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(54) **OIL WELL PIPE FOR EXPANDABLE-TUBE USE EXCELLENT IN TOUGHNESS AFTER PIPE EXPANSION AND PROCESS FOR PRODUCING THE SAME**

(57) The invention provides an oil well pipe for expandable tubular applications excellent in post-expansion toughness and a method of manufacturing the oil well pipe. The oil well pipe for expandable tubular applications comprises, in mass%, C: 0.03 to 0.14%, Si: 0.8% or less, Mn: 0.3 to 2.5%, P: 0.03% or less, S: 0.01% or less, Ti: 0.005 to 0.03%, Al: 0.1% or less, N: 0.001 to 0.01%, B: 0.0005 to 0.003%, optionally comprises one or more of Nb, Ni, Mo, Cr, Cu and V, and further optionally comprises one or both of Ca and REM, satisfies the re-

lationship  $A = 2.7 C + 0.4 Si + Mn + 0.45 Ni + 0.45 Cu + 0.8 Cr + 2 Mo \geq 1.8$ , has a balance of iron and unavoidable impurities, and is formed of tempered martensite structure. The manufacturing method according to the invention is **characterized in** subjecting a steel stock pipe of the foregoing composition to hardening from a temperature range of  $A_{c3}$  point + 30 °C or greater and to tempering at a temperature of 350 to 720 °C.

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## Description

## FIELD OF THE INVENTION

**[0001]** In one aspect, this invention relates to an oil well pipe for expandable tubular applications excellent in post-expansion toughness, namely to such an oil well pipe suitable for implementing expandable tubular technology for finishing an oil or gas well by expanding the oil well pipe in the oil well or gas well. In another aspect, the invention relates to a method of manufacturing the oil well pipe.

## DESCRIPTION OF THE RELATED ART

**[0002]** Although steel pipe for use in oil wells has conventionally been used by running it down the well in its form as manufactured, a technology that enables oil well pipe to be expanded 10 to 30% inside the well has recently been developed and is making a major contribution to oil well and gas well development cost reduction. However, plastic strain introduced into the steel pipe by the expansion lowers the low-temperature toughness of the pipe. Although Japanese Patent No. 3562461 sets out an invention of an oil well pipe for expandable tubular application, i.e., an oil well pipe that is expanded during use, it is silent regarding microstructure, which fundamentally has a major effect on expansion performance, and also makes no disclosure regarding toughness after pipe expansion. But superior expansion performance is essential and a need is felt for steel pipe excellent in post-expansion toughness so as to prevent pipe destruction owing to damage to the pipe in the course of expansion in the well.

## SUMMARY OF THE INVENTION

**[0003]** The present invention provides an oil well pipe for expandable tubular applications excellent in post-expansion toughness, particularly to such an oil well pipe having a pre-expansion yield strength of 482 to 689 MPa (70 to 100 ksi) that is suitable for implementing expandable tubular technology for finishing an oil or gas well by expanding the oil well pipe in the oil well or gas well. This invention also provides a method of manufacturing the oil well pipe.

**[0004]** The pre-expansion strength is the strength needed to prevent the steel pipe from breaking, bursting due to internal pressure, and crushing due to external pressure between insertion into an oil well and expansion therein. It is the strength standard generally applied in oil well design.

**[0005]** The inventors carried out an in-depth study on how steel chemical composition and manufacturing method affect toughness after pipe expansion and learned that imparting a structure of tempered martensite low in added C content gives the best results.

**[0006]** The present invention was achieved based on this knowledge and the gist thereof is as follows:

1) An oil well pipe for expandable tubular applications excellent in post-expansion toughness, which oil well pipe for expandable tubular applications comprises, in mass%, C: 0.03 to 0.14%, Si: 0.8% or less, Mn: 0.3 to 2.5%, P: 0.03% or less, S: 0.01% or less, Ti: 0.005 to 0.03%, Al: 0.1% or less, N: 0.001 to 0.01%, B: 0.0005 to 0.003%, and the balance of iron and unavoidable impurities, where A represented by Expression (1) below has a value of 1.8 or greater; and is formed of tempered martensite structure:

$$A = 2.7 C + 0.4 Si + Mn + 0.45 Ni + 0.45 Cu + 0.8 Cr + 2 Mo$$

... (1),

where C, Si, Mn, Ni, Cu, Cr and Mo represent contents of the respective elements (in mass%).

2) An oil well pipe for expandable tubular applications excellent in post-expansion toughness according to 1), further comprising, in mass%, one or more of Nb: 0.01 to 0.3%, Ni: 0.1 to 1.0%, Mo: 0.05 to 0.6%, Cr: 0.1 to 1.0%, Cu: 0.1 to 1.0%, and V: 0.01 to 0.3%.

3) An oil well pipe for expandable tubular applications excellent in post-expansion toughness according to 1) or 2), further comprising, in mass%, one or both of Ca: 0.001 to 0.01% and REM: 0.002 to 0.02%.

4) An oil well pipe for expandable tubular applications excellent in post-expansion toughness according to any of 1) to 3), wherein S content of the oil well pipe for expandable tubular applications is 0.003 mass% or less.

5) An oil well pipe for expandable tubular applications excellent in post-expansion toughness according to any of 1) to 4), wherein the oil well pipe for expandable tubular applications is manufactured by hardening and tempering

an electric-resistance-welded steel pipe.

6) An oil well pipe for expandable tubular applications excellent in post-expansion toughness according to any of 1) to 5), wherein a minimum wall thickness of the oil well pipe for expandable tubular applications is not less than 95% of an average wall thickness thereof.

7) A method of manufacturing an oil well pipe for expandable tubular applications excellent in post-expansion toughness, comprising:

subjecting a steel stock pipe to hardening from a temperature range of  $A_{c3}$  point + 30 °C or greater and to tempering at a temperature of 350 to 720 °C, thereby giving it a tempered martensite structure, the steel stock pipe comprising, in mass%, C: 0.03 to 0.14%, Si: 0.8% or less, Mn: 0.3 to 2.5%, P: 0.03% or less, S: 0.01% or less, Ti: 0.005 to 0.03%, Al: 0.1% or less, N: 0.001 to 0.01%, B: 0.0005 to 0.003%, and the balance of iron and unavoidable impurities, where A represented by Expression (1) below has a value of 1.8 or greater; and being formed of tempered martensite structure:

$$A = 2.7 C + 0.4 Si + Mn + 0.45 Ni + 0.45 Cu + 0.8 Cr + 2 Mo$$

... (1),

where C, Si, Mn, Ni, Cu, Cr and Mo represent contents of the respective elements (in mass%).

8) A method of manufacturing an oil well pipe for expandable tubular applications excellent in post-expansion toughness according to 7), wherein the steel stock pipe further comprises, in mass%, one or more of Nb: 0.01 to 0.3%, Ni: 0.1 to 1.0%, Mo: 0.05 to 0.6%, Cr: 0.1 to 1.0%, Cu: 0.1 to 1.0%, and V: 0.01 to 0.3%, and satisfies  $A = 2.7 C + 0.4 Si + Mn + 0.45 Ni + 0.45 Cu + 0.8 Cr + 2 Mo \geq 1.8$ .

9) A method of manufacturing an oil well pipe for expandable tubular applications excellent in post-expansion toughness according to 7) or 8), wherein the steel stock pipe further comprises, in mass%, one or both of Ca: 0.001 to 0.01% and REM: 0.002 to 0.02%, and satisfies  $A = 2.7 C + 0.4 Si + Mn + 0.45 Ni + 0.45 Cu + 0.8 Cr + 2 Mo \geq 1.8$ .

10) A method of manufacturing an oil well pipe for expandable tubular applications excellent in post-expansion toughness according to any of 7) to 9), wherein the steel stock pipe is an electric-resistance-welded steel pipe.

## DETAILED DESCRIPTION OF THE INVENTION

**[0007]** The inventors made a detailed study of the effect that steel chemical composition and manufacturing method have on the expandability and post-expansion toughness of an oil well pipe for expandable tubular applications. Through this study they discovered that tempered martensite, which is of uniform structure, is excellent in pipe expandability and that the most effective way to improve post-expansion toughness is to impart a structure of tempered martensite low in added C content. However, when the amount of added C is lowered, hardenability declines and ferrite readily forms during hardening, and when even a small amount of ferrite forms, cracking occurs at that portion during pipe expansion. Japanese Patent No. 3562461 teaches with regard to the invention set out therein that the strength of the steel pipe declines and that reduction of C content is required. But a steel having no added B and low in C content is poor in hardenability, so that there is no possibility of obtaining martensite even if hardening treatment is conducted. In order to substantially impart martensite to a steel pipe having a wall thickness of around 10 mm, it is necessary for an alloy having an A value of 1.8 or greater to be included.

**[0008]** On the other hand, when B is added to an oil well pipe for expandable tubular applications, martensite can be obtained by hardening treatment even at low C content, thereby enabling production of an oil well pipe for expandable tubular applications that is excellent in high-hardness expandability and also excellent in post-expansion toughness.

**[0009]** Although the method of fabricating such a steel pipe is not particularly limited, and either a seamless pipe or a welded pipe will do, an electric-resistance-welded steel pipe is especially preferable owing to its excellent thickness uniformity.

**[0010]** The reasons for limiting the chemical composition of the steel will now be explained. The oil well pipe under the aforesaid manufacturing conditions is basically required to be made of a high-strength steel having a yield strength of 482 to 689 MPa and a thickness of 7 to 15 mm, and be excellent in expandability and post-expansion toughness. The chemical composition was defined to meet these requirements. Since the temperature in an oil well is 0 °C or greater, toughness at 0 °C was taken into account.

**[0011]** C is a required element for enhancing hardenability and improving steel strength. The lower limit of C content necessary for achieving the desired strength is 0.03 mass%. However, post-expansion toughness decreases when the C content is excessive. The upper limit of C content is therefore defined as 0.14 mass%.

**[0012]** Si is an element added to improve deoxidation and strength. However, it markedly degrades low-temperature toughness when added in a large amount. The upper limit of Si content is therefore made 0.8 mass%. Either Al or Si suffices for deoxidation of the steel, so that addition of Si is not absolutely necessary. Therefore, no lower limit is defined, but 0.1 mass% or greater is usually entrained as an impurity.

**[0013]** Mn is an indispensable element for enhancing hardenability and ensuring high strength. The lower limit of Mn content is 0.3 mass%. However, an excessive Mn content makes the strength too high by causing formation of much martensite. The upper limit is therefore defined as 2.5 mass%.

**[0014]** The invention steel further contains B and Ti as required elements.

**[0015]** B is an element required for increasing low carbon steel hardenability and obtaining martensite structure by hardening. B content of less than 0.0005 mass% does not improve hardenability sufficiently and one of greater than 0.003 mass% lowers toughness owing to precipitation of B at the grain boundaries. B content is therefore defined as 0.0005 to 0.003 mass%. But for B to contribute to hardenability, it is necessary to prevent formation of BN, which in turn makes it necessary to fix N as TiN. Even when N content is low, Ti needs to be added to a content of at least 0.005 mass%, but addition in a large amount exceeding 0.03 mass% lowers toughness by causing precipitation of coarse TiN and TiC. Moreover, the relationship  $Ti \geq 3.4 N$  should preferably be satisfied for fixing N as TiN.

**[0016]** Al is an element usually included in steel as a deoxidizer and also has a structure refining effect. But an Al content exceeding 0.1 mass% impairs steel cleanliness by increasing Al nonmetallic inclusions. The upper limit is therefore defined as 0.1 mass%. However, addition of Al is not absolutely necessary because Ti or Si can be used as deoxidizer. Therefore, no lower limit is defined, but 0.001 mass% or greater is usually entrained as an impurity.

**[0017]** N forms TiN, thereby improving low-temperature toughness by inhibiting austenite grain coarsening during slab reheating. The minimum amount required for this is 0.001 mass%. However, an excessive N content causes TiN grain coarsening, which gives rise to adverse effects such as surface flaws and toughness degradation. The upper limit of N content must therefore be held to 0.01 mass%.

**[0018]** The present invention further limits the content of the impurity elements P and S to 0.03 mass% or less and 0.01 mass% or less, respectively. The chief purpose of this limitation is to further improve the low-temperature toughness of the base metal, particularly to enhance weld toughness. Reduction of P content mitigates center segregation in the continuously cast slab and also improves low-temperature toughness by preventing grain boundary fracture. Reduction of S content minimizes MnS inclusions elongated by hot rolling and thus works to improve ductility and toughness. Toughness is optimum when S content is lowered to 0.003 mass% or less. The contents of both P and S are preferably as low as possible but the extent to which they are lowered needs to be decided taking the balance between steel properties and cost into account.

**[0019]** The purpose of adding Nb, Ni, Mo, Cr, Cu and V will now be explained. The primary reason for adding these elements is to further improve the strength and toughness of the invention steel and increase the size of the steel product that can be manufactured, without loss of the superior properties of the steel.

**[0020]** Nb, when present together with B, enhances the hardenability improving effect of B. Nb also inhibits coarsening of crystal grains during hardening, thereby improving toughness. These effects are inadequate at an Nb content of less than 0.01 mass%. When B is added excessively to greater than 0.3 mass%, it conversely lowers toughness by causing heavy precipitation of NbC during tempering. Nb content is therefore defined as 0.01 to 0.3 mass%.

**[0021]** Ni is added for the purpose of improving hardenability. Ni addition causes less degradation of low-temperature toughness than does Mn, Cr or Mo addition. The hardening improvement effect of Ni is insufficient at a content of less than 0.1 mass%. Excessive addition of Ni increases the likelihood of reverse transformation during tempering. The upper limit of Ni content is therefore defined as 1.0 mass%.

**[0022]** Mo improves the hardenability of the steel and is added to achieve high strength. Moreover, when present together with Nb, Mo inhibits recrystallization of austenite during controlled rolling and thus also has an effect of refining the austenite structure before hardening. These effects are inadequate at an Mo content of less than 0.05 mass%. Excessive Mo addition causes formation of much martensite, making the steel strength too high. The upper limit of Mo content is therefore defined as 0.6 mass%.

**[0023]** Cr increases the strength of the base metal and welds. This effect is inadequate at a Cr content of less than 0.1 mass%, so this value is defined as the lower limit. When the Cr content is excessive, coarse carbide forms at the grain boundaries to lower toughness. The upper limit of Cr content is therefore defined as 1.0 mass%.

**[0024]** Cu is added for the purpose of improving hardenability. This effect is insufficient at a Cu content of less than 0.1 mass%. Excessive addition of Cu to greater than 1.0 mass% makes flaws more likely to occur during hot rolling. Cu content is therefore defined as 0.1 to 1.0 mass%.

**[0025]** V has substantially the same effect as Nb. But the effect of V is weaker than that of Nb and cannot be sufficiently obtained when the amount added is less than 0.01 mass%. Since excessive addition of V degrades low-temperature

toughness, the upper limit of V content is defined as 0.3 mass%.

**[0026]** The purpose of adding Ca and REM will now be explained. Ca and REM control the form of sulfides (MnS and the like), thereby improving low-temperature toughness. This effect is insufficient at a Ca content of less than 0.001 mass% and an REM content of less than 0.002 mass%. Addition of Ca to greater than 0.01 mass% or REM to greater than 0.02 mass% causes formation of a large amount of CaO-CaS or REM-CaS, giving rise to large clusters and large inclusions that impair steel cleanliness. The upper limits of Ca and REM addition are therefore defined as 0.01 mass% and 0.02 mass%, respectively. The preferred upper limit of Ca addition is 0.006 mass%.

**[0027]** Further, in order to ensure adequate hardenability and also to improve pipe expandability by preventing formation of ferrite during hardening, it is required that the value of A defined as follows be 1.8 or greater:  $A = 2.7 C + 0.4 Si + Mn + 0.45 Ni + 0.45 Cu + 0.8 Cr + 2 Mo$ . For reference it is noted that in the case of a steel not containing B,  $A = 2.7 C + 0.4 Si + Mn + 0.45 Ni + 0.45 Cu + 0.8 Cr + Mo - 1$ , so that the value of A cannot be made 1.8 or greater owing to the large amount of alloy that must be added.

**[0028]** In the equation representing A, the symbols C, Si, Mn, Ni, Cu, Cr and Mo are the contents (mass%) of the respective elements. When the contents of the optionally contained elements Ni, Cu, Cr and Mo are at the impurity level, specifically when the content of each of Ni, Cr and Cu is less than 0.05 mass% and the content of Mo is less than 0.02 mass%, the value of A is calculated using zero (mass%) as the content of each of these elements.

**[0029]** The manufacturing conditions other than chemical composition will now be explained.

**[0030]** The present invention restricts the structure of the steel pipe to low-carbon tempered martensite. This point is the most fundamental aspect of the invention. The tempered martensite structure is a required condition of an oil well pipe for expandable tubular applications. In other words, considering the desired strength and toughness, it is necessary to give the steel pipe a structure that is predominantly martensite or bainite. However, when hardenability is insufficient and ferrite occurs locally within the martensite structure, strain concentrates at the soft ferrite portions during pipe expansion, with the result that the pipe expansion ratio is small and cracking occurs. In the case of a bainite structure, a mixed structure occurs that makes uniformity hard to achieve. Also in this case, strain concentrates at the relatively soft portions, so that the pipe expansion ratio is low and cracking occurs. On the other hand, when uniform martensite is first obtained by hardening and then tempering is conducted for strength adjustment, the resulting structure has very high uniformity, so that cracking does not occur even at a high pipe expansion ratio. Martensite formation requires heating to within the austenite single phase range and quenching (hardening). If the heating temperature is made the  $A_{c3}$  point, it is in the austenite range but for fully realizing the hardening improvement effect of B, heating to the  $A_{c3}$  point + 30 °C or higher is required. Quenching (hardening) as termed here presumes cooling at around 20 °C/sec or greater at all locations in the thickness direction. The hardened steel pipe is tempered for strength adjustment. A stable structure is not obtained at a hardening temperature below 350 °C, while austenite forms when the temperature exceeds 720 °C. The tempering temperature is therefore defined as 350 to 720 °C..

**[0031]** Tempered martensite, which is a structure exhibiting uniform expandability, is excellent for avoiding cracking at a high pipe expansion ratio. However, if small thickness regions are present, the pipe expansion ratio may be lowered as a result of cracking caused by strain concentrating at these regions. The effect of the small thickness regions on expandability is very small if the thickness of the thinnest region is not less than 95%, preferably not less than 97%, the average thickness. These conditions are best met by an electric-resistance-welded (ERW) steel pipe of small thickness variation produced by cold-forming hot-rolled steel plate. It should be noted that an ERW pipe is thickened somewhat at the weld and the vicinity thereof at the time of pipe-making welding. A 50 mm region centered on the weld should therefore be avoided in determining the average thickness.

**[0032]** The steel pipe manufactured in this manner is run down an oil well and thereafter expanded 10 to 30% for use. This is done, for example, by passing a cone-shaped plug of an outer diameter larger than the inner diameter of the steel pipe through the pipe interior from bottom to top. In this case, the pipe expansion ratio is calculated by dividing the difference in inner diameter between before and after expansion by the inner diameter before expansion and converting the result to a percentage.

## EXAMPLES

**[0033]** Steels of the chemical compositions shown in Table 1 that were produced in a converter were used to manufacture electric-resistance-welded steel pipes and seamless steel pipes of an outer diameter of 193.7 mm and thickness of 12.7 mm. The empty cells in Table 1 indicate that the contents of the elements concerned were below the detection limit. The steel pipes of Table 1 were heat-treated under the conditions of Table 2. An ultrasonic thickness gage was used to measure the thickness of each steel pipe at 36 locations regularly spaced at 10 degree intervals in the circumferential direction and selected so as to avoid a 50 mm region centered on the weld. The arithmetic average of the thicknesses at the 36 locations (hereinafter sometimes called the "average thickness") was calculated and the smallest thickness among the 36 thicknesses was determined. The smallest thickness was divided by the average thickness to calculate the minimum thickness ratio and the result was converted to a percentage.

**[0034]** Next, a cone-shaped plug having a maximum diameter 20% larger than the inner diameter of the pipe was inserted into the pipe bore to expand the pipe at a pipe expansion ratio of 20%, thereby obtaining steel pipe of 201.96 mm inner diameter. The plug surface was coated with a spray-type lubricant containing molybdenum disulfide so as to prevent seizing between the plug and steel pipe inner wall during insertion. After the expansion, the steel pipe surface was carefully examined for cracking.

**[0035]** The steel pipes manufactured in the foregoing manner were subjected to Charpy testing for assessing toughness. The Charpy test was conducted in accordance with JIS Z 2242 at 0 °C using a V-notch specimen.

**[0036]** The results are shown in Table 2. The invention steel pipes all exhibited tempered martensite structure, were free of cracking, and had a high post-expansion toughness of 140 J or greater. In contrast, pipe No. 11 experience expansion cracking and had low post-expansion toughness because it was hardened at a low temperature and therefore had a bainite structure not a martensite structure. No. 12 had low post-expansion toughness because the steel composition was high in C. No. 13 experience expansion cracking and had low post-expansion toughness because the steel contained no B and therefore assumed a mixed structure of ferrite and bainite.

**[0037]** The steel pipes were further subjected to flare testing to evaluate expansion performance. The flare test was conducted by driving a punch of 60 degree apex angle into the pipe bore until cracking occurred and stopping the insertion at this point. The pipe expansion ratio was calculated by determining the difference in inner diameter of the pipe between that at the time cracking occurred and that before testing, dividing the difference by the inner diameter of the pipe before testing, and converting the result to a percentage. The comparative examples that experienced cracking when expanded at a pipe expansion ratio of 20% were also poor in flare pipe expansion ratio. Among the steel pipes that successfully expanded at a pipe expansion ratio of 20%, the seamless steel pipe No. 7 was somewhat low in pipe expansion ratio in the flare test because it had a low minimum thickness ratio.

Table 1

| Steel | Chemical composition (mass%) |      |     |       |       |       |       |        |        |       |      |      |     |      |      | A      | Ac3 point<br>°C | Remark |             |
|-------|------------------------------|------|-----|-------|-------|-------|-------|--------|--------|-------|------|------|-----|------|------|--------|-----------------|--------|-------------|
|       | C                            | Si   | Mn  | P     | S     | Ti    | Al    | N      | B      | Nb    | Ni   | Mo   | Cr  | Cu   | V    |        |                 |        | Ca          |
| A     | 0.12                         | 0.24 | 1.5 | 0.012 | 0.005 | 0.014 | 0.035 | 0.0042 | 0.0012 |       |      |      |     |      |      |        | 1.92            | 864    | Invention   |
| B     | 0.11                         | 0.31 | 1.3 | 0.015 | 0.003 | 0.015 | 0.012 | 0.0035 | 0.0009 |       |      | 0.12 | 0.3 |      |      | 0.0014 | 2.20            | 879    |             |
| C     | 0.08                         | 0.12 | 1.1 | 0.008 | 0.002 | 0.012 | 0.046 | 0.0028 | 0.0011 | 0.018 | 0.46 | 0.36 |     |      |      |        | 2.29            | 885    |             |
| D     | 0.13                         | 0.18 | 0.8 | 0.012 | 0.002 | 0.016 | 0.027 | 0.0033 | 0.0008 |       | 0.35 | 0.18 |     | 0.38 | 0.06 | 0.0011 | 1.91            | 868    |             |
| E     | 0.06                         | 0.15 | 2.1 | 0.011 | 0.002 | 0.014 | 0.008 | 0.0037 | 0.0014 |       |      | 0.08 |     |      |      |        | 2.48            | 878    |             |
| F     | 0.09                         | 0.16 | 1.9 | 0.006 | 0.001 | 0.015 | 0.024 | 0.0022 | 0.0009 |       |      |      |     |      |      | 0.0012 | 2.21            | 866    |             |
| G     | 0.08                         | 0.14 | 1.9 | 0.009 | 0.001 | 0.015 | 0.051 | 0.0038 | 0.0013 |       |      |      |     |      |      |        | 2.17            | 869    |             |
| H     | 0.08                         | 0.25 | 1.8 | 0.016 | 0.002 | 0.007 | 0.065 | 0.0039 | 0.0012 |       |      |      | 0.2 |      |      |        | 2.28            | 876    |             |
| I     | 0.27                         | 0.28 | 1.2 | 0.014 | 0.002 | 0.017 | 0.045 | 0.0036 | 0.0013 |       |      |      |     |      |      |        | 2.04            | 800    | Comparative |
| J     | 0.11                         | 0.14 | 1.8 | 0.009 | 0.004 | 0.014 | 0.028 | 0.0041 |        |       |      |      |     |      |      |        | 1.15            | 857    |             |

| No. | Steel | Pipe-making method | Minimum thickness ratio | Hardening temp | Tempering temp | Microstructure                | YS  | TS  | Expansion cracking | Post-expansion Charpy value | Flare expansion ratio | Remark      |
|-----|-------|--------------------|-------------------------|----------------|----------------|-------------------------------|-----|-----|--------------------|-----------------------------|-----------------------|-------------|
|     |       |                    | %                       | °C             | °C             |                               | MPa | MPa |                    | J                           | %                     |             |
| 1   | A     | ERW                | 97                      | 930            | 700            | Tempered martensite           | 512 | 601 | No                 | 157                         | 49                    | Invention   |
| 2   | A     | ERW                | 98                      | 930            | 660            | Tempered martensite           | 618 | 694 | No                 | 162                         | 51                    |             |
| 3   | A     | ERW                | 95                      | 1030           | 680            | Tempered martensite           | 555 | 651 | No                 | 144                         | 48                    |             |
| 4   | B     | ERW                | 97                      | 960            | 680            | Tempered martensite           | 524 | 602 | No                 | 172                         | 51                    |             |
| 5   | C     | ERW                | 98                      | 960            | 700            | Tempered martensite           | 499 | 567 | No                 | 196                         | 52                    |             |
| 6   | D     | ERW                | 96                      | 960            | 680            | Tempered martensite           | 542 | 630 | No                 | 142                         | 48                    |             |
| 7   | E     | Seamless           | 93                      | 960            | 680            | Tempered martensite           | 491 | 564 | No                 | 190                         | 42                    |             |
| 8   | F     | ERW                | 96                      | 960            | 680            | Tempered martensite           | 501 | 575 | No                 | 171                         | 47                    |             |
| 9   | G     | ERW                | 97                      | 960            | 680            | Tempered martensite           | 577 | 648 | No                 | 167                         | 49                    |             |
| 10  | H     | ERW                | 98                      | 960            | 680            | Tempered martensite           | 565 | 641 | No                 | 169                         | 52                    |             |
| 11  | A     | ERW                | 97                      | 870            | 600            | Tempered bainite              | 496 | 621 | Yes                | 61                          | 36                    | Comparative |
| 12  | I     | ERW                | 96                      | 960            | 700            | Tempered martensite           | 545 | 664 | No                 | 54                          | 49                    |             |
| 13  | J     | ERW                | 98                      | 960            | 550            | Ferrite + tempered martensite | 491 | 681 | Yes                | 38                          | 31                    |             |

**[0038]** The present invention enables provision of an oil well pipe for expandable tubular applications excellent in post-expansion toughness in an oil well.

5 **Claims**

1. An oil well pipe for expandable tubular applications excellent in post-expansion toughness, which oil well pipe for expandable tubular applications comprises, in mass%:

10 C: 0.03 to 0.14%,  
Si: 0.8% or less,  
Mn: 0.3 to 2.5%,  
P: 0.03% or less,  
S: 0.01% or less,  
15 Ti: 0.005 to 0.03%,  
Al: 0.1% or less,  
N: 0.001 to 0.01%,  
B: 0.0005 to 0.003%, and

20 the balance of iron and unavoidable impurities,  
where A represented by Expression (1) below has a value of 1.8 or greater; and  
is formed of tempered martensite structure:

$$25 \quad A = 2.7 C + 0.4 Si + Mn + 0.45 Ni + 0.45 Cu + 0.8 Cr \\ + 2 Mo \\ \dots (1),$$

30 where C, Si, Mn, Ni, Cu, Cr and Mo represent contents of the respective elements (in mass%).

2. An oil well pipe for expandable tubular applications excellent in post-expansion toughness according to claim 1, further comprising, in mass%, one or more of:

35 Nb: 0.01 to 0.3%,  
Ni: 0.1 to 1.0%,  
Mo: 0.05 to 0.6%,  
Cr: 0.1 to 1.0%,  
40 Cu: 0.1 to 1.0%, and  
V: 0.01 to 0.3%.

3. An oil well pipe for expandable tubular applications excellent in post-expansion toughness according to claim 1 or 2, further comprising, in mass%, one or both of:

45 Ca: 0.001 to 0.01% and  
REM: 0.002 to 0.02%.

4. An oil well pipe for expandable tubular applications excellent in post-expansion toughness according to any of claims 1 to 3, wherein S content of the oil well pipe for expandable tubular applications is 0.003 mass% or less.

5. An oil well pipe for expandable tubular applications excellent in post-expansion toughness according to any of claims 1 to 4, wherein the oil well pipe for expandable tubular applications is manufactured by hardening and tempering an electric-resistance-welded steel pipe.

- 55 6. An oil well pipe for expandable tubular applications excellent in post-expansion toughness according to any of claims 1 to 5, wherein a minimum wall thickness of the oil well pipe for expandable tubular applications is not less than 95% of an average wall thickness thereof.

7. A method of manufacturing an oil well pipe for expandable tubular applications excellent in post-expansion toughness, comprising:

subjecting a steel stock pipe to hardening from a temperature range of  $A_{c3}$  point + 30 °C or greater and to tempering at a temperature of 350 to 720 °C, thereby giving it a tempered martensite structure, the steel stock pipe comprising, in mass%,

C: 0.03 to 0.14%,

Si: 0.8% or less,

Mn: 0.3 to 2.5%,

P: 0.03% or less,

S: 0.01% or less,

Ti: 0.005 to 0.03%,

Al: 0.1% or less,

N: 0.001 to 0.01%,

B: 0.0005 to 0.003%, and

the balance of iron and unavoidable impurities,

where A represented by Expression (1) below has a value of 1.8 or greater; and being formed of tempered martensite structure:

$$A = 2.7 C + 0.4 Si + Mn + 0.45 Ni + 0.45 Cu + 0.8 Cr + 2 Mo$$

... (1),

where C, Si, Mn, Ni, Cu, Cr and Mo represent contents of the respective elements (in mass%).

8. A method of manufacturing an oil well pipe for expandable tubular applications excellent in post-expansion toughness according to claim 7, wherein the steel stock pipe further comprises, in mass%, one or more of:

Nb: 0.01 to 0.3%,

Ni: 0.1 to 1.0%,

Mo: 0.05 to 0.6%,

Cr: 0.1 to 1.0%,

Cu: 0.1 to 1.0%, and

V: 0.01 to 0.3%, and

satisfies  $A = 2.7 C + 0.4 Si + Mn + 0.45 Ni + 0.45 Cu + 0.8 Cr + 2 Mo \geq 1.8$ .

9. A method of manufacturing an oil well pipe for expandable tubular applications excellent in post-expansion toughness according to claim 7 or 8, wherein the steel stock pipe further comprises, in mass%, one or both of:

Ca: 0.001 to 0.01% and

REM: 0.002 to 0.02%.

10. A method of manufacturing an oil well pipe for expandable tubular applications excellent in post-expansion toughness according to any of claims 7 to 9, wherein the steel stock pipe is an electric-resistance-welded steel pipe.

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2006/312080

## A. CLASSIFICATION OF SUBJECT MATTER

C22C38/00(2006.01)i, C21D9/08(2006.01)i, C21D9/50(2006.01)i, C22C38/14(2006.01)i, C22C38/58(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C38/00-38/60, C21D9/08, C21D9/50

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2006

Kokai Jitsuyo Shinan Koho 1971-2006 Toroku Jitsuyo Shinan Koho 1994-2006

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                              | Relevant to claim No. |
|-----------|-----------------------------------------------------------------------------------------------------------------|-----------------------|
| Y<br>A    | JP 62-10240 A (Sumitomo Metal Industries, Ltd.),<br>19 January, 1987 (19.01.87),<br>Full text<br>(Family: none) | 2-6,8-10<br>1,7       |
| Y<br>A    | JP 6-322478 A (Nippon Steel Corp.),<br>22 November, 1994 (22.11.94),<br>Full text<br>(Family: none)             | 2-6,8-10<br>1,7       |
| Y<br>A    | JP 5-271772 A (Nippon Steel Corp.),<br>19 October, 1993 (19.10.93),<br>Full text<br>(Family: none)              | 2-6,8-10<br>1,7       |



Further documents are listed in the continuation of Box C.



See patent family annex.

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search  
08 September, 2006 (08.09.06)

Date of mailing of the international search report  
19 September, 2006 (19.09.06)

Name and mailing address of the ISA/  
Japanese Patent Office

Authorized officer

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**REFERENCES CITED IN THE DESCRIPTION**

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**Patent documents cited in the description**

- JP 3562461 B [0002] [0007]