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(54) **Low alloy steel having good stress corrosion cracking resistance.**

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## Description

The invention relates to low alloy steel and more specifically to nickel-chrome-molybdenum steel having good stress corrosion cracking resistance, which material is used for steam turbines or the like.

5 Materials which are used for steam turbines (operating with water vapor under high temperature and high pressure of approximately 300 °C and 70 bar) need excellent strength and toughness over a wide temperature range. Thus a nickel-chrome-molybdenum steel containing vanadium, i.e. a high strength steel, is used as a material to meet these requirements. Such a steel is obtained by adding molybdenum or vanadium which is a fine carbide deposited element to nickel-chrome high strength steel sensitive to  
10 temper embrittlement as is known whereby increasing a restraint of softening, that is, a tempering resistance at a high tempering temperature. This steel is well suitable for the above-described use.

However, recently it has been revealed that stress corrosion cracking is frequently encountered in low pressure steam turbines and peripheral equipment which use nickel-chrome-molybdenum steel with vanadium added thereto; if this happens in nuclear power stations it is really a significant problem. This  
15 stress corrosion cracking occurs mainly in a key way where a disk and a shaft are secured together and in a joint between a blade and a disk. Probably Na in the form of impurities in the vapor is concentrated as NaOH in crevices of such portions as described above to form a crack along a grain boundary in the presence of a high load stress when the turbine is operated.

The GB-PS 1 009 924 describes steel alloys containing C, Cr, Ni, Mo, Nb, V, Mn, Si, Al, P, S, H, N and  
20 balance Fe. It is said that this material has good yield strength and tensile strength, ductility, toughness and impact resistance. However, it does not suffice with respect to the a.m. requirements with turbines. It is generally known that intergranular stress corrosion cracking occurs in carbon steels which are subjected to tensile stress and to an environment containing OH.

Thus the object of the invention is to provide a nickel-chrome-molybdenum steel which meets the  
25 requirements of high stress corrosion cracking resistance even under severe application condition.

According to the invention this object is solved by the low alloy steel of claim 1, i.e. a low alloy steel having good stress corrosion cracking resistance containing

C :  $\leq 0.40$  %,  
Si :  $\leq 0.15$  %,   
30 Mn :  $\leq 0.20$  %,   
P :  $\leq 0.010$  %,   
S :  $\leq 0.030$  %,   
Ni : 0.50 to 4.00 %,   
Cr : 0.50 to 2.50 %,   
35 Mo : 0.25 to 4.00 % and   
V :  $\leq 0.30$  %,   
said Si, Mn and P being fulfilled with relationship of  $Si + Mn + 20 P \leq 0.30$  %, the remainder being Fe and unavoidable impurities, the prior austenite crystal grain size being in excess of 4 of ASTM crystal grain size number.

40 In order to further specify the conditions of the combination of stress corrosion cracking sensitivity with nickel-chrome-molybdenum steels and alloy-composition, micro-alloying elements and microstructures, certain sample steels modified with the aforesaid various factors have been subjected to testing the stress corrosion cracking; and the test results have been analyzed.

Further embodiments of NiCrMo steels having excellent stress corrosion cracking resistance are as  
45 follows:

A low alloy steel having good stress corrosion cracking resistance containing

C :  $\leq 0.40$  %,   
Si :  $\leq 0.15$  %,   
Mn :  $\leq 0.60$  %,   
50 P :  $\leq 0.010$  %,   
S :  $\leq 0.030$  %,   
Ni : 0.50 to 4.00 %,   
Cr : 0.50 to 2.50 %,   
Mo : 0.25 to 4.00 % and   
55 V :  $\leq 0.30$  %

and further containing at least one of the kind selected from the following groups (i) and (ii):

- (i) at least one kind of Al, Ti, Nb, W, B and Ce: 0.001 to 0.50 % in total,
- (ii) Sn : 0.003 to 0.015 %,

said Si, Mn and P being fulfilled with the relationship of  $Si + Mn + 20 P \leq 0,75 \%$ , the remainder being Fe and unavoidable impurities.

A low alloy steel having good stress corrosion cracking resistance containing

- C :  $\leq 0.40 \%$ ,
- 5 Si :  $\leq 0.15 \%$ ,
- Mn :  $\leq 0.60 \%$ ,
- P :  $\leq 0.010 \%$ ,
- S :  $\leq 0.030 \%$ ,
- Ni :  $0.50$  to  $4.00 \%$ ,
- 10 Cr :  $0.50$  to  $2.50 \%$ ,
- Mo :  $0.25$  to  $4.00 \%$  and
- V :  $\leq 0.30 \%$

and further containing at least one kind selected from the following groups (i) and (ii):

- (i) at least one kind of Al, Ti, Nb, W, B and Ce:  $0.001$  to  $0.50 \%$  in total,
- 15 (ii) Sn :  $0.003$  to  $0.015 \%$ ,

the remainder being Fe and unavoidable impurities, the prior austenite crystal grain size being in excess of 4 of ASTM crystal grain size number.

A low alloy steel having good stress corrosion cracking resistance containing

- C :  $\leq 0.40 \%$ ,
- 20 Si :  $\leq 0.15 \%$ ,
- Mn :  $\leq 0.60 \%$ ,
- P :  $\leq 0.010 \%$ ,
- S :  $\leq 0.030 \%$ ,
- Ni :  $0.50$  to  $4.00 \%$ ,
- 25 Cr :  $0.50$  to  $2.50 \%$ ,
- Mo :  $0.25$  to  $4.00 \%$  and
- V :  $\leq 0.30 \%$

and further containing at least one kind selected from the following groups (i) and (ii):

- (i) at least one kind of Al, Ti, Nb, W, B and Ce:  $0.001$  to  $0.50 \%$  in total,
- 30 (ii) Sn :  $0.003$  to  $0.015 \%$ ,

said Si, Mn and P being fulfilled with the relationship of  $Si + Mn + 20 P \leq 0.75 \%$ , the remainder being Fe and unavoidable impurities, the prior austenite crystal grain size being in excess of 4 of ASTM crystal grain size number.

A low alloy steel as particularly mentioned in claim 5 in which Si, Mn and P are in the relationship of Si + Mn + 20 P  $\leq 0.50 \%$ .

A low alloy steel as particularly mentioned in claim 6 wherein Ni :  $3.25$  to  $4.00 \%$  and Cr :  $1.25$  to  $2.00 \%$ .

A low alloy steel having good stress corrosion cracking resistance containing

- C :  $\leq 0.40 \%$ ,
- 40 Si :  $\leq 0.15 \%$ ,
- Mn :  $\leq 0.60 \%$ ,
- P :  $\leq 0.010 \%$ ,
- S :  $\leq 0.030 \%$ ,
- Ni :  $3.25$  to  $4.00 \%$ ,
- 45 Cr :  $1.25$  to  $2.00 \%$ ,
- Mo :  $0.25$  to  $4.00 \%$  and
- V :  $\leq 0.30 \%$  and
- Nb :  $0.005$  to  $0.50 \%$ ,

said Si, Mn and P being fulfilled with the relationship of  $Si + Mn + 20 P \leq 0.50 \%$ , the remainder being Fe and unavoidable impurities.

The specific inventive use of these steels according to claim 8 is for steam turbines or the like where these high mechanical properties are desired.

In the following, the influences of the chemical components and ASTM crystal grain size number will be described and this demonstrates the reasons for the %-data:

55 C is an element for securing the strength. However, this element increases the sensitivity of stress corrosion cracking, and when its content exceeds  $0.4 \%$ , toughness is deteriorated in relation to other alloy elements. Therefore, in claims, the upper limit is set to  $0.40 \%$ .

S is an element which greatly deteriorates hot processing characteristics, and in view of preventing

cracking during hot forging, the upper limit is set to 0.030 % in claims.

Ni and Cr are elements indispensable to an increase in strength, improvement of hardenability and enhancement in toughness. Both the elements have each to be added in the amount in excess of 0.50 %. Preferably, Ni and Cr should be added in the amount in excess of 3.25 % and 1.25 %, respectively, in order to win further improvement of hardenability and toughness. When the contents of said elements exceed 4.00 % and 2.50 %, respectively, the transformation characteristics are greatly varied, and it takes a long time for heat treatment to obtain an excellent toughness, which is therefore impractical. Thus in the claims 1 to 5 the Ni content and Cr content are limited to the range of 0.50 to 4.00 % and 0.50 to 2.50 %, respectively and 3.25 to 4.00 % and 1.25 to 2.00 %, respectively, in claims 6 and 7.

Mo enhances the corrosion resistance of the prior  $\gamma$  grain boundary to materially reduce the sensitivity of intergranular stress corrosion cracking, as deposited in grains as a fine carbide during the tempering and greatly contributes to prevention of temper embrittlement and increase in strength. In order to obtain such effects, more than 0.25 % of Mo must be added; but when the content thereof exceeds 4.00 %, the aforesaid effects are saturated and the toughness begins to deteriorate. Furthermore, higher addition of Mo as necessary is uneconomical. Thus in the claims, the Mo content is limited to the range of 0.25 % to 4.00 %.

V is an effective element which increases the strength of steel by formation of fine crystals and precipitation hardening. V is added as necessary but when the content thereof exceeds 0.30 %, the effect thereof is saturated, and therefore, in the claims, the upper limit is set to 0.30 %.

Si, P and Mn are greatly concerned in the sensitivity of intergranular stress corrosion cracking. They are important elements which should be complementarily limited in relation to the size of crystal grain and a small addition of Ti, Al, Nb, W, B, Ce and Sn.

Si is an element necessary for deoxidation during refining. When the content of Si exceeds 0.15 %, the corrosion resistance of the prior  $\gamma$  grain boundary deteriorates and the sensitivity of intergranular stress corrosion cracking materially increases. Therefore, in the claims, the upper limit of Si is set to 0.15 %.

P is an impurity element which is segregated in the prior  $\gamma$  grain boundary to deteriorate the corrosion resistance and to increase the sensitivity of intergranular stress corrosion cracking and to promote temper embrittlement. In chrome-molybdenum steel and nickel-chrome-molybdenum steel according to JIS Standards, the content thereof is limited to 0.030 % or less in view of temper embrittlement. However, in order to reduce the stress corrosion cracking, said content is necessary to be further limited, thus in the claims 1 to 5 the content of P is set to 0.010 % or less.

Mn is added for deoxidation and desulfurization during refining. When the content of Mn exceeds 0.20 %, the a.m. segregation of grain boundary is promoted and the sensitivity of stress corrosion cracking materially increased; furthermore Si and P compositely act on the stress corrosion cracking, and the range of application thereof is greatly concerned in the size of crystal grains and the small addition of Ti, Al, Nb, W, B, Ce and Sn, as is demonstrated by the invention. Thus it is necessary, in terms of prevention of stress corrosion cracking in claim 1 wherein the small addition of Ti, Al, Nb, W, B, Ce and Sn is not effected, to limit the content of Mn to the range of 0.20 % or less, and to strictly limit the contents so that the contents of Si, P and Mn fulfill the relationship of  $(Mn + Si + 20 P) \leq 0.30$  %, i.e. the total of the weight % of contained Mn, the weight % of contained Si and 20 times of weight % of contained P is less than 0.30 %. On the other hand, it has been found from the detailed study of the influence of the microstructure in an attempt of further enhancing the reliability of sensitivity of stress corrosion cracking that the sensitivity of stress corrosion cracking also depends on the prior austenite crystal grain size, and sufficient reliability cannot be obtained even if the a.m. alloy composition should be satisfied when the ASTM crystal grain size number is smaller than 3. Accordingly in the present claim 1 the prior austenite crystal grain size number is limited to above 4 in addition to the limitation of the a.m. alloy elements.

The proper range of Mn content and/or  $Si + Mn + 20 P$  in claims 2 to 5 is different from the case of claim 1. This results from the fact that the sensitivity of stress corrosion cracking is greatly related to the size of crystal grains and containment of small addition elements of Ti, Al, Nb, W, B, Ce and Sn. It is possible to further enhance the reliability of the sensitivity of stress corrosion cracking by a proper combination of these various conditions.

Al, Ti, Nb, Ce, W, B and Sn are addition elements indispensable for enhancement of corrosion resistance of the prior  $\gamma$  grain boundary and for great contribution to reduce the sensitivity of stress corrosion cracking of the grain boundary type. In order to obtain such effects, among these six elements, i.e., Al, Ti, Nb, Ce, W and B, more than one kind of these elements need be added in the amount of 0.001 % or more in total. Among them the Nb addition set to 0.005 % or more, is the most effective to reduce the stress corrosion cracking, relating to the limitations of  $Si + Mn + 20 P \leq 0.50$  %. However, when the total of addition exceeds 0.50 %, the toughness is materially deteriorated. Thereby, the total amount of addition

of these elements is limited to the range of 0.001 to 0.50 %. On the other hand, in case of Sn, similar effect to the addition of the aforesaid six elements may be obtained by addition of more than 0.003 % of Sn but when the content thereof exceeds 0.015 %, the temper embrittlement is increased to materially deteriorate the toughness. Thus the content of Sn is limited to the range of 0.003 to 0.015 %. In order to reduce the stress corrosion cracking, however, the microalloying element addition, limitation of Mn content and/or range of Si + Mn + 20 P or limitation of size of crystal grains are necessary. Thus it is necessary to fulfill either condition  $Mn \leq 0.60 \%$  and  $Si + Mn + 20 P \leq 0.75 \%$ , and the size of the prior austenite crystal grain is above 4 of ASTM crystal grain number. The former condition and the latter condition correspond to required conditions of claims 2 and 3, respectively. It has been found that if both conditions are simultaneously fulfilled, the excellent stress corrosion cracking properties as of claims 2 and 3 may be further improved. This requirement is defined in claim 4. And it has been found that by the provision of  $Si + Mn + 20 P \leq 0.50 \%$ , further improvement with respect to the reduction of stress corrosion cracking according to claims 2 and 4 is obtained as defined in claim 5.

NiCrMo steel according to the present invention contains optimum alloy elements having the excellent stress corrosion cracking resistance in the range of an optimum composition ratio and or has an appropriate microstructure (crystal grain size); and therefore, even if said steel is used for members subjected to a high load stress under the corrosion environment such as NaOH,  $OH^-$  or the like, there is less possibility in producing stress corrosion cracking.

#### 20 Example 1

The embodiment of claim 1 is described.

Table 1 gives chemical compositions of sample steel used for stress corrosion cracking test and the prior  $\gamma$  crystal grain size. These steels were produced by adjusting compositions and melting them in a high frequency induction electric furnace, thereafter making ingots, hot forging them into 25 mm thickness, heating them to a temperature for forming austenite and water quenching them, thereafter heating them up to 620 °C and holding them for one hour and then cooling them at a speed of 4 °C/min. The crystal grain size was variously varied by adjusting the heating temperature and its holding time. The sample steel thus produced was machined to produce a strip of testpiece of 1.5 mm thickness x 15 mm width x 65 mm length.

In the stress corrosion cracking test the corresponding testpiece was attached to a four-point bending constant load testing apparatus; bending stress corresponding to 60% of 0.2 % proof stress of the steel was applied thereto; the testpiece was immersed in 30 % NaOH aqueous solution at 150 °C for one week, and thereafter the presence of cracking and the depth of cracking of the testpiece were measured by observation with an optical microscope. The results of the stress corrosion cracking tests are shown in Table 1, and in Fig. 1 and 2. As can be seen from the Table and the figures, and steels (Nos 1 to 24) according to the present invention have no stress corrosion cracking therein. On the other hand, comparative steels (Nos. 25 to 50) outside the claims have stress corrosion cracking of the grain boundary type. Particularly, as will be seen from Figs. 1 and 2, it is evident that no stress corrosion cracking is produced by the provision of  $Mn \leq 0.20 \%$ ,  $Si + Mn + 20 P \leq 0.30 \%$ , and ASTM grain size number in excess of 4. It is found from these facts that the limitation of Mn, Si and P, the limitation of (Mn + Si + 20 P) and the limitation of crystal grain size are very effective in prevention of stress corrosion cracking.

#### Example 2

The embodiment of claims 2 to 5 is described.

Table 3 gives chemical composition of sample steel used for stress corrosion cracking test and the prior  $\gamma$  crystal grain size. Similarly to Example 1, these steels were produced by adjusting compositions and melting them in a high frequency induction electric furnace, thereafter making ingots, hot forging them into 25 mm thickness, heating them to a temperature for forming austenite and water quenching them, thereafter heating them up to 620 °C and holding them for one hour and then cooling them at a speed of 4 °C/min. The crystal grain size was variously varied by adjusting the heating temperature and its holding time. The sample steel thus produced was machined to produce a strip of testpiece of 1.5 mm thickness x 15 mm width x 65 mm length.

In the stress corrosion cracking test, the corresponding testpiece was attached to a four-point bending constant load testing apparatus, bending stress corresponding to 60 % or 100 % of 0.2 % proof stress of the steel was applied thereto, the testpiece was immersed in 30 % NaOH aqueous solution at 150 °C for one week or three weeks, and thereafter the presence of cracking and the depth of cracking of the testpiece

were measured by observation with an optical microscope.

The results of these tests are shown in Table 3.

As will be apparent from the test results, the steels (Nos. 51 to 94) according to the present invention corresponding to claims 2 and 3 including claims 4 and 5 have no stress corrosion cracking. On the other hand, comparative steels (Nos. 95 to 109) outside the claims have intergranular stress corrosion cracking. Thus it is found by these facts that the limitation of Mn, Si and P, the limitation of  $Mn + Si + 20 P$  or the limitation of the crystal grain size according to the present invention are very effective in prevention of stress corrosion cracking.

On the other hand, even in Test II more severe conditions in terms of stress than in Test I steels (Nos. 66 to 87) corresponding to claims 4 and 5 have no stress corrosion cracking; and it is found that simultaneously the limitation of  $(Mn + Si + 20 P)$  and the limitation of crystal grain size leads to a further increase in improvement of stress corrosion cracking.

Moreover, in Test III which has the most severe testing conditions, only steels corresponding to Nos. 85 to 94, that is, those which are fulfilled with  $Si + Mn + 20 P \leq 0.50$  and ASTM crystal grain size number in excess of 4 have no stress corrosion cracking. Thus it is evident that this condition is the most effective embodiment to limit the prevention of stress corrosion craking.

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Table 1

| Test<br>steel<br>No. | Chemical component (Weight %) |      |      |       |       |      |      |      |      |      | Mn+Si<br>+20P<br>(Weight %) | Prior<br>Grain<br>size | Classification |
|----------------------|-------------------------------|------|------|-------|-------|------|------|------|------|------|-----------------------------|------------------------|----------------|
|                      | C                             | Si   | Mn   | P     | S     | Ni   | Cr   | Mo   | V    |      |                             |                        |                |
| 1                    | 0.23                          | 0.04 | 0.18 | 0.002 | 0.009 | 3.54 | 1.66 | 0.33 | 0.10 | 0.26 | 4                           | Invention steel        |                |
| 2                    | "                             | "    | "    | "     | "     | "    | "    | "    | "    | "    | 6                           | "                      |                |
| 3                    | "                             | "    | "    | "     | "     | "    | "    | "    | "    | "    | 7                           | "                      |                |
| 4                    | 0.21                          | 0.14 | 0.02 | 0.004 | 0.012 | 3.49 | 1.57 | 0.34 | 0.10 | 0.24 | 4                           | "                      |                |
| 5                    | "                             | "    | "    | "     | "     | "    | "    | "    | "    | "    | 5                           | "                      |                |
| 6                    | "                             | "    | "    | "     | "     | "    | "    | "    | "    | "    | 8                           | "                      |                |
| 7                    | 0.20                          | 0.03 | 0.12 | 0.007 | 0.005 | 3.53 | 1.62 | 0.33 | 0.11 | 0.29 | 5                           | "                      |                |
| 8                    | "                             | "    | "    | "     | "     | "    | "    | "    | "    | "    | 7                           | "                      |                |
| 9                    | "                             | "    | "    | "     | "     | "    | "    | "    | "    | "    | 9                           | "                      |                |
| 10                   | 0.20                          | 0.04 | 0.03 | 0.001 | 0.002 | 3.56 | 1.69 | 0.32 | 0.12 | 0.09 | 4                           | "                      |                |
| 11                   | "                             | "    | "    | "     | "     | "    | "    | "    | "    | "    | 6                           | "                      |                |
| 12                   | "                             | "    | "    | "     | "     | "    | "    | "    | "    | "    | 10                          | "                      |                |
| 13                   | 0.23                          | 0.05 | 0.07 | 0.006 | 0.006 | 3.53 | 1.62 | 0.35 | 0.09 | 0.24 | 4                           | "                      |                |
| 14                   | "                             | "    | "    | "     | "     | "    | "    | "    | "    | "    | 6                           | "                      |                |
| 15                   | "                             | "    | "    | "     | "     | "    | "    | "    | "    | "    | 8                           | "                      |                |
| 16                   | 0.21                          | 0.04 | 0.19 | 0.003 | 0.007 | 3.54 | 1.62 | 0.30 | 0.10 | 0.26 | 4                           | "                      |                |
| 17                   | "                             | "    | "    | "     | "     | "    | "    | "    | "    | "    | 6                           | "                      |                |
| 18                   | "                             | "    | "    | "     | "     | "    | "    | "    | "    | "    | 8                           | "                      |                |
| 19                   | 0.22                          | 0.03 | 0.02 | 0.010 | 0.003 | 3.52 | 1.58 | 0.32 | 0.11 | 0.25 | 4                           | "                      |                |
| 20                   | "                             | "    | "    | "     | "     | "    | "    | "    | "    | "    | 5                           | "                      |                |
| 21                   | "                             | "    | "    | "     | "     | "    | "    | "    | "    | "    | 7                           | "                      |                |
| 22                   | 0.22                          | 0.04 | 0.01 | 0.005 | 0.004 | 3.53 | 1.62 | 0.34 | 0.10 | 0.16 | 5                           | "                      |                |
| 23                   | "                             | "    | "    | "     | "     | "    | "    | "    | "    | "    | 7                           | "                      |                |
| 24                   | "                             | "    | "    | "     | "     | "    | "    | "    | "    | "    | 11                          | "                      |                |

Table 1 (Cont'd)

| Test steel No. | Chemical component (Weight %) |       |       |        |       |      |      |      |      |       | N+Si +20P (Weight %) | Prior Oxide size | Classification              | Remarks |
|----------------|-------------------------------|-------|-------|--------|-------|------|------|------|------|-------|----------------------|------------------|-----------------------------|---------|
|                | C                             | Si    | Mn    | P      | S     | Ni   | Cr   | Mo   | V    |       |                      |                  |                             |         |
| 25             | 0.23                          | 0.04  | 0.18  | 0.002  | 0.009 | 3.54 | 1.66 | 0.33 | 0.10 | 0.26  | 3*                   | Reference steel  | Same steel with No. 1 ~ 3   |         |
| 26             | "                             | "     | "     | "      | "     | "    | "    | "    | "    | "     | 1*                   | "                | "                           |         |
| 27             | 0.2                           | 0.14  | 0.02  | 0.004  | 0.012 | 3.49 | 1.57 | 0.34 | 0.10 | 0.24  | 2*                   | "                | Same steel with No. 4 ~ 6   |         |
| 28             | "                             | "     | "     | "      | "     | "    | "    | "    | "    | "     | 0*                   | "                | "                           |         |
| 29             | 0.20                          | 0.03  | 0.12  | 0.007  | 0.005 | 3.53 | 1.62 | 0.33 | 0.11 | 0.29  | 3*                   | "                | Same steel with No. 7 ~ 9   |         |
| 30             | "                             | "     | "     | "      | "     | "    | "    | "    | "    | "     | 1*                   | "                | "                           |         |
| 31             | 0.20                          | 0.04  | 0.03  | 0.001  | 0.002 | 3.56 | 1.69 | 0.32 | 0.12 | 0.09  | 2*                   | "                | Same steel with No. 10 ~ 12 |         |
| 32             | "                             | "     | "     | "      | "     | "    | "    | "    | "    | "     | -2*                  | "                | "                           |         |
| 33             | 0.23                          | 0.05  | 0.07  | 0.006  | 0.006 | 3.53 | 1.62 | 0.35 | 0.09 | 0.24  | 2*                   | "                | Same steel with No. 13 ~ 15 |         |
| 34             | "                             | "     | "     | "      | "     | "    | "    | "    | "    | "     | -1*                  | "                | "                           |         |
| 35             | 0.21                          | 0.04  | 0.19  | 0.003  | 0.007 | 3.54 | 1.62 | 0.30 | 0.10 | 0.26  | 3*                   | "                | Same steel with No. 16 ~ 18 |         |
| 36             | "                             | "     | "     | "      | "     | "    | "    | "    | "    | "     | 1*                   | "                | "                           |         |
| 37             | 0.22                          | 0.03  | 0.02  | 0.010  | 0.003 | 3.52 | 1.58 | 0.32 | 0.11 | 0.25  | 3*                   | "                | Same steel with No. 19 ~ 21 |         |
| 38             | "                             | "     | "     | "      | "     | "    | "    | "    | "    | "     | 2*                   | "                | "                           |         |
| 39             | 0.22                          | 0.04  | 0.10  | 0.005  | 0.004 | 3.53 | 1.62 | 0.34 | 0.10 | 0.16  | 3*                   | "                | Same steel with No. 22 ~ 24 |         |
| 40             | "                             | "     | "     | "      | "     | "    | "    | "    | "    | "     | 0*                   | "                | "                           |         |
| 41             | 0.23                          | 0.08  | 0.17  | 0.006  | 0.005 | 3.60 | 1.70 | 0.37 | 0.13 | 0.37* | 3*                   | "                | "                           |         |
| 42             | "                             | "     | "     | "      | "     | "    | "    | "    | "    | "     | 7*                   | "                | "                           |         |
| 43             | 0.22                          | 0.07  | 0.15  | 0.006  | 0.006 | 3.47 | 1.62 | 0.38 | 0.12 | 0.34* | 4                    | "                | "                           |         |
| 44             | "                             | "     | "     | "      | "     | "    | "    | "    | "    | "     | 6                    | "                | "                           |         |
| 45             | 0.23                          | 0.02  | 0.50* | 0.008  | 0.003 | 3.68 | 1.72 | 0.36 | 0.10 | 0.68* | 2*                   | "                | "                           |         |
| 46             | "                             | "     | "     | "      | "     | "    | "    | "    | "    | "     | 5                    | "                | "                           |         |
| 47             | 0.21                          | 0.16* | 0.49* | 0.011* | 0.004 | 3.42 | 1.70 | 0.38 | 0.10 | 0.87* | 3*                   | "                | "                           |         |
| 48             | "                             | "     | "     | "      | "     | "    | "    | "    | "    | "     | 6                    | "                | "                           |         |
| 49             | 0.20                          | 0.01  | 0.22* | 0.001  | 0.007 | 3.49 | 1.72 | 0.39 | 0.10 | 0.25  | 5                    | "                | "                           |         |
| 50             | 0.20                          | 0.02  | 0.23* | 0.002  | 0.008 | 3.50 | 1.68 | 0.35 | 0.11 | 0.29  | 4                    | "                | "                           |         |

\*: Beyond the scope of claim



Table 2

| Test steel No. | Resistance to stress corrosion cracking property |                     |                 | Remarks                   | Test steel No. | Resistance to stress corrosion cracking property |                     |                 | Remarks                                                               |
|----------------|--------------------------------------------------|---------------------|-----------------|---------------------------|----------------|--------------------------------------------------|---------------------|-----------------|-----------------------------------------------------------------------|
|                | Occurrence of cracking                           | Depth of crack (mm) | Classification  |                           |                | Occurrence of cracking                           | Depth of crack (mm) | Classification  |                                                                       |
| 1              | No cracking                                      | 0.00                | Invention steel |                           | 26             | Cracking                                         | 0.18                | Reference steel | Unsatisfactory grain size                                             |
| 2              | "                                                | 0.00                | "               |                           | 27             | "                                                | 0.13                | "               | "                                                                     |
| 3              | "                                                | 0.00                | "               |                           | 28             | "                                                | 0.20                | "               | "                                                                     |
| 4              | "                                                | 0.00                | "               |                           | 29             | "                                                | 0.02                | "               | "                                                                     |
| 5              | "                                                | 0.00                | "               |                           | 30             | "                                                | 0.11                | "               | "                                                                     |
| 6              | "                                                | 0.00                | "               |                           | 31             | "                                                | 0.08                | "               | "                                                                     |
| 7              | "                                                | 0.00                | "               |                           | 32             | "                                                | 0.30                | "               | "                                                                     |
| 8              | "                                                | 0.00                | "               |                           | 33             | "                                                | 0.09                | "               | "                                                                     |
| 9              | "                                                | 0.00                | "               |                           | 34             | "                                                | 0.12                | "               | "                                                                     |
| 10             | "                                                | 0.00                | "               |                           | 35             | "                                                | 0.17                | "               | "                                                                     |
| 11             | "                                                | 0.00                | "               |                           | 36             | "                                                | 0.16                | "               | "                                                                     |
| 12             | "                                                | 0.00                | "               |                           | 37             | "                                                | 0.03                | "               | "                                                                     |
| 13             | "                                                | 0.00                | "               |                           | 38             | "                                                | 0.05                | "               | "                                                                     |
| 14             | "                                                | 0.00                | "               |                           | 39             | "                                                | 0.01                | "               | "                                                                     |
| 15             | "                                                | 0.00                | "               |                           | 40             | "                                                | 0.09                | "               | "                                                                     |
| 16             | "                                                | 0.00                | "               |                           | 41             | "                                                | 0.55                | "               | Unsatisfactory of grain size (Mn+Si+20P) weight                       |
| 17             | "                                                | 0.00                | "               |                           | 42             | "                                                | 0.12                | "               | Unsatisfactory (Mn+Si+20P) weight                                     |
| 18             | "                                                | 0.00                | "               |                           | 43             | "                                                | 0.33                | "               | "                                                                     |
| 19             | "                                                | 0.00                | "               |                           | 44             | "                                                | 0.43                | "               | "                                                                     |
| 20             | "                                                | 0.00                | "               |                           | 45             | "                                                | ≥1.50               | "               | Unsatisfactory of Mn weight, grain size and (Mn+Si+20P) weight        |
| 21             | "                                                | 0.00                | "               |                           | 46             | "                                                | ≥1.50               | "               | Unsatisfactory of Mn weight and (Mn+Si+20P) weight                    |
| 22             | "                                                | 0.00                | "               |                           | 47             | "                                                | ≥1.50               | "               | Unsatisfactory of Mn weight and (Mn+Si+20P) weight                    |
| 23             | "                                                | 0.00                | "               |                           | 48             | "                                                | ≥1.50               | "               | Unsatisfactory of Mn, Si, P weight, and grain size (Mn+Si+20P) weight |
| 24             | "                                                | 0.00                | "               |                           | 49             | "                                                | 0.22                | "               | Unsatisfactory of Mn, Si, P weight, and (Mn+Si+20P) weight            |
| 25             | Cracking                                         | 0.09                | Reference steel | Unsatisfactory grain size | 50             | "                                                | 0.40                | "               | Unsatisfactory of Mn weight                                           |

Table 3

| Test steel No. | Chemical component (Wt%) |      |      |       |       |      |      |      |      |                             | Si+ Mn+ 20P | Prior grain size | Resistance to stress corrosion cracking property (Maximum crack depth) |         |          | Remarks                      |
|----------------|--------------------------|------|------|-------|-------|------|------|------|------|-----------------------------|-------------|------------------|------------------------------------------------------------------------|---------|----------|------------------------------|
|                | C                        | Si   | Mn   | P     | S     | Ni   | Cr   | Mo   | V    | Others                      |             |                  | Test I                                                                 | Test II | Test III |                              |
|                |                          |      |      |       |       |      |      |      |      |                             |             |                  |                                                                        |         |          |                              |
| 51             | 0.23                     | 0.09 | 0.58 | 0.009 | 0.003 | 3.75 | 1.69 | 0.36 | 0.09 | Nb:0.003, Ti:0.001          | 0.85        | 4                | 0.00                                                                   | 0.09    | 0.30     |                              |
| 52             | "                        | "    | "    | "     | "     | "    | "    | "    | "    | "                           | "           | 7                | 0.00                                                                   | 0.08    | 0.32     |                              |
| 53             | "                        | "    | "    | "     | "     | "    | "    | "    | "    | "                           | "           | 10               | 0.00                                                                   | 0.05    | —        |                              |
| 54             | 0.24                     | 0.08 | 0.58 | 0.005 | 0.004 | 3.50 | 1.65 | 0.39 | 0.10 | B:0.009                     | 0.76        | 4                | 0.00                                                                   | 0.12    | —        |                              |
| 55             | "                        | "    | "    | "     | "     | "    | "    | "    | "    | "                           | "           | 8                | 0.00                                                                   | 0.01    | —        |                              |
| 56             | 0.20                     | 0.10 | 0.57 | 0.005 | 0.001 | 3.64 | 1.75 | 0.35 | 0.11 | Sn:0.006                    | 0.77        | 5                | 0.00                                                                   | 0.04    | —        |                              |
| 57             | "                        | "    | "    | "     | "     | "    | "    | "    | "    | "                           | "           | 9                | 0.00                                                                   | 0.06    | —        |                              |
| 58             | 0.06                     | 0.10 | 0.31 | 0.006 | 0.005 | 3.49 | 1.70 | 0.38 | 0.10 | Nb:0.005                    | 0.53        | -1               | 0.00                                                                   | 0.06    | 0.29     |                              |
| 59             | 0.20                     | 0.07 | 0.32 | 0.007 | 0.004 | 3.58 | 1.72 | 0.39 | 0.01 | Ti:0.055, Al:0.020          | 0.53        | 3                | 0.00                                                                   | 0.00    | 0.34     |                              |
| 60             | 0.21                     | 0.07 | 0.52 | 0.006 | 0.004 | 3.58 | 1.72 | 0.39 | 0.25 | Nb:0.003, B:0.012           | 0.71        | 2                | 0.00                                                                   | 0.07    | —        |                              |
| 61             | 0.21                     | 0.08 | 0.31 | 0.008 | 0.005 | 3.65 | 1.84 | 0.38 | 0.10 | Nb:0.010                    | 0.55        | 2                | 0.00                                                                   | 0.02    | —        |                              |
| 62             | 0.22                     | 0.08 | 0.31 | 0.006 | 0.004 | 3.52 | 1.72 | 0.37 | 0.11 | Nb:0.001, Ti:0.005, B:0.012 | 0.51        | 1                | 0.00                                                                   | 0.04    | —        |                              |
| 63             | 0.20                     | 0.08 | 0.40 | 0.006 | 0.001 | 3.60 | 1.75 | 0.34 | 0.10 | Sn:0.004                    | 0.60        | 0                | 0.00                                                                   | 0.07    | —        |                              |
| 64             | 0.19                     | 0.10 | 0.59 | 0.002 | 0.010 | 3.70 | 1.70 | 0.35 | 0.10 | Ce:0.020, W:0.015           | 0.73        | 3                | 0.00                                                                   | 0.11    | —        |                              |
| 65             | 0.25                     | 0.01 | 0.58 | 0.004 | 0.008 | 3.58 | 1.69 | 0.35 | 0.09 | W:0.006, Al:0.05            | 0.75        | 3                | 0.00                                                                   | 0.08    | —        |                              |
| 66             | 0.06                     | 0.10 | 0.31 | 0.006 | 0.005 | 3.49 | 1.70 | 0.38 | 0.10 | Nb:0.005                    | 0.53        | 4                | 0.00                                                                   | 0.00    | 0.12     | Same steel with No. 58 steel |
| 67             | 0.20                     | 0.07 | 0.32 | 0.007 | 0.004 | 3.58 | 1.72 | 0.39 | 0.09 | Ti:0.055, Al:0.020          | 0.53        | 4                | 0.00                                                                   | 0.00    | 0.09     | Same steel with No. 59 steel |
| 68             | 0.21                     | 0.07 | 0.52 | 0.006 | 0.004 | 3.58 | 1.72 | 0.39 | 0.25 | Ti:0.003, Nb:0.010          | 0.71        | 5                | 0.00                                                                   | 0.00    | 0.01     | Same steel with No. 60 steel |
| 69             | 0.21                     | 0.08 | 0.31 | 0.008 | 0.005 | 3.65 | 1.84 | 0.38 | 0.10 | B:0.002                     | 0.55        | 8                | 0.00                                                                   | 0.00    | 0.00     | Same steel with No. 61 steel |
| 70             | 0.22                     | 0.08 | 0.31 | 0.006 | 0.004 | 3.52 | 1.72 | 0.37 | 0.11 | Nb:0.001, Ti:0.005, B:0.012 | 0.51        | 4                | 0.00                                                                   | 0.00    | 0.04     | Same steel with No. 62 steel |
| 71             | 0.20                     | 0.08 | 0.40 | 0.006 | 0.001 | 3.60 | 1.75 | 0.34 | 0.10 | Sn:0.004                    | 0.60        | 7                | 0.00                                                                   | 0.00    | 0.06     | Same steel with No. 63 steel |
| 72             | 0.19                     | 0.10 | 0.59 | 0.002 | 0.010 | 3.70 | 1.70 | 0.35 | 0.10 | Ce:0.020, W:0.015           | 0.73        | 6                | 0.00                                                                   | 0.00    | 0.11     | Same steel with No. 64 steel |
| 73             | 0.25                     | 0.09 | 0.58 | 0.004 | 0.008 | 3.58 | 1.69 | 0.35 | 0.09 | W:0.006, Al:0.05            | 0.75        | 4                | 0.00                                                                   | 0.00    | 0.10     | Same steel with No. 65 steel |
| 74             | "                        | "    | "    | "     | "     | "    | "    | "    | "    | "                           | "           | 7                | 0.00                                                                   | 0.00    | 0.02     | Same steel with No. 65 steel |
| 75             | 0.20                     | 0.01 | 0.31 | 0.005 | 0.004 | 3.48 | 1.72 | 0.38 | 0.10 | Nb:0.005                    | 0.42        | 2                | 0.00                                                                   | 0.00    | 0.06     |                              |
| 76             | 0.22                     | 0.08 | 0.32 | 0.001 | 0.005 | 3.50 | 1.73 | 0.32 | 0.10 | Ti:0.002                    | 0.42        | 3                | 0.00                                                                   | 0.00    | 0.08     |                              |
| 77             | 0.22                     | 0.03 | 0.32 | 0.003 | 0.006 | 3.65 | 1.76 | 0.34 | 0.10 | Sn:0.005                    | 0.40        | 3                | 0.00                                                                   | 0.00    | 0.09     |                              |
| 78             | 0.18                     | 0.04 | 0.30 | 0.003 | 0.004 | 3.54 | 1.71 | 0.38 | —    | W:0.010, B:0.010            | 0.40        | 3                | 0.00                                                                   | 0.00    | 0.06     |                              |

Table 3 (Cont'd)

| Test steel No. | Chemical component (Wt%) |      |      |       |       |      |      |      |      |                    | Prior grain size | Resistance to stress corrosion cracking property (Maximum crack depth) |      |      |          | Remarks                           |
|----------------|--------------------------|------|------|-------|-------|------|------|------|------|--------------------|------------------|------------------------------------------------------------------------|------|------|----------|-----------------------------------|
|                | C                        | Si   | Mn   | P     | S     | Ni   | Cr   | Mo   | V    | Others             |                  | Test                                                                   |      |      | Test III |                                   |
|                |                          |      |      |       |       |      |      |      |      |                    |                  | I                                                                      | II   | III  |          |                                   |
| 79             | 0.21                     | 0.08 | 0.31 | 0.005 | 0.004 | 3.53 | 1.72 | 0.38 | 0.10 | Nb:0.054, Ce:0.015 | 0.49             | 0.00                                                                   | 0.00 | 0.13 |          |                                   |
| 80             | 0.20                     | 0.06 | 0.31 | 0.004 | 0.005 | 3.53 | 1.72 | 0.38 | 0.10 | Al:0.009           | 0.45             | 0.00                                                                   | 0.00 | 0.14 |          | Same steel with No. 75 steel      |
| 81             | 0.20                     | 0.02 | 0.20 | 0.002 | 0.005 | 3.50 | 1.69 | 0.35 | 0.12 | W:0.050, Nb:0.015  | 0.26             | 0.00                                                                   | —    | 0.02 |          |                                   |
| 82             | 0.23                     | 0.02 | 0.29 | 0.002 | 0.002 | 3.62 | 1.68 | 0.34 | 0.10 | Nb:0.032           | 0.35             | 0.00                                                                   | —    | 0.06 |          | Same steel with No. 76 steel      |
| 83             | "                        | "    | "    | "     | "     | "    | "    | "    | "    | "                  | "                | 0.00                                                                   | 0.00 | 0.07 |          |                                   |
| 84             | "                        | "    | "    | "     | "     | "    | "    | "    | "    | "                  | "                | 0.00                                                                   | 0.00 | 0.03 |          | Same steel with No. 77 steel      |
| 85             | 0.20                     | 0.01 | 0.31 | 0.005 | 0.004 | 3.48 | 1.72 | 0.38 | 0.10 | Nb:0.005           | 0.42             | 0.00                                                                   | 0.00 | 0.00 |          |                                   |
| 86             | 0.22                     | 0.08 | 0.32 | 0.001 | 0.005 | 3.50 | 1.73 | 0.32 | 0.10 | Ti:0.002           | 0.42             | 0.00                                                                   | 0.00 | 0.00 |          | Same steel with No. 78 steel      |
| 87             | 0.22                     | 0.03 | 0.32 | 0.003 | 0.006 | 3.65 | 1.26 | 0.34 | 0.10 | Sn:0.005           | 0.41             | 0.00                                                                   | 0.00 | 0.00 |          |                                   |
| 88             | 0.18                     | 0.04 | 0.30 | 0.003 | 0.004 | 3.54 | 1.71 | 0.38 | —    | B:0.005, W:0.010   | 0.40             | 0.00                                                                   | —    | 0.00 |          | Same steel with No. 79 steel      |
| 89             | 0.21                     | 0.08 | 0.31 | 0.005 | 0.004 | 3.53 | 1.72 | 0.38 | 0.10 | Nb:0.054, Ce:0.015 | 0.49             | 0.00                                                                   | —    | 0.00 |          |                                   |
| 90             | 0.20                     | 0.06 | 0.31 | 0.004 | 0.005 | 3.53 | 1.69 | 0.38 | 0.10 | Al:0.009           | 0.45             | 0.00                                                                   | —    | 0.00 |          | Same steel with No. 80 steel      |
| 91             | 0.20                     | 0.02 | 0.20 | 0.002 | 0.005 | 3.50 | 1.69 | 0.35 | 0.12 | W:0.050, Ce:0.015  | 0.26             | 0.00                                                                   | —    | 0.00 |          |                                   |
| 92             | 0.23                     | 0.02 | 0.29 | 0.002 | 0.002 | 3.62 | 1.68 | 0.34 | 0.10 | Nb:0.032           | 0.35             | 0.00                                                                   | —    | 0.00 |          | Same steel with No. 82 steel      |
| 93             | "                        | "    | "    | "     | "     | "    | "    | "    | "    | "                  | "                | 0.00                                                                   | —    | 0.00 |          |                                   |
| 94             | "                        | "    | "    | "     | "     | "    | "    | "    | "    | "                  | "                | 0.00                                                                   | —    | 0.00 |          | Same steel with No. 82 steel      |
| 95             | 0.23                     | 0.09 | 0.58 | 0.009 | 0.003 | 3.75 | 1.69 | 0.36 | 0.09 | Nb:0.003, Ti:0.001 | 0.85             | 0.29                                                                   | 1.20 | 1.50 |          |                                   |
| 96             | 0.24                     | 0.08 | 0.58 | 0.005 | 0.004 | 3.50 | 1.65 | 0.39 | 0.10 | B:0.009            | 0.76             | 0.16                                                                   | 0.85 | 1.50 |          | Same steel with No. 54 ~ 55 steel |
| 97             | "                        | "    | "    | "     | "     | "    | "    | "    | "    | "                  | "                | 0.50                                                                   | 1.35 | 1.50 |          |                                   |
| 98             | "                        | "    | "    | "     | "     | "    | "    | "    | "    | "                  | "                | 0.95                                                                   | 1.50 | 1.50 |          | Same steel with No. 54 ~ 55 steel |
| 99             | 0.20                     | 0.10 | 0.57 | 0.005 | 0.001 | 3.64 | 1.75 | 0.35 | 0.11 | Sn:0.006           | 0.77             | 0.23                                                                   | 0.84 | 1.50 |          |                                   |
| 100            | "                        | "    | "    | "     | "     | "    | "    | "    | "    | "                  | "                | 0.45                                                                   | 0.76 | 1.50 |          | Same steel with No. 56 ~ 57 steel |
| 101            | 0.20                     | 0.14 | 0.58 | 0.002 | 0.001 | 3.48 | 1.70 | 0.33 | 0.10 | Nb:0.004, Ti:0.001 | 0.76             | 0.32                                                                   | —    | 1.50 |          |                                   |
| 102            | 0.19                     | 0.10 | 0.55 | 0.007 | 0.003 | 3.60 | 1.74 | 0.35 | 0.11 | Sn:0.007           | 0.79             | 0.18                                                                   | —    | 1.50 |          | Same steel with No. 56 ~ 57 steel |
| 103            | 0.22                     | 0.18 | 0.59 | 0.010 | 0.009 | 3.50 | 1.80 | 0.35 | 0.10 | Al:0.015, W:0.009  | 0.97             | 0.60                                                                   | —    | 1.50 |          |                                   |
| 104            | "                        | "    | "    | "     | "     | "    | "    | "    | "    | "                  | "                | 0.45                                                                   | —    | —    |          | Same steel with No. 56 ~ 57 steel |
| 105            | 0.25                     | 0.12 | 0.31 | 0.006 | 0.005 | 3.48 | 1.73 | 0.37 | 0.10 | —                  | 0.55             | 1.30                                                                   | —    | —    |          |                                   |
| 106            | 0.20                     | 0.17 | 0.30 | 0.008 | 0.004 | 3.50 | 1.72 | 0.38 | 0.10 | —                  | 0.63             | 1.50                                                                   | —    | —    |          | Same steel with No. 56 ~ 57 steel |
| 107            | 0.22                     | 0.13 | 0.80 | 0.008 | 0.004 | 3.53 | 1.73 | 0.38 | 0.11 | —                  | 1.09             | 1.50                                                                   | —    | —    |          |                                   |
| 108            | 0.21                     | 0.10 | 0.32 | 0.012 | 0.004 | 3.53 | 1.72 | 0.36 | 0.10 | —                  | 0.66             | 1.30                                                                   | —    | —    |          | Same steel with No. 56 ~ 57 steel |
| 109            | 0.19                     | 0.08 | 0.32 | 0.001 | 0.005 | 3.60 | 1.69 | 0.35 | 0.09 | —                  | 0.42             | 0.92                                                                   | —    | —    |          |                                   |

\*Test I: 4 points bending, 150°C, 30% NaOH, immersed for 1 week, Load stress = 0.60y

Test II: 4 points bending, 150°C, 30% NaOH, immersed for 1 week, Load stress = 1.00y

Test III: 4 points bending, 150°C, 30% NaOH, immersed for 3 weeks, Load stress = 1.00y

## Claims

1. A low alloy steel having good stress corrosion cracking resistance containing

C :  $\leq 0.40\%$ ,Si :  $\leq 0.15\%$ ,

5 Mn :  $\leq 0.20$  %,  
P :  $\leq 0.010$  %,  
S :  $\leq 0.030$  %,  
Ni : 0.50 to 4.00 %,  
Cr : 0.50 to 2.50 %, Mo : 0.25 to 4.00 % and  
V :  $\leq 0.30$  %,
10

said Si, Mn and P being fulfilled with relationship of  $Si + Mn + 20 P \leq 0.30$  %, the remainder being Fe and unavoidable impurities, the prior austenite crystal grain size being in excess of 4 of ASTM crystal grain size number.

2. A low alloy steel having good stress corrosion cracking resistance containing

15 C :  $\leq 0.40$  %,  
Si :  $\leq 0.15$  %, Mn :  $\leq 0.60$  %, P :  $\leq 0.010$  %, S :  $\leq 0.030$  %, Ni : 0.50 to 4.00 %, Cr : 0.50 to 2.50 %, Mo : 0.25 to 4.00 % and  
20 V :  $\leq 0.30$  %

and further containing at least one of the kind selected from the following groups (i) and (ii):

(i) at least one kind of Al, Ti, Nb, W, B and Ce: 0.001 to 0.50 % in total,

(ii) Sn : 0.003 to 0.015 %,
25

said Si, Mn and P being fulfilled with the relationship of  $Si + Mn + 20 P \leq 0.75$  %, the remainder being Fe and unavoidable impurities.

3. A low alloy steel having good stress corrosion cracking resistance containing

30 C :  $\leq 0.40$  %,  
Si :  $\leq 0.15$  %, Mn :  $\leq 0.60$  %, P :  $\leq 0.010$  %, S :  $\leq 0.030$  %, Ni : 0.50 to 4.00 %, Cr : 0.50 to 2.50 %, Mo : 0.25 to 4.00 % and  
35 V :  $\leq 0.30$  %

and further containing at least one kind selected from the following groups (i) and (ii):

(i) at least one kind of Al, Ti, Nb, W, B and Ce: 0.001 to 0.50 % in total,

(ii) Sn : 0.003 to 0.015 %,
40

the remainder being Fe and unavoidable impurities, the prior austenite crystal grain size being in excess of 4 of ASTM crystal grain size number.

4. A low alloy steel having good stress corrosion cracking resistance containing

45 C :  $\leq 0.40$  %,  
Si :  $\leq 0.15$  %, Mn :  $\leq 0.60$  %, P :  $\leq 0.010$  %, S :  $\leq 0.030$  %, Ni : 0.50 to 4.00 %, Cr : 0.50 to 2.50 %, Mo : 0.25 to 4.00 % and  
50 V :  $\leq 0.30$  %

and further containing at least one kind selected from the following groups (i) and (ii):

(i) at least one kind of Al, Ti, Nb, W, B and Ce: 0.001 to 0.50 % in total,

(ii) Sn : 0.003 to 0.015 %,
55

said Si, Mn and P being fulfilled with the relationship of  $Si + Mn + 20 P \leq 0.75$  %, the remainder being Fe and unavoidable impurities, the prior austenite crystal grain size being in excess of 4 of ASTM

crystal grain size number.

5. A low alloy steel as set forth in claim 2 or 4 wherein Si, Mn and P are in the relationship of  $Si + Mn + 20 P \leq 0.50 \%$ .

6. A low alloy steel as set forth in claims 1 to 5 wherein Ni : 3.25 to 4.00 % and Cr : 1.25 to 2.00 %.

7. A low alloy steel having good stress corrosion cracking resistance containing

C :  $\leq 0.40 \%$ ,

Si :  $\leq 0.15 \%$ ,

Mn :  $\leq 0.60 \%$ ,

P :  $\leq 0.010 \%$ ,

S :  $\leq 0.030 \%$ ,

Ni : 3.25 to 4.00 %,

Cr : 1.25 to 2.00 %,

Mo : 0.25 to 4.00 %,

V :  $\leq 0.30 \%$  and

Nb : 0.005 to 0.50 %,

said Si, Mn and P being fulfilled with the relationship of  $Si + Mn + 20 P \leq 0.50 \%$ , the remainder being Fe and unavoidable impurities.

8. Use of the steel according to the preceding claims for steam turbines or the like.

## Revendications

1. Acier faiblement allié possédant une bonne résistance à la corrosion fissurante sous tension contenant les éléments qui suivent :

C :  $\leq 0,40\%$ ,

Si :  $\leq 0,15\%$ ,

Mn :  $\leq 0,20\%$ ,

P :  $\leq 0,010\%$ ,

S :  $\leq 0,030\%$ ,

Ni : 0,50 à 4,00%,

Cr : 0,50 à 2,50%,

Mo : 0,25 à 4,00% et

V :  $\leq 0,30\%$ ,

lesdits Si, Mn et P étant soumis à la relation  $Si + Mn + 20 P \leq 0,30\%$ , le reste étant constitué de Fe et d'impuretés inévitables, le calibre du grain de cristal du type austénite préalable étant supérieur de 4 à l'indice du calibre de grain de cristal ASTM.

2. Acier faiblement allié possédant une bonne résistance à la corrosion fissurante sous tension contenant les éléments qui suivent :

C :  $\leq 0,40\%$ ,

Si :  $\leq 0,15\%$ ,

Mn :  $\leq 0,60\%$ ,

P :  $\leq 0,010\%$ ,

S :  $\leq 0,030\%$ ,

Ni :  $\leq 0,50$  à 4,00%,

Cr : 0,50 à 2,50%,

Mo : 0,25 à 4,00% et

V :  $\leq 0,30\%$

et contenant, en outre, au moins l'un des éléments choisis parmi les groupes (i) et (ii) suivants :

(i) au moins un élément choisi parmi Al, Ti, Nb, W, B et Ce : 0,00 1 à 0,50% au total,

(ii) Sn : 0,003 à 0,015%,

lesdits Si, Mn et P étant soumis à la relation  $Si + Mn + 20 P \leq 0,75\%$ , le reste étant constitué de Fe et d'impuretés inévitables.

3. Acier faiblement allié possédant une bonne résistance à la corrosion fissurante sous tension contenant

les éléments qui suivent

- 5 C :  $\leq 0,40\%$ ,  
Si :  $\leq 0,15\%$ ,  
Mn :  $\leq 0,60\%$ ,  
P :  $\leq 0,010\%$ ,  
S :  $\leq 0,030\%$ ,  
Ni :  $0,50$  à  $4,00\%$ ,  
Cr :  $0,50$  à  $2,50\%$ ,  
Mo :  $0,25$  à  $4,00\%$  et  
10 V :  $\leq 0,30\%$

et contenant, en outre, au moins l'un des éléments choisis parmi les groupes (i) et (ii) suivants :

- (i) au moins l'un des éléments choisis parmi Al, Ti, Nb, W, B et Ce :  $0,001$  à  $0,50\%$  au total,  
(ii) Sn :  $0,003$  à  $0,015\%$ ,

15 le reste étant constitué de Fe et d'impuretés inévitables, le calibre du grain de cristal du type austénite préalable étant supérieur de 4 à l'indice du calibre de grain de cristal ASTM.

4. Acier faiblement allié possédant une bonne résistance à la corrosion fissurante sous tension contenant les éléments qui suivent

- 20 C :  $\leq 0,40\%$ ,  
Si :  $\leq 0,15\%$ ,  
Mn :  $\leq 0,60\%$ ,  
P :  $\leq 0,010\%$ ,  
S :  $\leq 0,030\%$ ,  
Ni :  $0,50$  à  $4,00\%$ ,  
25 Cr :  $0,50$  à  $2,50\%$ ,  
Mo :  $0,25$  à  $4,00\%$  et  
V :  $\leq 0,30\%$

et contenant, en outre, au moins l'un des éléments choisis parmi les groupes (i) et (ii) suivants :

- 30 (i) au moins l'un des éléments choisi parmi Al, Ti, Nb, W, B et Ce :  $0,001$  à  $0,50\%$  au total,  
(ii) Sn :  $0,003$  à  $0,015\%$ ,

lesdits Si, Mn et P étant soumis à la relation  $Si + Mn + 20 P \leq 0,75\%$ ,

le reste étant constitué de Fe et d'impuretés inévitables, le calibre du grain de cristal du type austénite préalable étant supérieur de 4 à l'indice du calibre de grain de cristal ASTM.

- 35 5. Acier faiblement allié suivant la revendication 2 ou 4, caractérisé en ce que Si, Mn et P sont soumis à la relation  $Si + Mn + 20 P \leq 0,50\%$ .

6. Acier faiblement allié suivant les revendication 1 à 5, caractérisé en ce que Ni :  $3,25$  à  $4,00\%$  et Cr :  $1,25$  à  $2,00\%$ .

- 40 7. Acier faiblement allié possédant une bonne résistance à la corrosion fissurante sous tension contenant les éléments qui suivent

- 45 C :  $\leq 0,40\%$ ,  
Si :  $\leq 0,15\%$ ,  
Mn :  $\leq 0,60\%$ ,  
P :  $\leq 0,010\%$ ,  
S :  $\leq 0,030\%$ ,  
Ni :  $3,25$  à  $4,00\%$ ,  
Cr :  $1,25$  à  $2,00\%$ ,  
50 Mo :  $0,25$  à  $4,00\%$ ,  
V :  $\leq 0,30\%$  et  
Nb :  $0,005$  à  $0,50\%$ ,

lesdits Si, Mn et P étant soumis à la relation  $Si + Mn + 20 P \leq 0,50\%$ , le reste étant constitué de Fe et d'impuretés inévitables.

- 55 8. Utilisation de l'acier suivant les revendications précédentes pour la confection de turbines à vapeur et analogues.

**Patentansprüche****1. Niedriglegierter Stahl mit guter Spannungsrißkorrosionsresistenz, enthaltend**

- 5 C :  $\leq 0.40$  %,  
 Si :  $\leq 0.15$  %,  
 Mn :  $\leq 0.20$  %,  
 P :  $\leq 0.010$  %,  
 S :  $\leq 0.030$  %,
   
 10 Ni : 0.50 bis 4.00 %,
   
 Cr : 0.50 bis 2.50 %
   
 Mo : 0.25 bis 4.00 % und
   
 V :  $\leq 0.30$  %,

15 wobei den Angaben zu Si, Mn und P genügt ist durch die Beziehung  $Si + Mn + 20 P \leq 0.30$  %, der Rest aus Fe und unvermeidbaren Verunreinigungen besteht und die Austenit Ausgangskristallkörngröße mehr als 4 in der ASTM-Kristallkörnungsnummernordnung beträgt.

**2. Niedriglegierter Stahl mit guter Spannungsrißkorrosionsresistenz, enthaltend**

- C :  $\leq 0.40$  %,  
 Si :  $\leq 0.15$  %,
   
 20 Mn :  $\leq 0.60$  %,
   
 P :  $\leq 0.010$  %,
   
 S :  $\leq 0.030$  %,
   
 Ni : 0.50 bis 4.00 %,
   
 Cr : 0.50 bis 2.50 %,
   
 25 Mo : 0.25 bis 4.00 % und
   
 V :  $\leq 0.30$  %

und weiterhin enthaltend wenigstens ein Element aus den folgenden Gruppen (i) und (ii):

- (i) wenigstens ein Element aus der Reihe Al, Ti, Nb, W, B und Ce: 0.001 bis 0.50 % insgesamt,  
 (ii) Sn : 0.003 bis 0.015 %,
   
 30 wobei den Angaben zu Si, Mn und P genügt ist durch die Beziehung  $Si + Mn + 20 P \leq 0,75$  % und der Rest aus Fe und unvermeidbaren Verunreinigungen besteht.

**3. Niedriglegierter Stahl mit guter Spannungsrißkorrosionsresistenz, enthaltend**

- C :  $\leq 0.40$  %,
   
 35 Si :  $\leq 0.15$  %,
   
 Mn :  $\leq 0.60$  %,
   
 P :  $\leq 0.010$  %,
   
 S :  $\leq 0.030$  %,
   
 Ni : 0.50 bis 4.00 %,
   
 40 Cr : 0.50 bis 2.50 %,
   
 Mo : 0.25 bis 4.00 % und
   
 V :  $\leq 0.30$  %

und weiterhin enthaltend wenigstens ein Element aus den folgenden Gruppen (i) und (ii):

- (i) wenigstens ein Element aus der Reihe Al, Ti, Nb, W, B und Ce: 0.001 bis 0.50 % insgesamt,  
 (ii) Sn : 0.003 bis 0.015 %,
   
 45 wobei der Rest aus Fe und unvermeidbaren Verunreinigungen besteht und die Austenit Ausgangskristallkörngröße mehr als 4 in der ASTM-Kristallkörnungsnummernordnung beträgt.

**4. Niedriglegierter Stahl mit guter Spannungsrißkorrosionsresistenz, enthaltend**

- 50 C :  $\leq 0.40$  %,
   
 Si :  $\leq 0.15$  %,
   
 Mn :  $\leq 0.60$  %,
   
 P :  $\leq 0.010$  %,
   
 S :  $\leq 0.030$  %,
   
 55 Ni : 0.50 bis 4.00 %,
   
 Cr : 0.50 bis 2.50 %,
   
 Mo : 0.25 bis 4.00 % und
   
 V :  $\leq 0.30$  %

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und weiterhin enthaltend wenigstens ein Element aus den folgenden Gruppen (i) und (ii):

(i) wenigstens ein Element aus der Reihe Al, Ti, Nb, W, B und Ce: 0.001 bis 0.50 % insgesamt,

(ii) Sn : 0.003 bis 0.015 %,

5 wobei den Angaben zu Si, Mn und P genügt ist durch die Beziehung  $Si + Mn + 20 P \leq 0,75 \%$ , der Rest aus Fe und unvermeidbaren Verunreinigungen besteht und die Austenit Ausgangskristallkörngröße mehr als 4 in der ASTM-Kristallkörnungsnummernordnung beträgt.

10 5. Niedriglegierter Stahl gemäß Anspruch 2 oder 4, worin Si, Mn und P der Beziehung  $Si + Mn + 20 P \leq 0.50 \%$  entsprechen.

6. Niedriglegierter Stahl gemäß den Ansprüchen 1 bis 5, worin gilt: Ni : 3.25 bis 4.00 % und Cr : 1.25 bis 2.00 %.

15 7. Niedriglegierter Stahl mit guter Spannungsrißkorrosionsresistenz, enthaltend

C :  $\leq 0.40 \%$ ,

Si :  $\leq 0.15 \%$ ,

Mn :  $\leq 0.60 \%$ ,

P :  $\leq 0.010 \%$ ,

S :  $\leq 0.030 \%$ ,

20 Ni : 3.25 bis 4.00 %,

Cr : 1.25 bis 2.00 %,

Mo : 0.25 bis 4.00 %,

V :  $\leq 0.30 \%$  und

Nb : 0.005 bis 0.50 %,

25 wobei den Angaben zu Si, Mn und P genügt ist durch die Beziehung  $Si + Mn + 20 P \leq 0,50 \%$  und der Rest aus Fe und unvermeidbaren Verunreinigungen besteht.

8. Verwendung des Stahls gemäß den vorhergehenden Ansprüchen für Dampfturbinen oder dergl.

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FIGURE 1

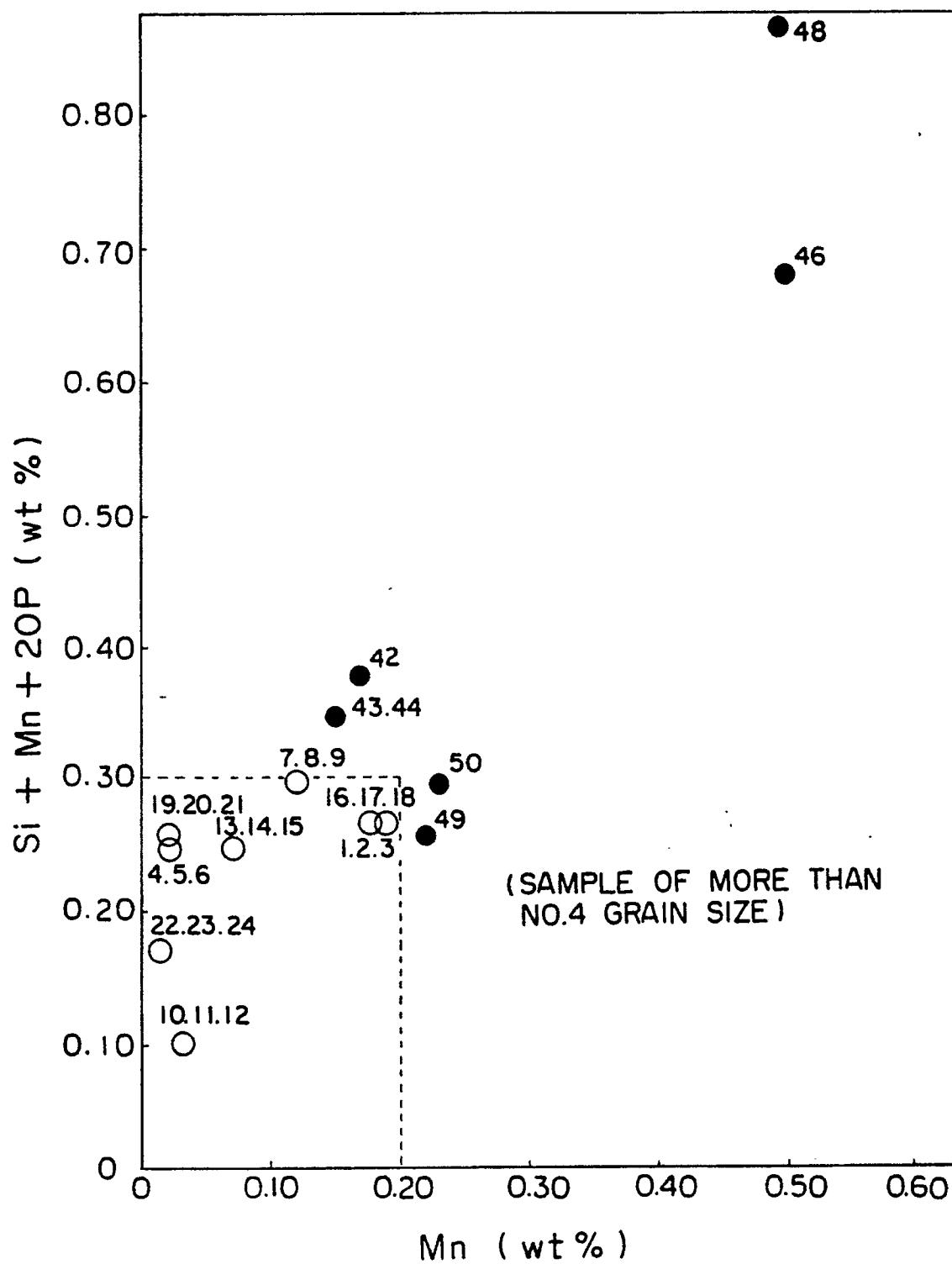


FIGURE 2

