



(11) **EP 1 746 175 A1**

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 158(3) EPC

(43) Date of publication:
24.01.2007 Bulletin 2007/04

(21) Application number: **05739174.0**

(22) Date of filing: **10.05.2005**

(51) Int Cl.:
C22C 38/00 (2006.01) **B21C 37/08** (2006.01)
C21D 8/10 (2006.01) **C22C 38/14** (2006.01)
C22C 38/58 (2006.01)

(86) International application number:
PCT/JP2005/008503

(87) International publication number:
WO 2005/108636 (17.11.2005 Gazette 2005/46)

(84) Designated Contracting States:
**AT BE BG CH CY CZ DE DK EE ES FI FR GB GR
HU IE IS IT LI LT LU MC NL PL PT RO SE SI SK TR**

(30) Priority: **11.05.2004 JP 2004141223**

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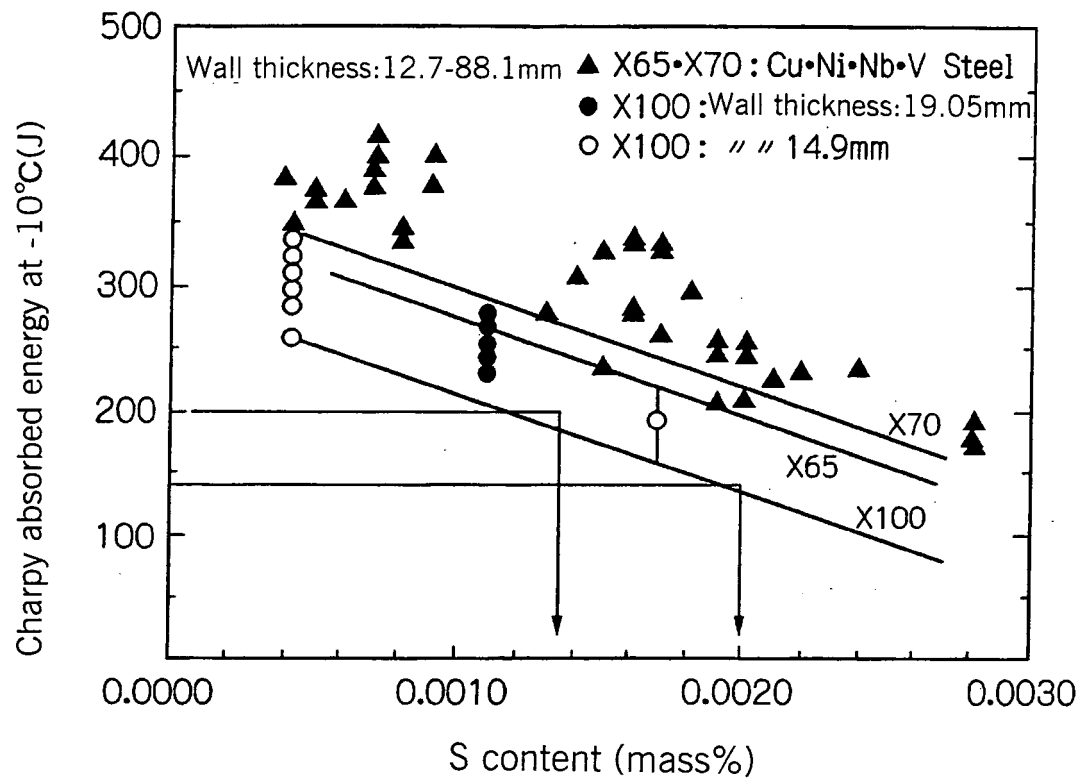
(54) **SUPER HIGH STRENGTH UOE STEEL PIPE AND METHOD FOR PRODUCTION THEREOF**

(57) A UOE steel pipe for use in linepipe having an ultrahigh strength in the circumferential direction of the pipe of at least 750 MPa and at most 900 MPa and having improved toughness in the base metal and weld heat affected zone along with improved joint fracture properties and good circumferential weldability is manufactured from a hot-rolled steel plate having a composition comprising, in mass percent, C: 0.03 - 0.08%, Mn: 1.70 - 2.2%, S: at most 0.0020%, Ti: 0.005 - 0.025%, N: at most 0.0050% and having a carbon equivalent (Ceq) as defined below of at least 0.50% and a weld cracking parameter (Pcm) as defined below of at most 0.24% wherein the temperature at the completion of water cooling after hot rolling is 350° C or higher:

$$Ceq = C + Mn/6 + (Cr + Mo + V)/5 + (Cu + Ni)/15,$$

$$Pcm = C + Si/30 + Mn/20 + Cu/20 + Ni/60 + Cr/20 + Mo/15 + V/10 + B.$$

EP 1 746 175 A1

Fig. 1

Description**Technical Field**

5 **[0001]** This invention relates to an ultrahigh strength UOE steel pipe having a strength (TS) in the circumferential direction of the pipe of at least 750 MPa and at most 900 MPa, having a good balance of strength and toughness, and having improved resistance to joint fracture and to a process for its manufacture.

Background Art

10 **[0002]** In recent years, there has been a strong demand for a reduction in the cost of pipelines. For this purpose, as manufacturing techniques have progressed, there has been a marked tendency to increase the strength of steel pipes themselves used to lay pipelines. In the past, up to X80 grade of steel has been standardized by the American Petroleum Institute (API) and is actually being used in pipelines.

15 **[0003]** At present, standardization and practical utilization of even higher strength X100 grade (corresponding to a strength in the circumferential direction of a pipe of at least 750 MPa) are being actively investigated. When actually applying such an ultrahigh strength steel to a steel pipe for a pipeline, taking safety from fracture into consideration, a significantly higher level of toughness is demanded compared to the level which is realized with conventional steel. Accordingly, there is a demand for a steel pipe having both ultrahigh strength and ultrahigh toughness and a base metal steel which can be used to manufacture such a steel pipe.

20 **[0004]** JP H08-209290-A and JP H08-209291A disclose high strength steel pipes having a high Mn + high Mo composition. The former discloses subjecting the pipe to tempering treatment, and the latter discloses carrying out dual phase rolling.

25 **[0005]** Similarly, JP H09-31536A discloses a high strength steel pipe having a Mn + high Mo composition, but disclosed therein is an ultrahigh strength steel pipe corresponding to X120 grade with a base metal strength of at least 950 MPa. JP 2000-199036A discloses an ultrahigh strength steel pipe with a steel pipe strength of at least 900 MPa. JP H08-199292A also discloses a high strength steel pipe in which the base metal structure has a martensite fraction of at least 90%, and in the examples, an ultrahigh strength steel having a base metal strength of at least 900 MPa is used.

30 **[0006]** The steel pipe strength and the base metal steel strength are the same. The steel pipe strength is a value measured in the circumferential direction of a pipe, i.e., the pipe circumferential strength.

Disclosure of the Invention

35 **[0007]** The above-described prior art documents are each aimed primarily at increasing strength, and they do not sufficiently disclose the toughness of the base metal and the toughness of the heat affected zones (HAZ) of joints. Up to the present time, a high strength steel which can adequately satisfy a balance between strength and toughness and resistance to joint fracture which are particularly demanded in high strength steels of higher than X80 grade, has not existed. In fact, in the above-described patent documents, there is no mention of both joint fracture properties and toughness in the high strength region which is the area of interest of the present invention.

40 **[0008]** According to the present invention, in order to increase resistance to joint fracture in a UOE steel pipe, the carbon equivalent (Ceq) of steel is increased to a high range which has not been utilized in the past. As a result, HAZ softening at the time of welding, which is a phenomenon characteristic of UOE steel pipes which are welded by submerged arc welding, can be markedly decreased.

45 **[0009]** On the other hand, taking into consideration the ability of on-site circumferential welding which is performed at the time of laying of a pipeline in the field, there is a demand for a balanced composition design which can realize a low weld cracking parameter (Pcm).

50 **[0010]** As the strength of a steel increases, the level of toughness demanded of the HAZ and the base metal increases. In this regard, it is essential to decrease Ti and N in order to increase HAZ toughness, and at the same time it is necessary to decrease S in order to increase the toughness of the base metal.

55 **[0011]** When a UOE steel pipe having its strength controlled to at least 750 MPa and at most 900 MPa (corresponding to X 100 grade) by composition design taking into consideration the above points was manufactured, it was found to have extremely good resistance to joint fracture and good toughness. At the time of manufacture, it was ascertained that if the temperature at the completion of cooling by water cooling after hot rolling was made 350° C or higher, an extremely high fracture toughness value of 150 J demanded of X100 grade could be satisfied.

60 **[0012]** According to one aspect, the present invention is a UOE steel pipe having a base metal chemical composition comprising, in mass percent, C: 0.03 - 0.08%, Mn: 1.70 - 2.2%, S: at most 0.0020%, Ti: 0.005 - 0.025%, N: at most 0.0050%, optionally at least one element selected from the following (i) through (iv), and a remainder of iron and unavoidable impurities, wherein the below-defined carbon equivalent (Ceq) is at least 0.50%, the weld cracking parameter

(Pcm) is at most 0.24%, and the strength of the pipe in the circumferential direction is at least 750 MPa and at most 900 MPa:

$$Ceq = C + Mn/6 + (Cr + Mo + V)/5 + (Cu + Ni)/15$$

$$Pcm = C + Si/30 + Mn/20 + Cu/20 + Ni/60 + Cr/20 + Mo/15 + V/10 + B$$

wherein Ceq = carbon equivalent, Pcm = weld cracking parameter, and the symbol for each element in the above equations indicates the content of the element in mass percent,

(i) one or two of Si: 0.05 - 0.50% and Al: at most 0.06%,

(ii) one or more of Cu: at most 1.0%, Ni: at most 2.0%, Cr: at most 1.0%, Nb: at most 0.1 %, and V: at most 0.1 %, and

(iii) Mo: at most 1.0%, and

(iv) Ca: at most 0.005%.

[0013] It is desired that a UOE steel pipe according to the present invention have a fracture toughness such that the Charpy absorbed energy at -10° C is at least 150 J in both the base metal and heat affected zone (HAZ).

[0014] From another aspect, the present invention is a process for manufacturing a UOE steel pipe having a carbon equivalent (Ceq) of at least 0.50% and a weld cracking parameter (Pcm) of at most 0.24% as defined above and a strength in the circumferential direction of the pipe of at least 750 MPa and at most 900 MPa, the process comprising producing a steel plate by hot rolling of a steel having the above-described chemical composition followed by water cooling with a temperature at the completion of water cooling of 350° C or higher, applying U-pressing and O-pressing to the resulting steel plate, and performing welding and pipe expanding to obtain a UOE steel pipe. Welding of the UOE steel pipe is carried out by submerged (arc) welding according to a conventional manner.

[0015] According to the present invention, by manufacturing a steel pipe which is controlled so as to have a high carbon equivalent (Ceq) and a strength of at least 750 MPa and at most 900 MPa, HAZ softening of the welded joint which is characteristic of UOE steel pipes which are welded by submerged arc welding is diminished, and the resistance to joint fracture of the UOE steel pipe is markedly improved. At the same time, by decreasing the content of S, Ti, and N, the toughness of the base metal and HAZ can be maintained.

[0016] A UOE steel pipe according to the present invention can be manufactured under the same conditions as a conventional UOE steel pipe of X80 grade or below, thereby making it possible to manufacture an ultrahigh strength UOE steel pipe while maintaining productivity equivalent to that of a conventional UOE steel pipe. Accordingly, the manufacturing costs of ultrahigh strength UOE steel pipes can be markedly decreased.

Brief Description of the Drawings

[0017] Figure 1 is a graph showing the relationship between the S content of steel and the toughness of the base metal (the Charpy absorbed energy at -10° C).

Best Mode for Carrying Out the Invention

[0018] In order to apply an ultrahigh strength steel which is not prescribed by API standards to an actual pipeline, it is necessary to provide a pipe having properties suited for the environment of use while taking into consideration (1) safety from fracture and (2) circumferential weldability.

[0019] Particularly in the case of a long distance pipeline for transporting natural gas or oil, occurrence of fracture of a pipe leads to a serious accident. Modes of fracture include brittle fracture and ductile fracture. In brittle fracture, fracture propagates at an ultrahigh speed of at least 500 m/sec, while in ductile fracture, the speed of propagation of fracture is lower and at most 300 m/sec. Accordingly, when steel pipe is applied to an actual pipeline, it is essential that the base metal have a toughness such that it undergoes ductile fracture in the environment of use.

[0020] Concerning the desired level of toughness, the HLP Committee (a Japanese organization for fracture research) proposes that a higher fracture toughness value becomes necessary as the strength of a steel increases in order to restrain the propagation of fracture within a prescribed distance even when high speed ductile fracture occurs. The necessary fracture toughness value (the Charpy absorbed energy at -10° C) depends upon the strength grade of steel, the size of a steel pipe, the internal pressure, and other factors, but with X 100 grade steel, it is not 40 to 50 J which is

required of usual steel (API X70 grade and below) but becomes at least 150 J. Accordingly, with X 100 grade steel, in addition to high strength, a high fracture toughness value of this level is required.

[0021] Safety from fracture can be evaluated by the location of fracture when a force is applied in the circumferential direction of pipe. The location of fracture can be classified as being the base metal, the weld metal, or the weld heat affected zone (HAZ). When fracture occurs in the base metal, as stated above, if sufficient toughness is provided, ductile fracture occurs. When fracture occurs in the weld metal, ductile fracture occurs in some cases, but in the majority of cases, brittle fracture occurs. Accordingly, it is absolutely necessary to avoid fracture in the weld metal. In general, fracture in the weld metal is prevented by making the strength of the weld metal at least as high as that of the base metal (performing overmatching). Fracture in the HAZ is a phenomenon which is observed particularly in high strength steels with a strength of at least 700 MPa.

[0022] A steel according to the present invention is particularly effective at preventing HAZ fracture. The following are conceivable as means of preventing HAZ fracture:

- (1) making the strength of the weld metal at least as high as that of the base metal (providing overmatching)
- (2) limiting the weld heat input as low as possible in order to reduce the area of the HAZ,
- (3) increasing the strength of the HAZ,
- (4) controlling the shape of the weld, i.e., reducing stress concentrations in the toe portion of the weld.

[0023] In the present invention, C_{eq} is increased in order to increase the strength of the HAZ. The HAZ has a structure formed by melting due to the effect of heat followed by resolidification or transformation. In order to increase the strength of the HAZ, it is effective to make the composition rich (increase both C_{eq} and P_{cm}) or to decrease the heat input. For this purpose, the heat input can be set to the lowest heat input which can provide the desired shape of the weld. However, making the composition rich has the problem that it leads to a decrease in circumferential weldability when joining steel pipes to each other in the field.

[0024] In the present invention, a high strength is achieved by increasing C_{eq} so as to suppress softening of the HAZ, while circumferential weldability is maintained at a good level by limiting P_{cm} up to a certain value.

[0025] In order to increased HAZ toughness, control of the content of N and Ti is also important. It was found that by optimizing the balance of content of these elements, a deterioration in toughness accompanying an increase in strength can be prevented.

[0026] In the past, a TMCP (thermo-mechanical control process) was generally applied to the manufacture of ultrahigh strength steel having a TS of 750 MPa or higher in such a manner that the temperature at the completion of water cooling after hot rolling was at most 200 °C (in many reports it is described to be room temperature). This cooling condition was employed in order to provide the steel with basic properties such as strength and toughness.

[0027] In the present invention, even though the steel has an ultrahigh strength of at least 750 MPa, taking into consideration safety from fracture, it has a chemical composition for which $C_{eq} \geq 0.50\%$ and manufactured with the temperature at the completion of water cooling after hot rolling being 350 °C or higher. As a result, fracture in the vicinity of a joint is prevented at the time of occurrence of fracture, and at the same time a high strength and high toughness can both be achieved.

[0028] By not employing an extremely low temperature for the temperature at the completion of water cooling, the deformability of the base metal, i.e., uniform elongation thereof can be greatly increased. Accordingly, a manufacturing process and a UOE steel pipe according to the present invention are extremely effective from the standpoint of safety from fracture.

[0029] Uniform elongation (degree of ultimate elongation) is the amount of plastic deformation of a material occurring up to the maximum load in a tensile test. Accordingly, the fact that a base metal has a large uniform elongation means that if the pressure abruptly increases during operation of a pipeline, the amount of plastic deformation up to the value of TS is large, and the safety from fracture is high. From this standpoint, it is desirable that the uniform elongation of the base metal be at least 5.0%.

[0030] Figure 1 is a graph showing the relationship between the S content and the toughness (the Charpy absorbed energy at -10 °C) of the base metal for X100 grade steels. From Figure 1, it can be seen that the toughness of the base metal is markedly improved by reducing the S content. From this result, it can be found that it is effective to control the S content in an ultrahigh strength steel when a high fracture toughness value is desired.

[0031] In the present invention, the necessary least fracture toughness value is 150 J, so the S content is made at most 20 ppm. When a still higher fracture toughness value such as 200 J or greater is desired, the S content can be made 14 ppm or less.

[0032] The present invention can provide a UOE steel pipe which can satisfy all of prevention of HAZ fracture of a joint, a high uniform elongation of a base metal, and good circumferential weldability required at the time of laying of a pipeline, which could not be achieved by conventional manufacturing processes.

[0033] According to the present invention, with a UOE steel pipe manufactured by TMCP with the temperature at the

completion of water cooling-being 350° C or higher which is the same as for usual steel of API X80 grade or below, a strength corresponding to API X100 grade is satisfied by increasing the carbon equivalent (Ceq) to 0.50% or greater, and circumferential weldability can be provided by limiting the weld cracking parameter (Pcm) to 0.24% or lower.

[0034] The chemical composition of the base metal in the present invention is as follows.

C: 0.03 - 0.08%

[0035] C is an element which is effective at increasing strength of steel. In order to impart a strength of X100 grade to steel, its content is made at least 0.03%. However, if the C content exceeds 0.08%, it leads to a marked decreases in toughness so that it has an adverse effect on the mechanical properties of the base metal, and at the same time it promotes formation of surface defects on a slab. A preferred C content is 0.03 - 0.05%.

Mn: 1.70 - 2.2%

[0036] Mn is an element which is effective at increasing the strength and toughness of steel, and its content is made at least 1.70% in order to impart sufficient strength and toughness. However, if the Mn content exceeds 2.2%, the toughness of a weld deteriorates. A preferred Mn content is 1.8 - 2.0%.

S: at most 0.0020%

[0037] S is one of the elements which it is necessary to limit their content in order to achieve the necessary toughness of a base metal. If the S content exceeds 0.0020%, the fracture toughness value necessary for the base metal cannot be achieved. As previously explained with respect to Figure 1, the S content may be further limited in accordance with the fracture toughness value required of the base metal, such as to at most 0.0014%.

Ti: 0.005 - 0.025%

[0038] Ti has an effect of suppressing grain growth in a HAZ by forming TiN and thus increasing the toughness of the HAZ. For this purpose, it is necessary for the Ti content to be at least 0.005%. However, if the Ti content exceeds 0.025%, the amount of dissolved N increases, and HAZ toughness deteriorates. A preferred Ti content is 0.005 - 0.018%.

N: at most 0.0050%

[0039] N forms nitrides with V, Ti, and the like and thus has the effect of increasing high temperature strength of steel. However, if the content of N exceeds 0.0050%, it forms carbonitrides with Nb, V, and Ti, thereby causing a decrease in the toughness of the base metal and the HAZ. When a high level of HAZ toughness is desired, N is preferably controlled at an extremely low value of at most 0.0035%.

[0040] In addition to the above-described basic components of composition, the carbon equivalent (Ceq) and weld cracking parameter (Pcm) of the base metal are extremely important factors in order to achieve a high strength of at least X100 grade and high toughness in the base metal and HAZ.

Ceq of the base metal: at least 0.50%

[0041] In order to ensure that a base metal strength of at least X100 grade is achieved by TMCP in which the temperature at the completion of water cooling is set to 350° C or higher, the carbon equivalent (Ceq) of the base metal is made at least 0.50%. As long as a base metal strength of X100 grade or higher can be achieved, there is no particular upper limit on the Ceq, but Ceq is preferably at most 0.55%. Ceq is given by the following equation (the symbols for elements in the equation indicate the content of those elements in mass percent):

$$Ceq = C + Mn/6 + (Cr + Mo + V)/5 + (Cu + Ni)/15.$$

Pcm of the base metal: at most 0.24%

[0042] The steel composition is designed such that the weld cracking parameter (Pcm) of the base metal is at most 0.24% in order to achieve high strength and high toughness even at the time of circumferential welding. There is no particular lower limit for Pcm, but normally it is at least 0.16%. Pcm is given by the following equation (the symbols for elements in the equation indicate the content of those elements in mass percent):

$$P_{cm} = C + Si/30 + Mn/20 + Cu/20 + Ni/60 + Cr/20 + Mo/15 + V/10 + B.$$

[0043] In a UOE steel pipe according to the present invention, there are no particular restrictions on the C_{eq} and P_{cm} of the weld metal.

[0044] In this specification, when C_{eq} and P_{cm} appear by themselves, they refer to the C_{eq} and P_{cm} of the base metal including the HAZ, i.e., that of the entire steel pipe except for the weld metal.

[0045] The strength in the circumferential direction of a UOE steel pipe according to the present invention is at least 750 MPa and at most 900 MPa. This strength level of a steel pipe is defined to indicate that it is the level of X 100 grade. In the present invention, by controlling the chemical composition of steel as described above, an ultrahigh strength UOE steel pipe of X 100 grade strength can be manufactured by the same process as for a conventional low strength UOE steel pipe in which the temperature at the completion of water cooling after hot rolling is 350° C or higher, and the pipe can be provided with the fracture toughness value required in the base metal and HAZ.

[0046] The base metal of a UOE steel pipe according to the present invention may further contain one or more optional elements selected from the group listed below as (i) - (iv).

(i) Si: 0.05 - 0.50%, Al: at most 0.060%

Si and Al both have a deoxidizing effect, and preferably at least one of them is included.

Si is effective not only as a deoxidizing agent but also at increasing the strength of steel. If the Si content is less than 0.05%, deoxidization is inadequate. If the Si content exceeds 0.5%, a large amount of martensite-austenite constituent is formed in the HAZ, thereby causing the toughness of the HAZ to deteriorate extremely and thus leading to a decrease in the mechanical properties of a steel pipe. The Si content can be selected within the range of 0.05 - 0.50% taking into consideration a balance with the plate thickness of the steel plate.

Like Si, Al functions as a deoxidizing agent. Its effects can be adequately attained when its content is at most 0.06%. Addition in excess of this amount adversely affects circumferential weldability in the field and is also not desirable from the standpoint of economy.

(ii) Cu: at most 1.0%, Ni: at most 2.0%, Cr: at most 1.0%, Nb: at most 0.1 %, V: at most 0.1 %

These elements serve to improve hardenability of steel when added in a small amount and thus have an effect of improving various properties.

Cu can increase strength without significantly impairing toughness as a result of a change in microstructure due to solid solution strengthening and the effect of increasing hardenability. If Cu exceeds 1.0%, the Cu checking phenomenon which is harmful in that it causes the formation of slab surface defects may occur. In order to prevent such defects, it becomes necessary for the slab to be heated at a low temperature, thereby imposing limitations on the range in which manufacture can be performed.

In the same manner as Cu, Ni also can increase strength without significantly impairing toughness by a microstructural change due to solid solution strengthening and the effect of increasing hardenability. At the same time, it serves to suppress a deterioration in the toughness of the base metal and HAZ after hot bending. However, addition of more than 2.0% of Ni increases costs so is not practical, and it also adversely affects ability of on-site circumferential welding.

Like Cu and Ni, Cr also can increase strength without significantly deteriorating toughness by a microstructural change due to solid solution hardening and the effect of increasing hardenability. However, if Cr exceeds 1.0%, the toughness of the HAZ decreases.

Nb and V have a great effect on increasing strength by precipitation strengthening and the effect of increasing hardenability, or on improving toughness by crystal grain refinement. However, if either is added in excess of 0.1%, it causes a decrease in the toughness of HAZ.

When at least one of these elements is added, a more preferred content is Cu: at most 0.50%, Ni: at most 0.80%, Cr: at most 0.40%, Nb: at most 0.06%, and V: at most 0.06%.

(iii) Mo: at most 1.0%

Mo is effective at increasing the strength of the base metal and of welds. If too much Mo is added, it causes a deterioration in ability of on-site circumferential welding and the toughness of the HAZ. Therefore, its upper limit is made 1.0%. When Mo is added, a more preferred content is at most 0.50%.

(iv) Ca: at most 0.005%

Ca has an effect on shape control and specifically spheroidizing of inclusions in steel, thereby preventing hydrogen-induced cracking or lamellar tears. However, these effects saturate at a Ca content of 0.005%.

[0047] A UOE steel pipe according to the present invention can be manufactured by subjecting a steel slab which is adjusted to have the above-described chemical composition to hot rolling, and after the completion of finish rolling, water

cooling is performed thereon such that the temperature at the completion of water cooling is 350° C or higher. The resulting hot rolled steel plate is formed into a tubular shape by usual U-pressing and O-pressing, and then the abutting edges are bonded by welding on the inner and outer surfaces. This welding is carried out by submerged arc welding. After the welded pipe is formed, it is subjected to pipe expanding so as to increase the roundness. Pipe expanding can be carried out by mechanical pipe expanding or hydraulic pipe expanding.

[0048] There are no particular restrictions on the steps of manufacture of a UOE steel pipe in a manufacturing process for a UOE steel pipe according to the present invention except for the water cooling conditions after hot rolling. Manufacture may be carried out in the same manner as for the manufacture of a conventional UOE steel pipe of X80 grade or below. Nevertheless, a UOE steel pipe having an ultrahigh strength of X100 grade (a strength in the pipe circumferential direction of at least 750 MPa and at most 900 MPa) and at the same time having improved resistance to fracture can be manufactured.

[0049] The following example is intended to illustrate the present invention more specifically, but it is merely for illustration purpose and does not restrict the invention in any way.

Example

[0050] Hot rolled steel plates for use as a base metal was prepared from steel slabs having the chemical compositions shown in Table 1 by heating and retaining them at a temperature of 1100 - 1200° C, then subjecting them to hot rolling with a finish rolling temperature in the range of 700 - 850° C so as to give a plate thickness of 20 mm. The hot-rolled plates were water cooled with the temperatures at the completion of water cooling shown in Table 1 and then air cooled to room temperature. The base metal steel plates were formed into a tubular shape by U-pressing and then O-pressing in cold conditions. Then, the abutting edges of the shapes were welded by usual submerged arc welding, and the resulting pipes were subjected to mechanical pipe expanding. In this manner, UOE steel pipes having an outer diameter of 910 mm (36 inches), a wall thickness of 20 mm, and a length of 1200 mm were manufactured.

[0051] Table 1 also shows the strength and toughness of the base metal, the tensile properties of the joint, and results of a circumferential welding test performed on the resulting UOE steel pipes. The base metal strength and the position at which joint tensile fracture occurs are particularly important parameters for ascertaining the effects of the present invention.

[0052] The toughness and strength of a base metal were evaluated by taking an impact test piece (JIS No. 4) and a tensile test piece (an ASTM rod-shaped test piece with a diameter of 6.35 mm) from the circumferential direction of each UOE steel pipe so as not to include the weld or the HAZ and determining the Charpy absorbed energy at -10° C (indicated as VE-10° C), the tensile strength (TS), and the uniform elongation (degree of ultimate elongation).

[0053] A tensile test of the joint was carried out by taking a tensile test piece in the circumferential direction such that the weld of each UOE steel pipe was in the center of the test piece, and performing a tensile test on the test piece having the reinforcement of weld as it was to determine the tensile strength and ascertain the location of fracture. An impact test piece (JIS No. 4) was taken from the HAZ (weld heat affected zone) of each UOE steel pipe and used to determine the Charpy absorbed energy at -10° C (VE-10° C). Weldability was evaluated by actually performing circumferential welding of the UOE steel pipes and determining whether cracking occurred at -10° C in y slit cracking test. Cases in which cracking was observed are indicated by an X and cases in which it were not observed are indicated by an O.

TABLE 1

No.	Base Metal															TCWC	Strength of Base Metal ²			VE-10°C (J)			Joint Tensile test		CW	RE
	C	Mn	S	Ti	N	Si	Cu	Ni	Cr	Mo	Nb	V	Al	Ceq	Pcm		TS	UEL	BM	HAZ	TS	POF				
mass%	ppm	mass%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	mass%	MPa	%	MPa	MPa						
1	0.06	1.90	10	0.015	45	0.15	0.20	0.20	0.15	0.35	0.03	0.03	0.02	0.51	0.21	420	821	6.2	212	204	825	BM	○			
2	0.06	1.90	10	0.015	45	0.15	0.20	0.20	0.15	0.35	0.03	0.03	0.02	0.51	0.21	300*	868	4.9	215	200	868	BM	○			
3	0.06	1.90	10	0.015	45	0.15	0.20	0.20	0.15	0.35	0.03	0.03	0.02	0.51	0.21	RT*	911*	4.5	222	203	898	HAZ	○			
4	0.10*	1.90	8	0.017	38	0.14	0.19	0.21	0.15	0.25	0.03	0.04	0.03	0.53	0.23	420	904*	7.3	168	147	838	BM	×			
5	0.02*	1.95	11	0.015	39	0.15	0.20	0.30	0.15	0.25	0.04	0.04	0.03	0.49*	0.18	470	749*	3.8	150	155	738	BM	○			
6	0.07	1.65*	11	0.014	42	0.20	0.30	0.30	0.30	0.25	0.03	0.03	0.03	0.50	0.22	430	800	5.1	147	151	801	BM	○			
7	0.06	2.20	10	0.015	45	0.15	0.20	0.20	0.15	0.35	0.03	0.03	0.02	0.57	0.25*	450	940*	5.1	225	231	920	HAZ	×			
8	0.06	1.90	21*	0.015	45	0.15	0.20	0.20	0.15	0.35	0.03	0.03	0.02	0.51	0.21	390	842	6.7	125	140	841	BM	○			
9	0.06	1.90	10	0.027*	45	0.15	0.20	0.20	0.15	0.35	0.03	0.03	0.02	0.51	0.21	450	833	5.4	210	119	822	HAZ	○			
10	0.06	1.90	9	0.015	72*	0.15	0.20	0.20	0.15	0.35	0.03	0.03	0.02	0.51	0.21	420	819	4.2	139	99	800	HAZ	○			
11	0.06	1.90	12	0.015	51*	0.03*	0.15	0.25	0.15	0.35	0.03	0.03	0.02	0.49*	0.21	450	745*	6.4	140	135	749	BM	○			
12	0.06	1.90	11	0.015	37	0.60*	0.15	0.25	0.15	0.35	0.03	0.03	0.02	0.50	0.25*	480	790	6.1	167	78	789	BM	×			
13	0.06	1.90	10	0.015	50	0.15	1.1*	0.60	0.03	0.02	0.03	0.03	0.02	0.50	0.26*	450	811	6.4	170	153	813	BM	×			
14	0.05	1.80	10	0.015	45	0.15	0.05	2.2*	0.03	0.02	0.03	0.03	0.03	0.51	0.22	450	833	5.7	244	242	832	BM	×			
15	0.05	1.80	8	0.015	43	0.15	0.05	0.04	1.1*	0.02	0.03	0.03	0.03	0.58	0.25*	450	921*	4.4	221	118	891	HAZ	×			
16	0.05	1.80	17	0.015	44	0.15	0.05	0.04	0.05	1.1*	0.03	0.03	0.03	0.59	0.26*	450	933*	5.2	151	88	912	HAZ	×			
17	0.06	1.92	15	0.015	49	0.15	0.20	0.20	0.15	0.35	0.11*	0.03	0.02	0.51	0.21	400	834	5.3	177	87	821	BM	○			
18	0.06	1.89	10	0.015	32	0.15	0.20	0.20	0.15	0.35	0.03	0.12*	0.02	0.53	0.24	450	834	5.5	157	78	830	BM	○			
19	0.06	1.89	10	0.015	42	0.15	0.20	0.20	0.15	0.35	0.03	0.03	0.08*	0.53	0.24	450	822	5.9	178	190	810	BM	×			
20	0.06	1.90	10	0.015	45	0.15	0.30	0.30	0.03	0.35	0.03	0.03	0.02	0.50	0.23	450	844	5.3	178	186	840	BM	○			
21	0.06	1.90	10	0.015	35	0.10	0.30	0.50	0.03	0.30	0.03	0.01	0.02	0.52	0.22	450	850	5.5	200	205	848	BM	○			
22	0.06	2.00	10	0.014	40	0.10	0.30	0.30	0.03	0.35	0.03	0.01	0.02	0.51	0.23	360	871	5.5	194	188	880	BM	○			
23	0.06	2.05	4	0.015	40	0.15	0.30	0.30	0.03	0.35	0.03	0.01	0.02	0.51	0.23	420	858	6.2	250	253	855	BM	○			
24	0.06	1.95	10	0.012	35	0.05	0.15	0.30	0.15	0.35	0.04	0.04	0.03	0.52	0.21	410	830	6.3	220	240	831	BM	○			

(Notes) TS: Tensile strength; UEL: Ultimate elongation; BM: Base metal; HAZ: Heat affected zone; * Outside the range defined herein

¹TCWC: Temperature at completion of water cooling; ²Circumferential strength of base metal; ³POF: Position of fracture;⁴CW: Circumferential Weldability; ⁵RE: Remarks, WE=Working example, CE=Comparative example

[0054] In Nos. 1 and 20 - 24 which are working examples of the present invention, the strength and toughness of the

base metal satisfy the prescribed conditions, and at the same time, due to optimization of the chemical composition, the resistance to joint fracture was excellent as evidenced by the fact that fracture at the base metal could be achieved in the joint tensile test. In addition, circumferential weldability was also excellent.

[0055] In contrast, in the comparative examples, appropriate level of strength or toughness or other properties could not be achieved. In particular, in Nos. 10, 12, and 16 - 18, there was an extreme decrease in the toughness of the HAZ.

Claims

1. A UOE steel pipe having a base metal with a chemical composition comprising, in mass percent, C: 0.03 - 0.08%, Mn: 1.70 - 2.2%, S: at most 0.0020%, Ti: 0.005 - 0.025%, N: at most 0.0050%, and a remainder of iron and unavoidable impurities, wherein the below-defined carbon equivalent (Ceq) is at least 0.50% and the below-defined weld cracking parameter (Pcm) is at most 0.24%, and the strength in the circumferential direction of the pipe being at least 750 MPa and at most 900 MPa:

$$Ceq = C + Mn/6 + (Cr + Mo + V)/5 + (Cu + Ni)/15,$$

$$Pcm = C + Si/30 + Mn/20 + Cu/20 + Ni/60 + Cr/20 + Mo/15 + V/10 + B,$$

wherein Ceq = carbon equivalent, Pcm = weld cracking parameter, and the symbols for elements in the equations indicate the content of those elements in mass percent.

2. A UOE steel pipe as set forth in claim 1 wherein the chemical composition of the base metal further contains, in mass percent, at least one element selected from the following (i) - (iv):

(i) one or two of Si: 0.05 - 0.50% and Al: at most 0.06%,

(ii) one or more of Cu: at most 1.0%, Ni: at most 2.0%, Cr: at most 1.0%, Nb: at most 0.1 %, and V: at most 0.1 %,

(iii) Mo: at most 1.0%, and

(iv) Ca: at most 0.005%

3. A process for manufacturing a UOE steel pipe having a carbon equivalent (Ceq) as defined below of at least 0.50% and a weld cracking parameter (Pcm) as defined below of at most 0.24% and having a strength in the circumferential direction of the pipe of at least 750 MPa and at most 900 MPa, comprising producing a steel plate having a base metal chemical composition comprising, in mass percent, C: 0.03 - 0.08%, Mn: 1.70 - 2.2%, S: at most 0.0020%, Ti: 0.005 - 0.025%, N: at most 0.0050%, optionally at least one element selected from the following (i) - (iv), and a remainder of iron and unavoidable impurities by hot rolling and subsequent water cooling with the temperature at the completion of water cooling being 350° C or higher, subjecting the resulting steel plate to U-pressing and O-pressing, and then performing welding and pipe expanding to obtain a UOE steel pipe:

$$Ceq = C + Mn/6 + (Cr + Mo + V)/5 + (Cu + Ni)/15,$$

$$Pcm = C + Si/30 + Mn/20 + Cu/20 + Ni/60 + Cr/20 + Mo/15 + V/10 + B,$$

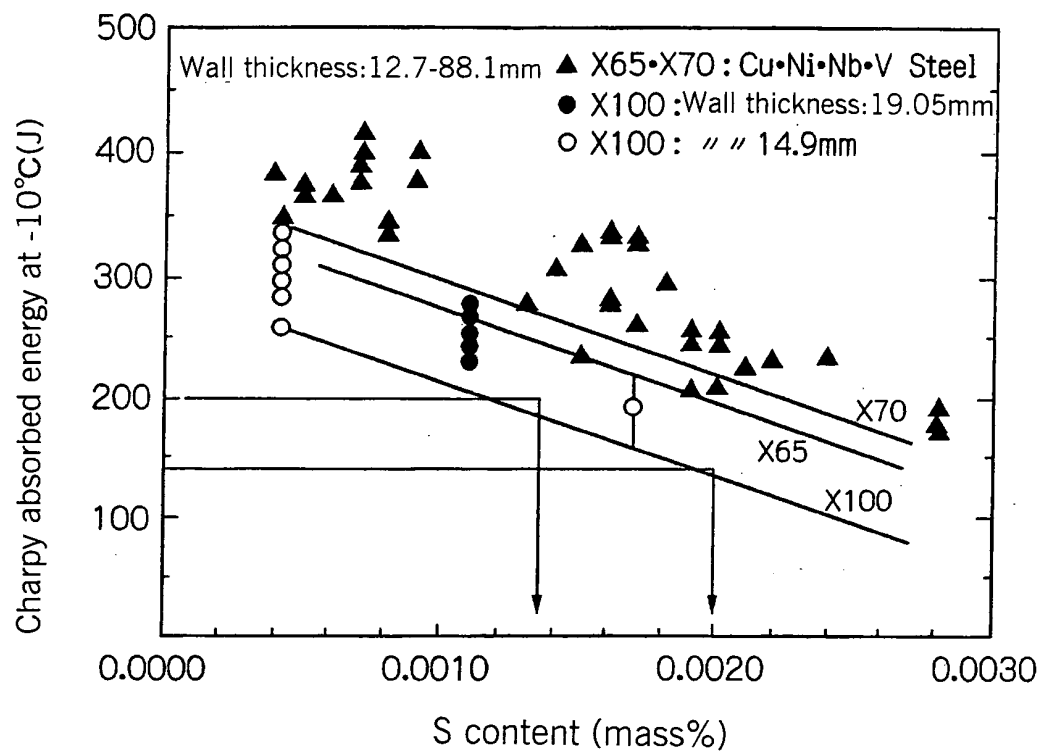
wherein Ceq = carbon equivalent, Pcm = weld cracking parameter, and the symbols for elements in the equations indicate the content of those elements in mass percent,

(i) one or two of Si: 0.05 - 0.50% and Al: at most 0.06%,

(ii) one or more of Cu: at most 1.0%, Ni: at most 2.0%, Cr: at most 1.0%, Nb: at most 0.1 %, and V: at most 0.1 %,

(iii) Mo: at most 1.0%, and

(iv) Ca: at most 0.005%.

Fig. 1

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2005/008503

A. CLASSIFICATION OF SUBJECT MATTER Int.Cl. ⁷ C22C38/00, B21C37/08, C21D8/10, C22C38/14, 38/58		
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) Int.Cl. ⁷ C22C38/00, B21C37/08, C21D8/10, C22C38/14, 38/58		
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 1996-2005 Kokai Jitsuyo Shinan Koho 1971-2005 Toroku Jitsuyo Shinan Koho 1994-2005		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) WPI		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2004-99930 A (Nippon Steel Corp.), 02 April, 2004 (02.04.04), Full text (Family: none)	1-3
X	JP 2004-52104 A (Nippon Steel Corp.), 19 February, 2004 (19.02.04), Full text & EP 1375681 A2 & US 2004/31544 A1	1-3
A	JP 2003-293078 A (Nippon Steel Corp.), 15 October, 2003 (15.10.03), Full text (Family: none)	1-3
☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "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 "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 01 August, 2005 (01.08.05)		Date of mailing of the international search report 16 August, 2005 (16.08.05)
Name and mailing address of the ISA/ Japanese Patent Office		Authorized officer
Facsimile No.		Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2005/008503

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2000-256779 A (Nippon Steel Corp.), 19 September, 2000 (19.09.00), Full text (Family: none)	1-3
A	JP 2003-342638 A (Nippon Steel Corp.), 03 December, 2003 (03.12.03), Full text (Family: none)	1-3
A	JP 2001-113374 A (Nippon Steel Corp.), 24 April, 2001 (24.04.01), Full text (Family: none)	1-3
A	JP 2003-306749 A (Nippon Steel Corp.), 31 October, 2003 (31.10.03), Full text (Family: none)	1-3
A	JP 2000-119797 A (Nippon Steel Corp.), 25 April, 2000 (25.04.00), Full text (Family: none)	1-3

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP H08209290 A [0004]
- JP H08209291 A [0004]
- JP H0931536 A [0005]
- JP 2000199036 A [0005]
- JP H08199292 A [0005]