount of aluminum nitride (AlN) precipitated, and since aluminum nitride is dissolved in a normalizing process even if aluminum nitride is precipitated in advance, there is a decrease in pinning effect, which results in a decrease in the lamellar spacing of pearlite due to austenite grains growing easily, and which results in a decrease in a change in hardness depending on a cooling rate.

[0016] The relationships of an austenite grain size to a lamellar spacing and strength are thought to be as follows. That is, in the case where an austenite grain size is large, since there is a decrease in the number of pearlite transformation sites (mainly austenite grain boundaries), there is a decrease in pearlite transformation temperature. As a result, it is considered that, since there is an increase in the temperature difference between the pearlite equilibrium transformation temperature and the transformation starting temperature, that is, the degree of undercooling, there is a decrease in lamellar spacing, which results in an increase in the strength of pearlite as expected based on the conventionally-known relationship between a lamellar spacing and the strength of pearlite. As a result, it is considered that, since a fatigue crack becomes less likely to penetrate pearlite microstructure due to an increase in the strength of pearlite, the crack propagates in a zig-zag manner avoiding the pearlite, which results in an increase in fatigue strength due to an increase in fatigue crack propagation resistance.

[0017] The present invention has been completed on the basis of the knowledge described above and further investigations, and the subject matter of the present invention is as follows.

[1] An electric resistance welded steel pipe, the steel pipe having a chemical composition consisting of by mass%, C: 0.35% or more and 0.55% or less, Si: 0.01% or more and 1.0% or less, Mn: 1.0% or more and 3.0% or less, P: 0.02% or less, S: 0.01% or less, Al: 0.003% or less, N: 0.0050% or less, Cr: 0.1% or more and 0.5% or less, optionally one or more selected from among Ti: 0.005% or more and 0.1% or less, B: 0.0003% or more and 0.0050% or less, Mo: 2% or less, W: 2% or less, Nb: 0.1% or less, V: 0.1% or less, Ni: 2% or less, Cu: 2% or less, Ca: 0.02% or less, and REM: 0.02% or less, and the balance being Fe and inevitable impurities and a metallic microstructure including pearlite, ferrite, and bainite, in which the area ratio of the pearlite is 85% or more, the total of the area ratios (including 0) of the ferrite and the bainite is 15% or less, and in which a prior austenite grain size is 25 μm or more.

[2] The electric resistance welded steel pipe excellent in terms of fatigue characteristic according to item [1], the steel pipe having the chemical composition further containing, by mass%, one or more selected from among Ti: 0.01% or more and 0.04% or less, B: 0.0010% or more and 0.0040% or less, Mo: 0.001% or more and 0.5% or less, W: 0.001% or more and 0.5% or less, Nb: 0.001% or more and 0.04% or less, V: 0.001% or more and 0.1% or less, Ni: 0.001% or more and 0.5% or less, Cu: 0.001% or more and 0.5% or less, Ca: 0.0020% or more and 0.02% or less, and REM: 0.0020% or more and 0.02% or less.

[Advantageous Effects of Invention]

[0018] According to the present invention, it is possible to obtain an electric resistance welded steel pipe having satisfactory fatigue resistance which is required for a drive shaft.

[Brief Description of Drawings]

[0019]

[Fig. 1] Fig. 1 is a diagram illustrating a relationship between a cooling rate when normalizing is performed and HV hardness.
[Fig. 2] Fig. 2 is a diagram illustrating a relationship between Al content in steel and lamellar spacing.
[Fig. 3] Fig. 3 is a diagram illustrating a relationship between Al content in steel and a prior austenite grain size.
[Fig. 4] Fig. 4 is a diagram illustrating a relationship between Al content in steel and torsion fatigue strength.
[Fig. 5] Fig. 5 is a diagram illustrating the propagation behavior of a fatigue crack. ((a)material containing 0.03%-Al, and (b) material containing 0.003%-Al)

[Description of Embodiments]

[0020] The reasons for the limitations on the constituent features of the present invention will be described hereafter.

1. Regarding chemical composition

[0021] First, the reasons for the limitations on the chemical composition of the steel according to the present invention will be described. Here, % used when describing a chemical composition always represents mass%.

C: 0.35% or more and 0.55% or less

[0022] In the case where the C content is less than 0.35%, it is not possible to achieve satisfactory strength or desired fatigue resistance. On the other hand, in the case where the C content is more than 0.55%, since there is a deterioration in weldability, it is not possible to achieve a stable welding quality of ERW. Therefore, the C content is set to be in a range of 0.35% or more and 0.55% or less, or preferably in a range of 0.40% or more and 0.45% or less.

Si: 0.01% or more and 1.0% or less

[0023] There is a case where Si is added for deoxidation, and it is not possible to realize a sufficient deoxidation effect in the case where the Si content is less than 0.01%. At the same time, Si is also a solute strengthening element, and it is necessary that the Si content be 0.01% or more in order to realize such an effect. On the other hand, in the case where the Si content is more than 1.0%, there is a deterioration in the hardenability of a steel pipe. The Si content is set to be in a range of 0.01% or more and 1.0% or less, or preferably 0.1% or more and 0.4% or less.

Mn: 1.0% or more and 3.0% or less

[0024] Mn is a chemical element which promotes pearlite transformation and improves hardenability, it is necessary that the Mn content be 1.0% or more in order to realize such effects. On the other hand, in the case where the Mn content is more than 3.0%, there is a deterioration in the welding quality of ERW, and in addition, there is a deterioration in fatigue resistance due to an increase in the amount of residual austenite. The Mn content is set to be in a range of 1.0% or more and 3.0% or less, or preferably in a range of 1.4% or more and 2.0% or less.

P: 0.02% or less

[0025] P is an inevitable impurity in the present invention, and the upper limit of the P content is set to be 0.02% or less. There is a tendency for P to be concentrated in a segregation part which is formed when continuous casting is performed and to remain in a hot-rolled steel sheet as a raw material of a pipe. Since the edges of a steel strip are abutted and subjected to upsetting when electric resistance welding is performed, the segregation part in which P is concentrated may be exposed on the outer surface and inner surface of a steel pipe, which results in there being a risk in that cracking occurs when secondary processing such as flattening forming is performed on this part. Therefore, it is preferable that the P content be 0.01% or less.

S: 0.01% or less

[0026] S is an inevitable impurity in the present invention, and the upper limit of the S content is set to be 0.01% or less. In the case where the S content is high, there is a deterioration in toughness of raw material, and S combines with Mn in steel to form MnS. Since MnS is elongated in the longitudinal direction of a steel sheet to form a long inclusion in a hot rolling process, there is a deterioration in workability and toughness. Therefore, it is preferable that the S content be 0.005% or less, or more preferably 0.003% or less.

Al: 0.003% or less

[0027] Although Al is an important chemical element in the present invention in order to achieve the desired prior austenite grain size accompanied by satisfactory torsion fatigue strength, since, in the case where the Al content is more than 0.005%, a pinning effect is realized in a normalizing process due to an increase in the amount of AlN precipitated, which results in the desired austenite grain size not being achieved due to the growth of austenite grains being suppressed. Therefore, the Al content is set to be 0.003% or less.

N: 0.0050% or less

[0028] Since N is a chemical element which contributes to suppressing the growth of austenite grains in a normalizing process as a result of combining with Al to form AlN, it is necessary that the N content be 0.0050% or less in order to suppress such an effect, or preferably 0.0035% or less.

Cr: 0.1% or more and 0.5% or less

[0029] Since Cr is a chemical element which decreases the pearlite transformation temperature, there is a decrease in the lamellar spacing of pearlite, which results in an increase in torsion fatigue strength due to an increase in the strength of pearlite. It is necessary that the Cr content be 0.1% or more in order to realize such an effect. On the other hand, in the case where the Cr content is more than 0.5%, since Cr forms oxides, and since the oxides may remain in a weld of ERW, there may be a deterioration in weldability of ERW. Therefore, the Cr content is set to be in a range of 0.1% or more and 0.5% or less, or preferably in a range of 0.15% or more and 0.30% or less.

[0030] The basic chemical composition according to the present invention is as described above, and one or more of Ti, B, Mo, W, Nb, V, Ni, Cu, Ca, and REM, which will be described below, may further be added in order to increase strength and fatigue strength.

Ti: 0.005% or more and 0.1% or less

[0031] Ti is effective for fixing N in steel in the form of TiN. However, in the case where the Ti content is less than 0.005%, there is insufficient effect of fixing N, and, in the case where the Ti content is more than 0.1%, there is a deterioration in the workability and toughness of steel. In the case where Ti is added, it is preferable that the Ti content be in a range of 0.005% or more and 0.1% or less, or more preferably in a range of 0.01% or more and 0.04% or less.

B: 0.0003% or more and 0.0050% or less

[0032] B is a chemical element which improves hardenability. In the case where the B content is less than 0.0003%, there is insufficient effect of increasing hardenability. On the other hand, in the case where the B content is more than 0.0050%, such an effect becomes saturated and there is a deterioration in fatigue resistance due to intergranular fracture being more likely to occur as a result of B being precipitated at the grain boundaries. In the case where B is added, it is preferable that the B content be in a range of 0.0003% or more and 0.0050% or less, or more preferably in a range of 0.0010% or more and 0.0040% or less.

Mo: 2% or less

[0033] Since Mo is a chemical element which improves hardenability, Mo is effective for increasing fatigue strength by increasing the strength of steel. It is preferable that the Mo content be 0.001% or more in order to realize such an effect. However, in the case where the Mo content is more than 2%, there is a significant deterioration in workability. In the case where Mo is added, it is preferable that the Mo content be 2% or less, or more preferably in a range of 0.001% or more and 0.5% or less.

W: 2% or less

[0034] W is effective for increasing the strength of steel by forming carbides. It is preferable that the W content be 0.001% or more in order to realize such an effect. However, in the case where the W content is more than 2%, since unnecessary carbides are precipitated, there is a deterioration in fatigue resistance and there is a deterioration in workability. In the case where W is added, it is preferable that the W content be 2% or less, or more preferably in a range of 0.001% or more and 0.5% or less.

Nb: 0.1% or less

[0035] Nb is a chemical element which improves hardenability and which contributes to an increase in strength by forming carbides. It is preferable that the Nb content be 0.001% or more in order to realize such effects. However, in the case where the Nb content is more than 0.1%, the effects become saturated and there is a deterioration in workability. In the case where Nb is added, it is preferable that the Nb content be 0.1% or less, or more preferably in a range of 0.001% or more and 0.04% or less.

V: 0.1% or less

[0036] V is a chemical element which is effective for increasing the strength of steel by forming carbides and which has temper softening resistance. It is preferable that the V content be 0.001% or more in order to realize such effects. However, in the case where the V content is more than 0.1%, the effects become saturated and there is a deterioration in workability. In the case where V is added, it is preferable that the V content be 0.1% or less, or more preferably in a range of 0.001% or more and 0.1% or less

Ni: 2% or less

[0037] Since Ni is a chemical element which improves hardenability, Ni is effective for increasing fatigue strength by increasing the strength of steel. It is preferable that the Ni content be 0.001% or more in order to realize such an effect. However, in the case where the Ni content is more than 2%, there is a significant deterioration in workability. In the case where Ni is added, it is preferable that the Ni content be 2% or less, or more preferably in a range of 0.001% or more and 0.5% or less.

Cu: 2% or less

[0038] Since Cu is a chemical element which improves hardenability, Cu is effective for increasing fatigue strength by increasing the strength of steel. It is preferable that the Cu content be 0.001% or more in order to realize such an effect. However, in the case where the Cu content is more than 2%, there is a significant deterioration in workability. In the case where Cu is added, it is preferable that the Cu content be 2% or less, or more preferably in a range of 0.001% or more and 0.5% or less.

Ca: 0.02% or less and REM: 0.02% or less

[0039] Since Ca and REM are both chemical elements which are effective for suppressing the formation of the origins of cracks which induce a fatigue breaking in a use environment in which cyclic stress is applied by making the shape of non-metal inclusions spherical, these chemical elements may be selectively added as needed. Such an effect is recognized in the case where the content of each of Ca and REM is 0.0020% or more. On the other hand, in the case where the content is more than 0.02%, there is a decrease in cleaning level due to an increase in the amount of inclusions. Therefore, in the case where Ca or REM is added, it is preferable that the content of each of Ca and REM be 0.02% or less. In the case where Ca and REM are added in combination, it is preferable that the total content be 0.03% or less.

[0040] The remainder of the chemical composition of the steel according to the present invention other than the constituents described above consists of Fe and inevitable impurities.

2. Regarding metallic microstructure

[0041] The metallic microstructure according to the present invention is a microstructure in which the area ratio of pearlite is 85% or more and in which the total of the area ratios of ferrite and bainite (including 0) is 15% or less.

[0042] In order to increase fatigue strength by increasing fatigue crack propagation resistance as a result of a fatigue crack propagating in a zig-zag manner as described above, it is necessary that the metallic microstructure include mainly pearlite and that the area ratio of pearlite be 85% or more to realize such an effect. On the other hand, in the case where the total of the area ratios (including 0) of soft ferrite and bainite, which is hard but not so effective than pearlite, is more than 15%, there is a decrease in the effect of increasing fatigue strength. Therefore, the area ratio of pearlite is set to be 85% or more, and the total of the area ratios (including 0) of ferrite and bainite is set to be 15% or less.

Prior austenite grain size: 25 μm or more

[0043] Since the degree of the deflection of a fatigue crack increases with increasing apparent grain size of pearlite which is surrounded by ferrite layers, there is an improvement in crack propagation resistance. Since ferrite is formed at prior austenite grain boundaries, the apparent pearlite grain size increases with increasing prior austenite grain size. It is necessary that the prior austenite grain size be 25 μm or more in order to improve crack propagation resistance, and there is an insufficient improvement in fatigue crack propagation resistance in the case where the prior austenite grain size is less than 25 μm.

[0044] It is conventionally known that the strength of pearlite increases with decreasing lamellar spacing of pearlite. In order to increase the strength of pearlite so that a fatigue crack does not penetrate the pearlite and goes around the pearlite, it is preferable that the lamellar spacing be 170 nm or less, or more preferably 150 nm or less.

[EXAMPLE 1]

[0045] Hot-reduced steel pipes (having an outer diameter of 45 mm and a wall thickness of 4.5 mm) were manufactured, by performing hot rolling on steel slabs having steel chemical compositions (mass%) given in Table 1 in order to obtain hot-rolled steel strips, by performing roll forming and high-frequency resistance welding on the hot-rolled steel strips in order to manufacture electric resistance welded steel pipes (having an outer diameter of 89 mm and a wall thickness of 4.7 mm), and by thereafter performing hot reducing on the formed and welded pipes. Subsequently, product steel pipes were manufactured, by performing cold drawing in order to obtain cold drawn steel tubes (having an outer diameter of 40 mm and a thickness of 4.0 mm), and thereafter performing normalizing (at a temperature of 920°C for a duration of 10 minutes and with a cooling rate of 0.5°C/sec. to 3.0°C/sec. after soaking had been performed).

[Table 1]

Steel Grade	Chemical Composition (mass%)																		Note
	C	Si	Mn	P	S	Al	N	Cr	Ti	B	Mo	W	Nb	V	Ni	Cu	Ca	REM	
A	0.42	0.22	1.53	0.009	0.004	0.0030	0.0035	0.20	–	–	–	–	–	–	–	–	–	–	Example Steel
B	0.42	0.22	1.53	0.009	0.004	0.0030	0.0035	0.20	–	–	–	–	–	–	–	–	0.0012	–	Example Steel
C	0.45	0.22	1.53	0.009	0.004	0.0040	0.0035	0.20	–	–	–	–	–	–	–	–	–	–	Example Steel
D	0.42	0.22	1.53	0.009	0.004	0.0030	0.0035	0.20	0.015	–	–	–	–	–	–	–	–	–	Example Steel
E	0.42	0.22	1.53	0.009	0.004	0.0030	0.0035	0.20	–	0.0015	–	–	0.01	–	–	–	–	–	Example Steel
F	0.42	0.22	1.53	0.009	0.004	0.0030	0.0035	0.20	–	–	0.1	–	–	–	–	–	–	–	Example Steel
G	0.42	0.22	1.53	0.009	0.004	0.0045	0.0035	0.20	–	–	–	0.1	–	–	–	–	–	–	Example Steel
H	0.42	0.22	1.53	0.009	0.004	0.0030	0.0035	0.20	–	–	–	–	–	0.1	–	–	–	–	Example Steel
I	0.42	0.22	1.53	0.009	0.004	0.0030	0.0035	0.20	–	–	–	–	–	–	0.1	0.1	–	–	Example Steel
J	0.42	0.22	1.53	0.009	0.004	0.0030	0.0035	0.20	–	–	–	–	–	–	–	–	–	0.001	Example Steel
K	0.31	0.22	1.53	0.009	0.004	0.0030	0.0035	0.20	–	–	–	–	–	–	–	–	–	–	Comparative Example Steel
L	0.42	0.22	0.80	0.009	0.004	0.0030	0.0035	0.20	–	–	–	–	–	–	–	–	–	–	Comparative Example Steel
M	0.42	0.22	1.53	0.009	0.004	0.0070	0.0035	0.20	–	–	–	–	–	–	–	–	–	–	Comparative Example Steel
N	0.42	0.22	1.53	0.009	0.004	0.0300	0.0035	0.20	–	–	–	–	–	–	–	–	–	–	Comparative Example Steel
O	0.42	0.22	1.53	0.009	0.004	0.0030	0.0035	0.05	–	–	–	–	–	–	–	–	–	–	Comparative Example Steel

Annotation: An underlined chemical composition indicates a value out of the range according to the present invention.

[0046] Examples C and G of Table 1 are comparative examples and not inventive examples according to this invention. Using a tensile specimen (JIS No. 12 specimen) which had been collected from the product steel pipe so that the longitudinal direction is the axis direction of the steel pipe, tensile strength was determined. In addition, etching was performed so that austenite grain boundaries were exposed in a cross-section in the circumferential direction of the steel pipe in order to determine the austenite grain size. The grain size was determined based on a method of section by taking photographs of 10 microscopic fields using an optical microscope at a magnificent of 400 times, and the average value of the determined values was used as a representative value.

[0047] In addition, a lamellar spacing of the pearlite was determined using a method of section, by performing a nital corrosion treatment on a cross-section in the circumferential direction of the steel pipe in the similar way as described above, and by taking photographs of 10 microscopic fields in which cementite layers were arranged as much at a right angle as possible to the paper plane using an electron scanning microscope of 20,000 times power, and the average value of the determined values was used as a representative value.

[0048] The fatigue strength σw of the steel pipe was determined by performing a torsion fatigue test under conditions that the frequency was 3 Hz, the wave shape was a sine wave, and the stress ratio R was -1 (reversed vibration). Here, σw was defined as the stress with which a fracture did not occur even after the number of the cycles reaches 2 million. These evaluation results of the properties are given in Table 2 and Table 3.

[Table 2]

Pipe No.	Steel Grade	Kind of Pipe	Reducing Condition			Cold Drawing Area Reduction (%)	Normalizing Condition		Area Fraction of Microstructure %			Prior Austenite Grain Size (μm)	Lamellar Spacing (nm)	Tensile Strength TS (MPa)	Torsion Fatigue Strength σw (MPa)	Strength TS Stability Result From Cooling Rate	Note
			Heating Temperature (°C)	Finish Rolling Temperature (°C)	Reducing Ratio (%)		Soaking Condition	Cooling Rate (°C/sec.)	Pearlite	Ferrite	Bainite						
1	A	Reduced Steel Pipe	950	830	49	21	920°C ×10 minutes	0.5	95.0	5.0	0.0	32	164	835	175	○	Example
2								1.0	96.0	4.0	0.0	31	162	840	175		Example
3								2.0	93.0	2.0	5.0	35	161	845	180		Example
4								3.0	92.0	1.0	7.0	33	159	850	180		Example
5	B	Reduced Steel Pipe	950	830	49	21	920°C ×10 minutes	0.5	94.0	6.0	0.0	34	165	832	175	○	Example
6								1.0	96.0	4.0	0.0	32	165	833	175		Example
7								2.0	92.0	3.0	5.0	35	162	840	175		Example
8								3.0	90.0	1.0	9.0	36	158	852	180		Example
9	C	Reduced Steel Pipe	950	830	49	21	920°C ×10 minutes	0.5	95.0	5.0	0.0	32	162	840	175	○	Example
10								1.0	95.0	4.0	1.0	34	164	835	175		Example
11								2.0	93.0	2.0	5.0	33	167	825	175		Example
12								3.0	92.0	1.0	7.0	31	162	840	175		Example
13	D	Reduced Steel Pipe	950	830	49	21	920°C ×10 minutes	0.5	95.0	5.0	0.0	31	164	835	175	○	Example
14								1.0	96.0	4.0	0.0	29	159	850	180		Example
15								2.0	91.0	2.0	7.0	30	164	836	175		Example
16								3.0	92.0	1.0	7.0	33	163	838	175		Example
17	E	Reduced Steel Pipe	950	830	49	21	920°C ×10 minutes	0.5	95.0	5.0	0.0	35	162	840	175	○	Example
18								1.0	96.0	4.0	0.0	34	161	845	180		Example
19								2.0	92.0	2.0	6.0	35	159	850	180		Example
20								3.0	90.0	1.0	9.0	33	163	839	175		Example

(continued)

Pipe No.	Steel Grade	Kind of Pipe	Reducing Condition			Cold Drawing Area Reduction (%)	Normalizing Condition		Area Fraction of Microstructure %			Prior Austenite Grain Size (μm)	Lamellar Spacing (nm)	Tensile Strength TS (MPa)	Torsion Fatigue Strength σw (MPa)	Strength TS Stability Result From Cooling Rate	Note
			Heating Temperature (°C)	Finish Rolling Temperature (°C)	Reducing Ratio (%)		Soaking Condition	Cooling Rate (°C/sec.)	Pearlite	Ferrite	Bainite						
21	F	Reduced Steel Pipe	950	830	49	21	920°C x10 minutes	0.5	95.0	5.0	0.0	32	166	830	175	○	Example
22								1.0	96.0	4.0	0.0	29	162	840	175		Example
23								2.0	93.0	2.0	5.0	33	161	845	180		Example
24								3.0	91.0	1.0	8.0	36	159	850	180		Example
25	G	Reduced Steel Pipe	950	830	49	21	920°C ×10 minutes	0.5	95.0	5.0	0.0	35	162	840	175	○	Example
26								1.0	96.0	4.0	0.0	36	161	845	180		Example
27								2.0	93.0	3.0	4.0	35	163	839	175		Example
28								3.0	90.0	1.0	9.0	32	161	843	180		Example
29	H	Reduced Steel Pipe	950	830	49	21	920°C ×10 minutes	0.5	95.0	5.0	0.0	33	162	840	175	○	Example
30								1.0	96.0	4.0	0.0	36	164	835	175		Example
31								2.0	93.0	3.0	4.0	35	159	850	180		Example
32								3.0	91.0	2.0	7.0	33	157	855	180		Example

[Table 3]

Pipe No.	Steel Grade	Kind of Pipe	Reducing Condition: Heating Temperature (°C)	Reducing Condition: Finish Rolling Temperature (°C)	Reducing Condition: Reducing Ratio (%)	Cold Drawing Area Reduction (%)	Normalizing Condition: Soaking Condition	Normalizing Condition: Cooling Rate (°C/sec.)	Area Fraction of Microstructure %: Pearlite	Area Fraction of Microstructure %: Ferrite	Area Fraction of Microstructure %: Bainite	Prior Austenite Grain Size (μm)	Lamellar Spacing (nm)	Tensile Strength TS (MPa)	Torsion Fatigue Strength σw (MPa)	Strength TS Stability Result From Cooling Rate	Note
33	I	Reduced Steel Pipe	950	830	49	21	920°C ×10 minutes	0.5	96.0	4.0	0.0	32	162	842	175	○	Example
34								1.0	94.0	4.0	2.0	33	164	836	175		Example
35								2.0	91.0	3.0	6.0	34	162	840	175		Example
36								3.0	89.0	2.0	9.0	33	159	850	180		Example
37	J	Reduced Steel Pipe	950	830	49	21	920°C ×10 minutes	0.5	96.0	4.0	0.0	36	162	840	175	○	Example
38								1.0	96.0	3.0	1.0	35	161	845	180		Example
39								2.0	92.0	3.0	5.0	33	166	830	175		Example
40								3.0	90.0	2.0	8.0	36	160	846	180		Example
41	K	Reduced Steel Pipe	950	830	49	21	920°C ×10 minutes	0.5	75.0	25.0	0.0	19	196	752	140	×	Comparative Example
42								1.0	78.0	22.0	0.0	20	185	780	145		Comparative Example
43								2.0	80.0	20.0	0.0	21	177	800	145		Comparative Example
44								3.0	82.0	18.0	0.0	23	172	812	150		Comparative Example

(continued)

Pipe No.	Steel Grade	Kind of Pipe	Reducing Condition			Cold Drawing Area Reduction (%)	Normalizing Condition		Area Fraction of Microstructure %			Prior Austenite Grain Size (μm)	Lamellar Spacing (nm)	Tensile Strength TS (MPa)	Torsion Fatigue Strength σw (MPa)	Strength TS Stability Result From Cooling Rate	Note
			Heating Temperature (°C)	Finish Rolling Temperature (°C)	Reducing Ratio (%)		Soaking Condition	Cooling Rate (°C/sec.)	Pearlite	Ferrite	Bainite						
45	L	Reduced Steel Pipe	950	830	49	21	920°C ×10 minutes	0.5	75.0	25.0	0.0	18	191	765	140	×	Comparative Example
46								1.0	76.0	24.0	0.0	20	185	780	140		Comparative Example
47								2.0	80.0	20.0	0.0	22	176	802	150		Comparative Example
48								3.0	81.0	19.0	0.0	22	169	820	150		Comparative Example
49	M	Reduced Steel Pipe	950	830	49	21	920°C ×10 minutes	0.5	80.0	20.0	0.0	18	197	750	135	×	Comparative Example
50								1.0	84.0	16.0	0.0	17	187	775	140		Comparative Example
51								2.0	82.0	17.0	1.0	20	177	800	150		Comparative Example
52								3.0	80.0	16.0	4.0	21	173	810	150		Comparative Example

(continued)

Pipe No.	Steel Grade	Kind of Pipe	Reducing Condition: Heating Temperature (°C)	Reducing Condition: Finish Rolling Temperature (°C)	Reducing Condition: Reducing Ratio (%)	Cold Drawing Area Reduction (%)	Normalizing Condition: Soaking Condition	Normalizing Condition: Cooling Rate (°C/sec.)	Area Fraction of Microstructure %: Pearlite	Area Fraction of Microstructure %: Ferrite	Area Fraction of Microstructure %: Bainite	Prior Austenite Grain Size (μm)	Lamellar Spacing (nm)	Tensile Strength TS (MPa)	Torsion Fatigue Strength σw (MPa)	Strength TS Stability Result From Cooling Rate	Note
53	N	Reduced Steel Pipe	950	830	49	21	920°C ×10 minutes	0.5	<u>79.0</u>	21.0	0.0	<u>17</u>	200	745	135	x	Comparative Example
54	N	Reduced Steel Pipe	950	830	49	21	920°C ×10 minutes	1.0	<u>80.0</u>	20.0	0.0	<u>18</u>	189	768	140	x	Comparative Example
55	N	Reduced Steel Pipe	950	830	49	21	920°C ×10 minutes	2.0	<u>81.0</u>	17.0	2.0	<u>19</u>	175	805	150	x	Comparative Example
56	N	Reduced Steel Pipe	950	830	49	21	920°C ×10 minutes	3.0	<u>81.0</u>	16.0	3.0	22	171	815	150	x	Comparative Example
57	O	Reduced Steel Pipe	950	830	49	21	920°C ×10 minutes	0.5	<u>78.0</u>	22.0	0.0	21	202	740	135	×	Comparative Example
58	O	Reduced Steel Pipe	950	830	49	21	920°C ×10 minutes	1.0	<u>78.0</u>	22.0	0.0	22	185	780	145	×	Comparative Example
59	O	Reduced Steel Pipe	950	830	49	21	920°C ×10 minutes	2.0	<u>79.0</u>	14.0	7.0	<u>21</u>	173	810	150	×	Comparative Example
60	O	Reduced Steel Pipe	950	830	49	21	920°C ×10 minutes	3.0	<u>76.0</u>	16.0	8.0	<u>23</u>	171	815	150	×	Comparative Example

Annotation: An underlined evaluated value indicates a value out of the range according to the present invention.

[0049] Examples C and G of Tables 2 and 3 are comparative examples and not inventive examples according to this invention. Here, regarding strength stability, a case where the deviation (the difference between the maximum value and the minimum value) of tensile strength TS when the cooling rate for normalizing was changed in the range of 0.5°C/sec. to 3.0°C/sec. was 50 MPa or less was judged as satisfactory (○), and a case where the deviation was more than 50 MPa was judged as unsatisfactory (×).

[0050] As Table 2 and Table 3 indicate, it is clarified that the electric resistance welded steel pipes according to the present invention were all excellent in terms of strength stability as indicated by the small deviation of strength caused by the change in the cooling rate for normalizing, had high fatigue crack propagation resistance as indicated by the strength stability, the small lamellar spacing, and the large prior austenite grain size, and stably had high torsion fatigue strength.

[0051] On the other hand, in the case of a raw material having a high Al content of more than the range according to the present invention, the tensile strength was low in the case where the cooling rate for normalizing was in the lower range, and the torsion fatigue strength was low. In addition, in the case where the cooling rate was in the higher range, although the difference from the examples of the present invention in tensile strength was small, the torsion fatigue strength was lower than that of the examples of the present invention. The reason for that is thought to be because of the difference in the prior austenite grain size and because of the difference in the strength of pearlite.

[0052] Here, although a hot-rolled steel sheet was used as a raw material of an electric resistance welded steel pipe in the present examples, the present invention is not limited to the examples, and a cold-rolled steel strip may be used as the raw material of a steel pipe. Also, an ordinary electric resistance welded steel pipe, which has not been subjected to hot reducing, may be used as a steel pipe which is subjected to cold drawing.

Claims

1. An electric resistance welded steel pipe, the steel pipe having a chemical composition containing, by mass%, C: 0.35% or more and 0.55% or less, Si: 0.01% or more and 1.0% or less, Mn: 1.0% or more and 3.0% or less, P: 0.02% or less, S: 0.01% or less, Al: 0.003% or less, N: 0.0050% or less, Cr: 0.1% or more and 0.5% or less, optionally one or more selected from among Ti: 0.005% or more and 0.1% or less, B: 0.0003% or more and 0.0050% or less, Mo: 2% or less, W: 2% or less, Nb: 0.1% or less, V: 0.1% or less, Ni: 2% or less, Cu: 2% or less, Ca: 0.02% or less, and REM: 0.02% or less, and the balance being Fe and inevitable impurities and a metallic microstructure including pearlite, ferrite, and bainite, wherein the area ratio of the pearlite is 85% or more, the total of the area ratios (including 0) of the ferrite and the bainite is 15% or less, and wherein a prior austenite grain size is 25 μm or more.

2. The electric resistance welded steel pipe according to Claim 1, the steel pipe having the chemical composition containing, by mass%, one or more selected from among Ti: 0.01% or more and 0.04% or less, B: 0.0010% or more and 0.0040% or less, Mo: 0.001% or more and 0.5% or less, W: 0.001% or more and 0.5% or less, Nb: 0.001% or more and 0.04% or less, V: 0.001% or more and 0.1% or less, Ni: 0.001% or more and 0.5% or less, Cu: 0.001% or more and 0.5% or less, Ca: 0.0020% or more and 0.02% or less, and REM: 0.0020% or more and 0.02% or less.

Patentansprüche

1. Widerstandsgeschweißtes Stahlrohr, wobei
das Stahlrohr eine chemische Zusammensetzung, die in Massen-% C: 0,35% oder mehr und 0,55% oder weniger, Si: 0,01% oder mehr und 1,0% oder weniger, Mn: 1,0% oder mehr und 3,0% oder weniger, P: 0,02% oder weniger, S: 0,01% oder weniger, Al: 0,003% oder weniger, N: 0,0050% oder weniger, Cr: 0,1% oder mehr und 0,5% oder weniger, optional eines oder mehrere ausgewählt aus Ti: 0,005% oder mehr und 0,1% oder weniger, B: 0,0003% oder mehr und 0,0050% oder weniger, Mo: 2% oder weniger, W: 2% oder weniger, Nb: 0,1% oder weniger, V: 0,1% oder weniger, Ni: 2% oder weniger, Cu: 2% oder weniger, Ca: 0,02% oder weniger, und REM: 0,02% oder weniger und als Rest Fe und unvermeidliche Verunreinigungen enthält und eine metallische Mikrostruktur einschließlich Perlit, Ferrit und Bainit aufweist, wobei das Flächenverhältnis des Perlits 85% oder mehr beträgt, die Gesamtheit der Flächenverhältnisse (einschließlich 0) des Ferrits und des Bainits 15% oder weniger beträgt und wobei eine Voraustenitkorngröße 25 μm oder mehr beträgt.

2. Widerstandsgeschweißtes Stahlrohr nach Anspruch 1, wobei
das Stahlrohr die chemische Zusammensetzung aufweist, die in Massen-% eines oder mehrere ausgewählt aus Ti: 0,01% oder mehr und 0,04% oder weniger, B: 0,0010% oder mehr und 0,0040% oder weniger, Mo: 0,001% oder mehr und 0,5% oder weniger, W: 0,001% oder mehr und 0,5% oder weniger, Nb: 0,001% oder mehr und 0,04%

oder weniger, V: 0,001% oder mehr und 0,1% oder weniger, Ni: 0,001% oder mehr und 0,5% oder weniger, Cu: 0,001% oder mehr und 0,5% oder weniger, Ca: 0,0020 % oder mehr und 0,02% oder weniger und REM: 0,0020% oder mehr und 0,02% oder weniger enthält.

Revendications

1. Tuyau en acier soudé par résistance électrique, le tuyau en acier ayant une composition chimique contenant, en % en masse, C : 0,35 % ou plus et 0,55 % ou moins, Si : 0,01 % ou plus et 1,0 % ou moins, Mn : 1,0 % ou plus et 3,0 % ou moins, P : 0,02 % ou moins, S : 0,01 % ou moins, Al : 0,003 % ou moins, N : 0,0050 % ou moins, Cr: 0,1% ou plus et 0,5% ou moins, optionnellement un ou plusieurs éléments choisis parmi Ti : 0,005 % ou plus et 0,1 % ou moins, B : 0,0003 % ou plus et 0,0050 % ou moins, Mo : 2 % ou moins, W : 2 % ou moins, Nb : 0,1 % ou moins, V : 0,1 % ou moins, Ni : 2 % ou moins, Cu : 2 % ou moins, Ca : 0,02 % ou moins, et les terres rares REM : 0,02 % ou moins, et le complément étant du Fe et des impuretés inévitables et une microstructure métallique incluant de la perlite, de la ferrite et de la bainite, dans lequel le rapport de surface de la perlite est de 85 % ou plus, le total des rapports de surface (y compris 0) de la ferrite et de la bainite est égal ou inférieur à 15%, et dans lequel une taille de grains d'austénite antérieure est égale ou supérieure à 25 μm.

2. Tuyau en acier soudé par résistance électrique selon la revendication 1, le tuyau en acier ayant la composition chimique contenant, en % en masse, un ou plusieurs éléments choisis parmi Ti : 0,01 % ou plus et 0,04 % ou moins, B : 0,0010 % ou plus et 0,0040 % ou moins, Mo : 0,001 % ou plus et 0,5 % ou moins, W : 0,001 % ou plus et 0,5 % ou moins, Nb : 0,001 % ou plus et 0,04 % ou moins, V : 0,001 % ou plus et 0,1 % ou moins, Ni : 0,001 % ou plus et 0,5 % ou moins, Cu : 0,001 % ou plus et 0,5 % ou moins, Ca : 0,0020 % ou plus et 0,02 % ou moins, et les terres rares REM : 0,0020 % ou plus et 0,02 % ou moins.

FIG. 1

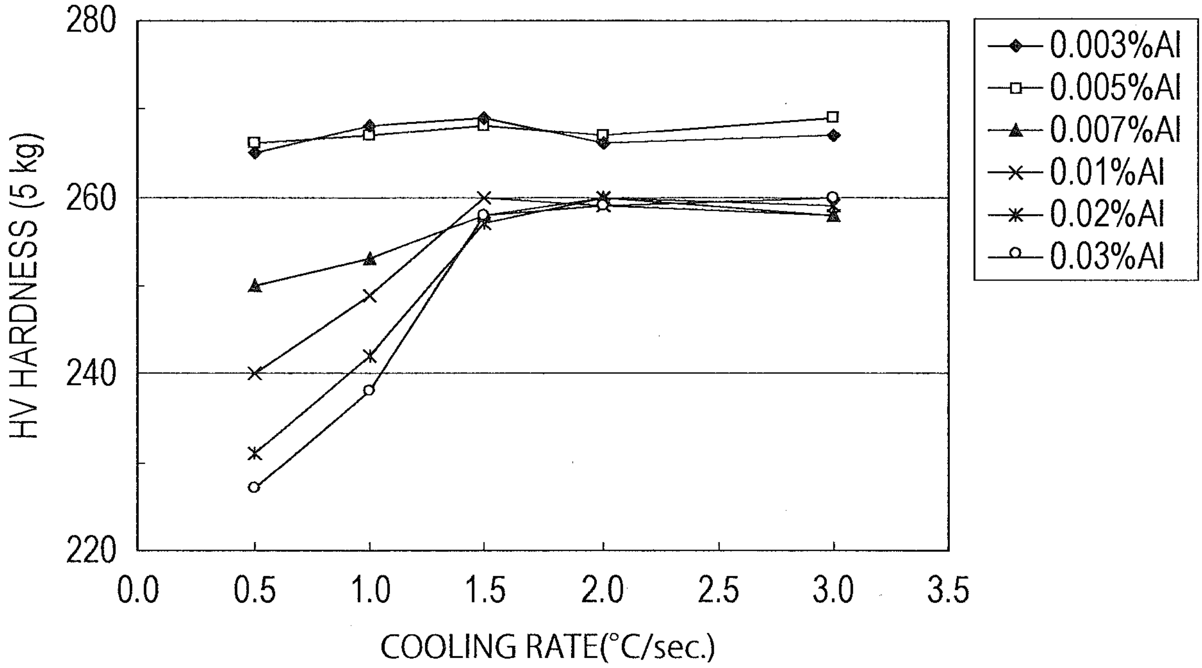

280
260
240
220
HV HARDNESS (5 kg)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
COOLING RATE(°C/sec.)
0.003%Al
0.005%Al
0.007%Al
0.01%Al
0.02%Al
0.03%Al

FIG. 2

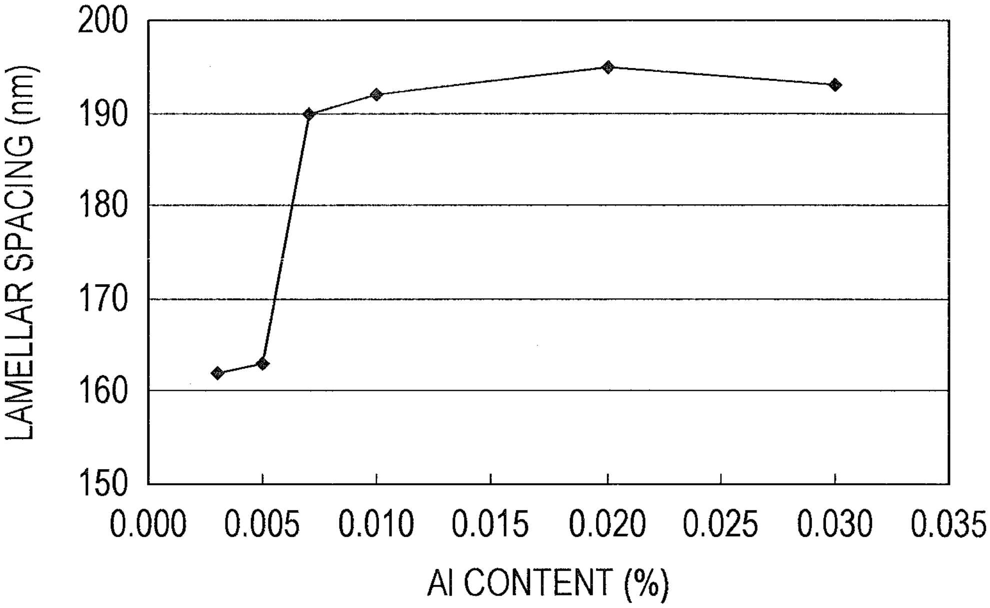

200
190
180
170
160
150
LAMELLAR SPACING (nm)
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
Al CONTENT (%)

FIG. 3

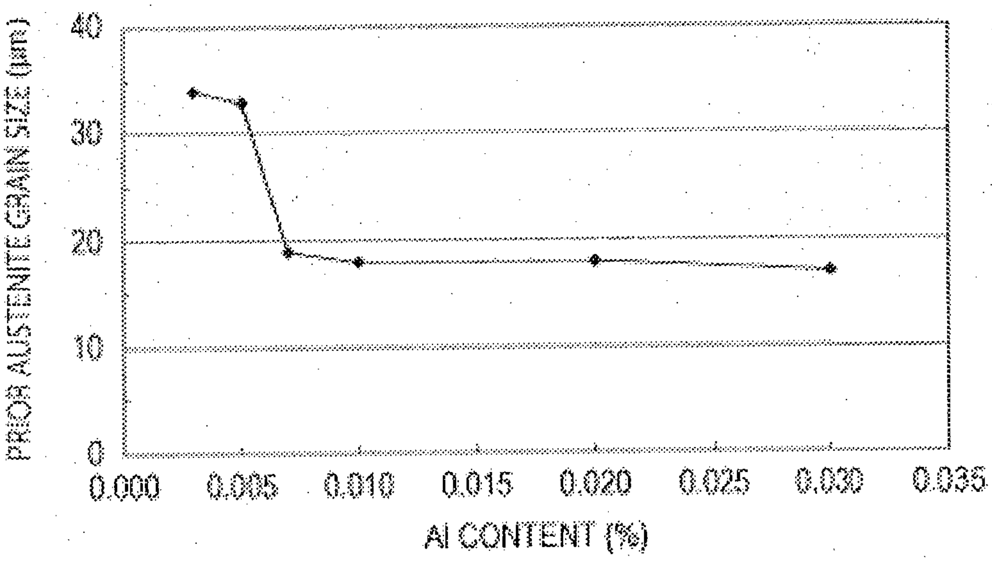

PRIOR AUSTENITE GRAIN SIZE (μm)
40
30
20
10
0
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
Al CONTENT (%)

FIG. 4

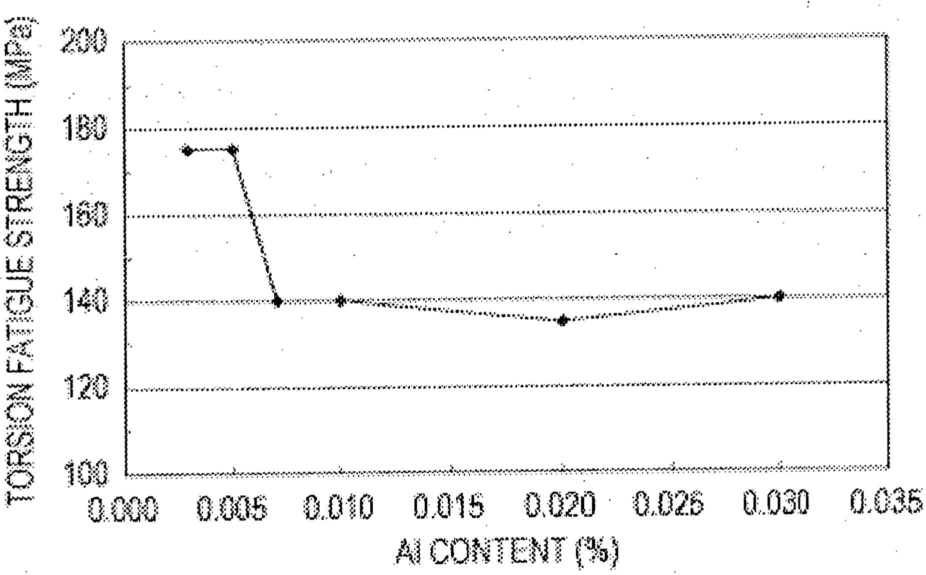
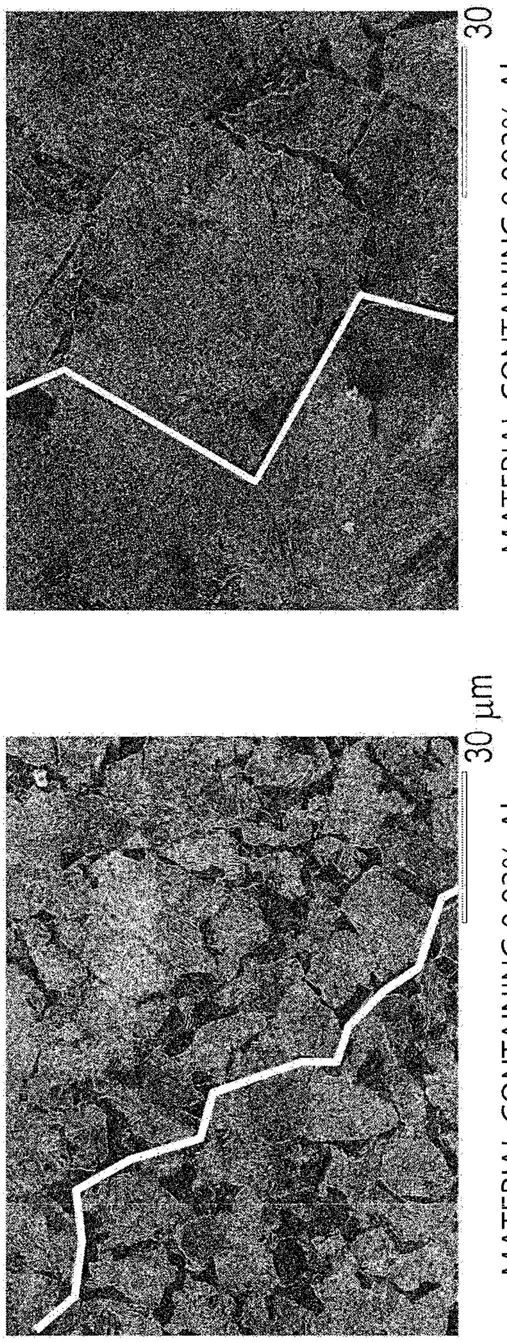

TORSION FATIGUE STRENGTH (MPa)
200
180
160
140
120
100
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
Al CONTENT (%)

FIG. 5



(a) MATERIAL CONTAINING 0.03%-Al

(b) MATERIAL CONTAINING 0.003%-Al

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- WO 2006104023 A **[0005]**
- JP 2002356742 A **[0005]**