

(19)



(11)

EP 2 039 786 A1

(12)

EUROPEAN PATENT APPLICATION published in accordance with Art. 153(4) EPC

(43) Date of publication:

25.03.2009 Bulletin 2009/13

(51) Int Cl.:

C21D 9/08 (2006.01)**C21D 1/18** (2006.01)**C22C 38/00** (2006.01)**C22C 38/58** (2006.01)(21) Application number: **07744417.2**

(86) International application number:

PCT/JP2007/061004(22) Date of filing: **30.05.2007**

(87) International publication number:

WO 2007/139158 (06.12.2007 Gazette 2007/49)

(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 LV MC MT NL PL PT RO SE SI SK TR

Designated Extension States:

AL BA HR MK RS

(72) Inventors:

- **OOSAKO, Hajime**
Osaka-shi Osaka 541-0041 (JP)
- **NAKATA, Junji**
Osaka-shi Osaka 541-0041 (JP)

(30) Priority: **30.05.2006 JP 2006150248**(74) Representative: **Dallmeyer, Georg**

Patentanwälte von Kreisler Selting Werner,
Bahnhofsvorplatz 1,
Deichmannhaus am Dom
50667 Köln (DE)

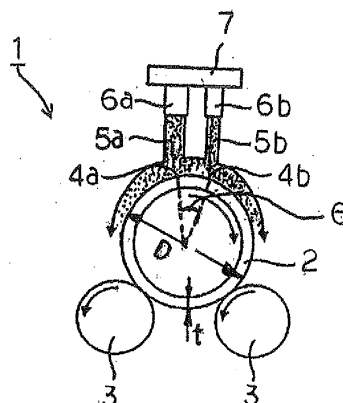
(71) Applicant: **Sumitomo Metal Industries Limited**
Osaka-shi,
Osaka 541-0041 (JP)

(54) **COOLING METHOD OF STEEL PIPE**

(57) A method of cooling a steel pipe which can effectively suppress quenching-induced bending which occurs when quenching a thin-walled steel pipe with a wall thickness/outer diameter ratio of at most 0.07 without decreasing the manufacturing efficiency of the steel pipe comprises cooling the inner surface of the steel pipe by spraying cooling water into the interior of a horizontally-disposed steel pipe 2 while rotating the pipe in its circumferential direction, and the outer surface is cooled by producing a downward flow of cooling water streams 5a and 5b in a planar shape from above onto the outer surface

along the axial direction of the steel pipe 2. Cooling of the inner surface is started at least 7 seconds before cooling of the outer surface. Cooling of the outer surface is carried out by producing downward flow in a planar shape of cooling water 5a and 5b at two locations 4a and 4b at approximately equal distances from the uppermost portion of the steel pipe 2, and the flow rate of cooling water 5a which flows down at a location on the upstream side in the rotational direction of the steel pipe 2 is made larger than the flow rate of cooling water 5b which flows down at a location on the downstream side in the rotational direction.

Fig. 1



Description

Technical Field

[0001] This invention relates to a method of cooling a steel pipe capable of effectively suppressing bending of steel pipes which can easily occur particularly when quenching thin-walled steel pipes, thereby making it possible to manufacture steel pipes having mechanical properties of increased uniformity.

Background Art

[0002] Bending of steel pipes sometimes occurs at the time of quenching. In the context of the present invention, "bending" of a steel pipe means curvature in the axial direction of the steel pipe. Below, bending which is observed at the time of quenching will be referred to as "quenching-induced bending".

[0003] Quenching-induced bending is caused by factors such as uneven cooling. In particular, when quenching a thin-walled steel pipe in which the ratio (t/D) of the wall thickness (t) to the outer diameter (D) has a low value such as at most 0.07, a large amount of quenching-induced bending, which is considered a defect in quality, can easily occur. There have been many proposals in the past concerning cooling methods intended to suppress this quenching-induced bending.

[0004] For example, JP H02-7372 B (1990) discloses a heat treatment method which, during quenching of a metal pipe, suppresses quenching-induced bending by performing slow cooling in the initial stage of cooling the outer surface of the pipe so as to reduce the temperature difference over the entire surface of the pipe followed by usual rapid cooling.

[0005] In JP S61-4896 B (1986), a cooling method is disclosed in which a pipe is cooled by spraying water into the interior of the pipe from one end thereof while water sprayed from nozzles is allowed to impinge on the outer surface of the pipe over substantially the entire length thereof. In this method, toward the end of the pipe which corresponds to the discharge end of water sprayed into the pipe, the amount of water sprayed on the outer surface of the pipe is increased, or the timing of the start of outer surface cooling is made earlier, or the completion of outer surface cooling is delayed, whereby the entire pipe is uniformly cooled in a short period.

[0006] In the method disclosed in JP H02-7372 B, because slow cooling is performed at the initial stage of cooling and only the outer surface of a pipe is cooled, the cooling time is necessarily elongated and the manufacturing efficiency of a pipe is decreased.

[0007] In the method disclosed in JP S61-4896 B, it is necessary to vary the amount of sprayed water for cooling the outer surface or the timing of spraying (the timing of the start or completion of spraying) in the axial direction of a pipe. As a result, the structure and control of the apparatus become complicated. In addition, although that document discloses that the entire pipe can be uniformly cooled, there is no specific disclosure as to whether quenching-induced bending can be suppressed. In that patent document, the only specific example of an object which was cooled is a steel pipe measuring 114 x 8.6 x 29,000 mm (see column 4, line 13), and the outer diameter/wall thickness ratio (t/D) of this steel pipe is approximately 0.075 ($= 8.6/114$). There is no mention concerning thin-walled pipes having a t/D ratio of at most 0.07 which readily experience quenching-induced bending.

Disclosure of Invention

[0008] This invention provides a method of cooling a steel pipe which can suppress quenching-induced bending during quenching of thin-walled steel pipes having a t/D ratio of at most 0.07 and which can solve the problems of the above-described prior art.

[0009] The present invention is a method of cooling a steel pipe in which the inner surface and outer surface of a horizontally-disposed steel pipe are cooled while rotating the steel pipe in its circumferential direction, characterized in that the ratio of the wall thickness to the outer diameter of the steel pipe is preferably at most 0.07 and more preferably at most 0.06, cooling of the inner surface of the steel pipe is carried out by spraying cooling water inside the steel pipe and cooling of the outer surface of the steel pipe is carried out by making cooling water flow downwards in a planar shape in the axial direction onto the outer surface of a steel pipe from above at two locations approximately equally spaced from the uppermost portion of the steel pipe on both sides thereof, the flow rate of cooling water which flows downwards at a location on the upstream side in the direction of rotation of the steel pipe is equal to or greater than the flow rate of cooling water flowing downwards at a location on the downstream side in the rotational direction, and cooling of the inner surface of the steel pipe is commenced at least 7 seconds prior to cooling of the outer surface of the steel pipe.

[0010] A method of cooling a steel pipe according to the present invention can effectively suppress quenching-induced bending of steel pipes without a decrease in the manufacturing efficiency of steel pipes even when quenching thin-walled steel pipes for which t/D is at most 0.07. In addition, the uniformity of cooling in both the circumferential and axial directions of a steel pipe is improved, leading to improvement in the uniformity of quenching and accordingly uniformity

of the mechanical properties of a steel pipe. Thus, the steel pipe has improved toughness.

Brief Description of the Drawings

[0011]

Figure 1 is a vertical cross-sectional view schematically showing the structure of a cooling apparatus for carrying out an embodiment of a method of cooling a steel pipe according to the present invention.

Figure 2 shows graphs showing the results of numerical calculation of the surface temperature, the yield strength YS, and the axial stress σ_z of a steel pipe when the inner surface and the outer surface of the steel pipe are cooled.

Figure 2(a) shows the case in which cooling of the inner surface and the outer surface of the steel pipe are started simultaneously (inner surface advance time = 0 seconds), and Figure 2(b) shows the case in which only cooling of the inner surface of the steel pipe is carried out (inner surface advance = ∞ seconds).

Best Mode For Carrying Out The Invention

[0012] An embodiment of a method of cooling a steel pipe according to the present invention will be explained in detail while referring when suitable to the accompanying drawings.

[0013] Figure 1 is a vertical cross-sectional view schematically showing the structure of a cooling apparatus for carrying out a method of cooling a steel pipe according to this embodiment.

[0014] In Figure 1, a cooling apparatus 1 includes a pair of rotating rollers 3, 3 which support a horizontally-disposed steel pipe 2 and rotate it in its circumferential direction. The cooling apparatus 1 additionally includes an inner surface cooling nozzle (not shown) which is disposed near one end of the steel pipe 2 and which is designed to spray cooling water into the interior of the steel pipe 2, and an outer surface cooling nozzle 7 which is installed above the steel pipe 2. The inner surface cooling nozzle may be a conventional spraying nozzle. The outer surface cooling nozzle 7 has slit-shaped discharge ports 6a and 6b for allowing streams of cooling water 5a and 5b which have a planar shape in the pipe axial direction to flow downwards from above at two locations 4a and 4b which are approximately equally spaced from the uppermost (top) portion of the outer peripheral surface of the steel pipe 2 on both sides thereof (namely, at two locations which are approximately symmetric with respect to the uppermost portion). The discharge ports 6a and 6b preferably have a length extending over substantially the entire length of the steel pipe 2. The cooling water for cooling the outer surface preferably flows naturally downwards in a laminar flow from the discharge ports 6a and 6b of the nozzle 7, but it is also possible to apply pressure to the cooling water.

[0015] A steel pipe 2 to which a cooling method according to this embodiment can be advantageously applied is a thin-walled steel pipe having a ratio t/D of the wall thickness t with respect to the outer diameter D of at most 0.07 with which a significant amount of quenching-induced bending which becomes a problem with respect to quality can easily occur. This cooling method can be applied particularly suitably to cooling of the inner and outer surfaces of line pipe made from low carbon steel which is of low strength and easily bends or line pipe of a grade not higher than API X60 (having a composition in mass percent of, for example, (a) C: 0.06%, Si: 0.26%, Mn: 1.24%, P: 0.013%, S: 0.001%, Cr: 0.16%, V: 0.06%, a remainder of Fe and impurities, with Ceq: 0.311%, or (b) C: 0.06%, Si: 0.40%, Mn: 1.60%, P: 0.020%, S: 0.003%, Cu: 0.30%, Ni: 0.50%, Cr: 0.28%, Mo: 0.23%, V: 0.08%, a remainder of Fe and impurities, with Ceq: 0.498%). Even when this cooling method is applied to a long steel pipe 2 with a length of at least 20 meters, it can effectively suppress the occurrence of quenching-induced bending.

[0016] When cooling a steel pipe 2 with the cooling apparatus 1 according to this embodiment, first, the steel pipe 2 is rotated in its circumferential direction by rotating the rotating rollers 3, 3 in the direction of the arrows. Then, cooling of the inner surface of the steel pipe 2 is commenced by spraying cooling water from the unillustrated inner surface cooling nozzle into the interior of the steel pipe from one end thereof. The sprayed cooling water is discharged from the other end of the steel pipe 2. Cooling of the outer surface of the steel pipe 2 is then commenced by making cooling water 5a and 5b from the discharge ports 6a and 6b of the outer surface cooling nozzle 7 flow downwards towards the outer peripheral surface of the steel pipe 2. The cooling water may if necessary contain an additive such as a corrosion inhibitor as is well known in the art.

[0017] The rotational speed of the steel pipe 2 is preferably at least 30 rpm and at most 80 rpm. If the rotational speed of the steel pipe 2 is less than 30 rpm, the condition of the steel pipe 2 after quenching can easily vary in the circumferential direction thereof. On the other hand, if the rotational speed of the steel pipe 2 exceeds 80 rpm, the necessary equipment becomes large in size and complicated and equipment costs increase.

[0018] The rate at which cooling water is sprayed into the interior of the steel pipe 2 from the inner surface cooling nozzle is preferably at least 2,000 m³ per hour and at most 6,500 m³ per hour. If the flow rate of cooling water sprayed into the steel pipe 2 is less than 2,000 m³ per hour, the cooling ability is inadequate, whereas if it exceeds 6,500 m³ per hour, the necessary equipment becomes large in size and complicated and equipment costs increase.

[0019] In a cooling method according to this embodiment, cooling of the inner surface of the steel pipe 2 begins at least 7 seconds before cooling of the outer surface of the steel pipe 2 for the following reasons.

[0020] Figure 2 are graphs showing the results of numerical calculation of the surface temperature, the yield strength YS, and the axial stress σ_z of the steel pipe 2 when the inner surface and the outer surface of the steel pipe 2 were cooled. Figure 2(a) shows the results when cooling of the inner surface and cooling of the outer surface of the steel pipe 2 were commenced simultaneously (advance time for the inner surface = 0 seconds) and Figure 2(b) shows the results when only the inner surface of the steel pipe 2 was cooled (advance time for the inner surface = ∞ seconds). The results shown in the graphs of Figure 2(a) and 2(b) were observed under conditions in which the outer diameter of the steel pipe 2 was 412.3 mm, the wall thickness was 8.30 mm, the length was 30 mm, the material of the pipe was low carbon steel, the flow rate of cooling water sprayed into the steel pipe 2 from the inner surface cooling nozzle was 5,400 m³ per hour, the flow rate of cooling water which flowed downwards onto the outer surface of the steel pipe 2 from the outer surface cooling nozzle 7 was 2,700 m³ per hour, and the rotational speed of the steel pipe 2 was 65 rpm.

[0021] As shown in Figure 2(a), if cooling of the inner surface and cooling of the outer surface of a steel pipe P are commenced simultaneously, the absolute value $|\sigma_z|$ of the axial stress produced by thermal expansion and contraction of the steel pipe 2 in the initial stage after the start of cooling, i.e., in the stage in which the surface temperature of the steel pipe 2 is 550° C or higher (the axial stress in the region indicated by symbol A in the graph of Figure 2(a)), or that of the axial stress produced after the surface temperature of the steel pipe 2 decreases to lower than 550° C (the axial stress in the region shown by symbol B in the graph of Figure 2(a)) and including the stress caused by bainite transformation or martensite transformation or the like is sometimes larger than the absolute value $|\text{YS}|$ of the yield stress.

[0022] In contrast, as shown in the graph of Figure 2(b), when only cooling of the inner surface of the steel pipe 2 is carried out, the absolute value $|\sigma_z|$ of the axial stress is always less than the absolute value $|\text{YS}|$ of the yield stress from the start to the completion of cooling, namely, in the period until the surface temperature of the steel pipe 2 decreases to room temperature.

[0023] The reason for this is thought to be that compared to outer surface cooling in which only the portion where the planar streams of cooling water 5a and 5b flow down is cooled for an instant, in the case of inner surface cooling, it is possible to substantially uniformly cool the steel pipe 2 over its entire periphery, so temperature unevenness of the steel pipe 2 does not readily develop, and variation in the axial stress σ_z decreases.

[0024] In a cooling test performed on an actual steel pipe 2 under the same conditions as were set for obtaining the results shown in the graphs of Figures 2(a) and 2(b), a significant amount of quenching-induced bending occurred when cooling of the inner surface and cooling of the outer surface were simultaneously carried out, whereas a significant amount of troublesome quenching-induced bending did not occur when only inner surface cooling was carried out.

[0025] Based on the above-described results from Figures 2(a) and 2(b) and from the cooling test, it is thought that quenching-induced bending of a steel pipe 2 occurs when the absolute value $|\sigma_z|$ of the axial stress is greater than the absolute value $|\text{YS}|$ of the yield stress (i.w., $|\sigma_z| > |\text{YS}|$). Accordingly, quenching-induced bending of a steel pipe 2 can be suppressed by cooling a steel pipe 2 such that the relationship $|\sigma_z| < |\text{YS}|$ is always established. As shown in Figure 2(b), the relationship $|\sigma_z| < |\text{YS}|$ is always established if only inner surface cooling is carried out. However, with only inner surface cooling, the cooling capacity of the steel pipe 2 per unit time is inadequate and cooling takes a long time. As a result, the manufacturing efficiency of a steel pipe 2 decreases, or the steel pipe 2 cannot be sufficiently uniformly cooled due to the effect of recuperation of heat from the steel pipe 2, whereby a steel pipe having uniform mechanical properties cannot be obtained.

[0026] Therefore, according to an embodiment of the present invention, in order to prevent a decrease in manufacturing efficiency and guarantee uniform quenching, cooling is carried out not only on the inner surface but also on the outer surface of a steel pipe 2. In order to establish the relationship $|\sigma_z| < |\text{YS}|$ at least in the initial stage of cooling in which the surface temperature of the steel pipe 2 is 550° C or higher, it is effective to begin cooling of the inner surface of the steel pipe 2 before cooling of the outer surface. Specifically, by making the advance time at least 7 seconds, the relationship $|\sigma_z| < |\text{YS}|$ can be maintained throughout all the period of cooling the steel pipe 2.

[0027] For the above-described reasons, in this embodiment, by starting cooling of the inner surface of the steel pipe 2 at least 7 seconds in advance of cooling of the outer surface of the steel pipe 2, i.e., by setting the timing of the start of spraying of cooling water from the inner surface cooling nozzle to be at least 7 seconds before the timing of the start of allowing cooling water 5a and 5b to flow down from the discharge ports 6a and 6b of the outer surface cooling nozzle, the relationship $|\sigma_z| < |\text{YS}|$ is maintained over substantially the entire cooling process. As a result, quenching-induced bending of a steel pipe can be effectively suppressed with certainty.

[0028] If the advance time of inner surface cooling exceeds 30 seconds, a long time is required for cooling of a steel pipe 2 and operating efficiency decreases. Therefore, the advance time is preferably at most 30 seconds.

[0029] In order to increase the cooling efficiency of the outer surface of a steel pipe 2, it is conceivable to increase both the flow rates of the cooling water 5a and 5b which flows down from the discharge ports 6a and 6b, respectively. However, if the flow rates of cooling water 5a and 5b are both too large, a water film which accumulates on the outer surface of the steel pipe 2 between the locations 4a and 4b where the cooling water 5a and 5b runs down becomes

thicker than necessary, and the rate of effective utilization of cooling water (the proportion of cooling water which contributes purely to cooling of the steel pipe 2) decreases, and cooling water no longer smoothly flows in the rotational direction of the steel pipe 2.

[0030] A considerable portion of the cooling water 5a which flows down at position 4a on the upstream side in the rotational direction of the steel pipe 2, i.e., a considerable portion of the cooling water which runs down from discharge port 6a flows in the rotational direction on the outer surface of the steel pipe 2 as it rotates. In contrast, a certain amount of the cooling water 5b which flows down at position 4b on the downstream side in the direction of rotation, i.e., of the cooling water which runs down from discharge port 6b flows backwards against the direction of rotation of the steel pipe 2, but almost all of it flows to the downward side and then drops immediately after it flows down. Namely, the contribution to cooling of the outer surface of the steel pipe 2 is greater for cooling water 5a than for cooling water 5b.

[0031] Therefore, in this embodiment, the flow rate of cooling water which flows down at location 4a on the upstream side in the rotational direction of the steel pipe 2 is made equal to or larger than the flow rate of cooling water 5b which flows down at location 4b on the downstream side in the rotational direction of the steel pipe 2. The flow rates of cooling water 5a and 5b can be set by adjusting the width of the slits of the discharge ports 6a and 6b, respectively.

[0032] As a result, the amount of cooling water which flows in the rotational direction along the outer surface of the steel pipe 2 can be increased as needed, and the water film which accumulates between positions 4a and 4b on the outer surface of the steel pipe where cooling water streams 5a and 5b, respectively, flow down can be made a suitable thickness, thereby making it possible to further increase the cooling efficiency of the outer surface of the steel pipe 2.

[0033] The ratio of the flow rate of cooling water 5b which flows down at location 4b on the downstream side in the rotational direction of the steel pipe 2 with respect to the flow rate of cooling water 5a which flows down at location 4a on the upstream side in the rotational direction of the steel pipe 2 is preferably in the range of 1 - 0.6 and more preferably in the range of 1 - 0.8. By making this ratio somewhat smaller than 1, the amount of bending can be decreased compared to when the ratio is 1 (namely, when the flow rates of cooling water streams 5a and 5b are the same). However, if this ratio is too small, the amounts of cooling water on both sides of the outer peripheral surface of the steel pipe become significantly unequal and the amount of bending ends up increasing.

[0034] The angle θ between positions 4a and 4b where the two streams of cooling water 5a and 5b impact the outer peripheral surface of the steel pipe 2 as measured from the center of the steel pipe 2 is preferably at least 12° and at most 95° . If this angle θ is less than 12° , the region formed by the water film on the surface of the steel pipe 2 (the region between positions 4a and 4b) becomes extremely narrow. If this angle exceeds 95° , except for the case in which the outer diameter of the steel pipe 2 is extremely large, it is difficult to supply a sufficient amount of water for cooling between positions 4a and 4b of cooling water 5a and 5b on the outer surface of the steel pipe, and cooling sometimes becomes insufficient particularly at the uppermost portion of the steel pipe 2.

[0035] Particularly when the angle θ is large, a third discharge port for cooling water which flows downwards in a planar shape (not shown) may be installed preferably in a position immediately above the uppermost portion of the steel pipe 2. The flow rate of cooling water which flows down from this third discharge port is preferably smaller than the flow rates of cooling water from the discharge ports 6a and 6b on both sides.

[0036] Although the cooling apparatus becomes complicated, it is possible to have two rows of third streams of cooling water in a planar shape. For example, it is possible to install two pairs of two rows of discharge ports (namely, an inner pair and an outer pair) for cooling water which flows down on the outer peripheral surface of the steel pipe at roughly equal distances from the uppermost portion on both sides of the uppermost portion of the steel pipe. In this case, for the discharge ports of each pair, the flow rate of cooling water which flows down in a position on the upstream side in the rotational direction of the steel pipe 2 is preferably set to be equal to or greater than the flow rate of cooling water which flows down at a position on the downstream side in the rotational direction of the steel pipe 2.

[0037] In this manner, in this embodiment, the amount of quenching-induced bending which develops when quenching a thin-walled steel pipe P for which the ratio t/D is at most 0.07 can be made such that the maximum overall bending in a lot of pipes is effectively suppressed without a decrease in the manufacturing efficiency of steel pipes. As a result, the quenched steel pipes have improved toughness. In contrast to the method disclosed in JP S61-4896 B, cooling of the outer surface can be carried out under the same conditions over the entire length of the steel pipe without varying the starting time and the ending time in the axial direction of the steel pipe, so complexity of the structure of equipment and of control can be avoided. However, the timing of start of cooling of the outer surface is delayed relative to cooling of the inner surface over the entire length of the steel pipe.

Examples

[0038] Using the cooling apparatus 1 shown in Figure 1, cooling was carried out on API X60 grade steel pipes 2 (in mass %, C: 0.06%, Si: 0.26%, Mn: 1.24%, P: 0.013%, S: 0.001%, Cr: 0.16%, V: 0.06%, a remainder of Fe and impurities, and Ceq: 0.311%) having the outer diameter D, wall thickness t, ratio t/D , and length shown in Table 1 while rotating it at a rotational speed of 60 rpm with the inner surface flow rate (the flow rate of cooling water for cooling the inner surface),

the total flow rate on the outer surface (the total flow rate of cooling water for cooling the outer surface), the inner surface advance time (the time interval from the start of inner surface cooling to the start of outer surface cooling), the separation between the streams of outer surface cooling water (the distance in the circumferential direction between 4a and 4b in Figure 1), and the angle θ having the values shown in Table 1. The heating temperature of the steel pipe 2 prior to the start of cooling was 920° C. The discharge ports 6a and 6b for cooling the outer surface extended over the entire length of the steel pipe. Cooling was carried out until the inner and outer surfaces of the steel pipe reached room temperature.

[0039] For comparison, cooling of the steel pipe 2 was carried out using one stream of cooling water which flowed downwards in a planar shape on the outer surface of the steel pipe 2. In this case, the discharge port for cooling water was disposed immediately above the uppermost portion of the steel pipe 2.

[0040] The amount of quenching-induced bending which was produced in the steel pipe 2 after the completion of cooling (in unit of mm/10 m; determined by measuring the amount of bending (mm) with a thread stretched over the overall length of a pipe for the pipe having the largest amount of bending in a lot of pipes undergoing the same heat treatment, and converting this value into the amount of bending per 10 meters) and the maximum fracture appearance transition temperature vTs (the maximum value measured at 4 locations in the circumferential direction of the steel pipe) in a Charpy impact test were determined.

[0041] Bending amounts of at most 10 mm are indicated by DOUBLE CIRCLE ($\odot$), bending amounts of greater than 10 mm and at most 20 mm are indicated by CIRCLE ($\circ$), bending amounts of greater than 20 mm and at most 30 mm are indicated by TRIANGLE ($\triangle$), and bending amounts exceeding 30 mm are indicated by X. For the maximum fracture appearance transition temperature vTs in a Charpy impact test, a value of -40° C or below is indicated by CIRCLE, a value of greater than -40° C and at most 0° C is indicated by TRIANGLE, and a value exceeding 0° C is indicated by X. The overall evaluation was whichever of the above two evaluations was the worst, with the highest evaluation being CIRCLE. The results are shown in Table 1.

Table 1

Outersurface cooling water in planar shape	Number of streams (flow rate ratio)	Spacing [mm]	Angle θ [°]	Overall evaluation	Run No.
Charpy max. vTs (°C)					
Amount of bending [mm/10m]					
Inner surface cooling advance time [sec]					
Outer surfaces overall flow rate [t/hr]					
Inner surface flow rate [t/hr]					
Rotational speed [rpm]					
Length [m]					
t/D					
Wall thickness [mm]					
Outer diameter D [mm]					
	0	0	0	X	1
	10	0	0	Δ	2
	20	0	0	Δ	3
	0	100	18	X	4
	10	100	18	O	5
	20	100	18	O	6
	20	100	18	O	7
	20	0	0	Δ	8
	5	100	14	X	9
	7	100	14	O	10
	20	100	14	O	11

(continued)

Outer diameter D [mm]	Wall thickness t [mm]	t/D	Length [m]	Rotational speed [rpm]	Inner surface flow rate [t/hr]	Outer surfaces overall flow rate [t/hr]	Inner surface cooling advance time [see]	Amount of bending [mm/ 10m]	Charpy max. vTs (°C)	Outer surface cooling water in planar shape			Overall evaluation	Run No.
										Number of streams (flow rate ratio)	Spacing [mm]	Angle θ [°]		
219.1	12.7	0.058	25	60	4500	2800	12	9(⊙)	-30°C (△)	1	0	0	△	12
							4	17(o)	-30°C (△)	2 (1:1)	100	26	△	13
							7	8(⊙)	-50°C (○)	2 (1:1)	100	26	○	14
							12	4(⊙)	-50°C (○)	2 (1:1)	100	26	○	15
Note: Flow rate ratio = flow rate on upstream side: flow rate on downstream side														

[0042] Runs Nos. 5 - 7, 10, 11, 14, and 15 in Table 1 are examples of carrying out cooling by the method according to the present invention (namely, there were two streams of outer surface cooling water, and inner surface cooling was carried out at least 7 seconds in advance). For each example, the amount of bending was CIRCLE or DOUBLE CIRCLE, and even with a thin-walled steel pipe having a t/D ratio of at most 0.07 (i.e., 0.031 to 0.058), quenching-induced bending could be effectively suppressed without decreasing the manufacturing efficiency of a steel pipe. In addition, the Charpy maximum fracture appearance transition temperature (maximum vTs) was -40° C or below, so the toughness was good.

[0043] Runs Nos. 6 and 7 had the same cooling conditions as each other except that the distribution of the flow rate of the two streams of outer surface cooling water was different. Whereas the amount of quenching-induced bending was 10 mm for Run No. 6 in which the flow rates of the two streams of outer surface cooling water were the same, for Run No. 7 in which the flow rate for the stream on the upstream side in the rotational direction of the steel pipe was made larger than the flow rate for the stream on the downstream side, the amount of quenching-induced bending was further decreased to 6 mm.

[0044] In contrast, in Run No. 1 in which there was one stream of outer surface cooling water and inner surface cooling and outer surface cooling were started simultaneously, the amount of quenching-induced bending was too large, and toughness was poor with a maximum vTs of -30° C. In Runs Nos. 2, 3, 8, and 12 in which inner surface cooling began earlier than outer surface cooling but there was one stream of outer surface cooling water, toughness was poor with a maximum vTs of -30° C. In Run No. 4 in which there were two streams of outer surface cooling water but inner surface cooling and outer surface cooling were started simultaneously, the amount of quenching-induced bending was too large. In Runs Nos. 9 and 13 in which there were two streams of outer surface cooling but the advance time of inner surface cooling was shorter than 7 seconds, the amount of quenching-induced bending was relatively large and the toughness was poor with a maximum vTs of -30° C.

Claims

1. A method of cooling a steel pipe in which the inner surface and the outer surface of a horizontally-disposed steel pipe are cooled while the steel pipe is rotated in its circumferential direction, **characterized in that** cooling of the inner surface of the steel pipe is carried out by spraying cooling water inside the steel pipe, cooling of the outer surface of the steel pipe is carried out by producing downwards flow of cooling water in a planar shape along the axial direction onto the outer surface of the steel pipe from above at two locations approximately equal distances from the uppermost portion of the steel pipe on both sides of the uppermost portion, wherein the flow rate of cooling water which flows downwards at a location on the upstream side in the rotational direction of the steel pipe is equal to or greater than the flow rate of cooling water which flows downwards at a location on the downstream side in the rotational direction, and cooling of the inner surface of the steel pipe is started at least 7 seconds before cooling of the outer surface of the steel pipe.
2. A method of cooling a steel pipe as set forth in claim 1 wherein the ratio of the wall thickness to the outer diameter of the steel pipe is at most 0.07.

Fig. 1

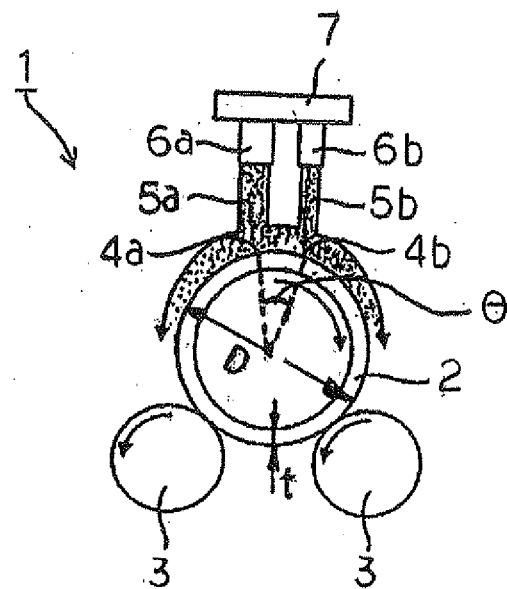
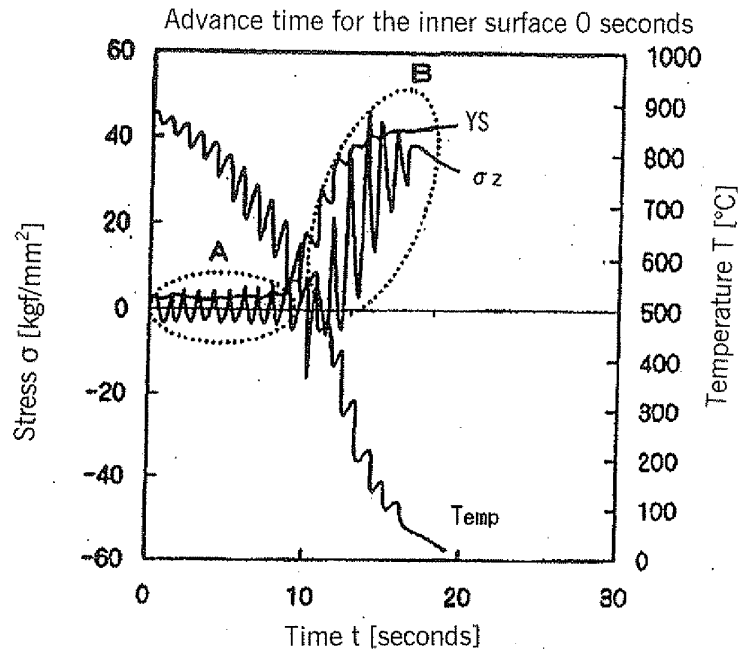
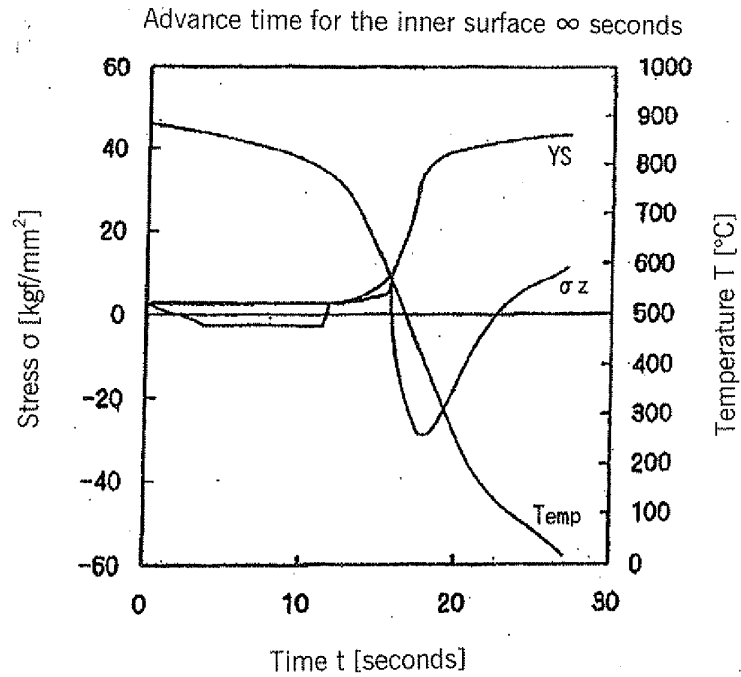


Fig. 2

(a)



(b)



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2007/061004

A. CLASSIFICATION OF SUBJECT MATTER <i>C21D9/08</i> (2006.01)i, <i>C21D1/18</i> (2006.01)i, <i>C22C38/00</i> (2006.01)n, <i>C22C38/58</i> (2006.01)n 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) <i>C21D9/08</i> , <i>C21D1/18</i> , <i>C22C38/00</i> , <i>C22C38/58</i> 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 1996-2007 Kokai Jitsuyo Shinan Koho 1971-2007 Toroku Jitsuyo Shinan Koho 1994-2007 Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) WPI, Science Direct, JSTPlus(JDream2)		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2000-8125 A (Sumitomo Metal Industries, Ltd.), 11 January, 2000 (11.01.00), Claims; Par. Nos. [0017] to [0022]; Fig. 2 (Family: none)	1, 2
Y	JP 11-21628 A (Sumitomo Metal Industries, Ltd.), 26 January, 1999 (26.01.99), Claims; Par. Nos. [0012] to [0014], [0035] to [0043]; Figs. 1, 2 (Family: none)	1, 2
☒ 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 24 July, 2007 (24.07.07)		Date of mailing of the international search report 14 August, 2007 (14.08.07)
Name and mailing address of the ISA/ Japanese Patent Office		Authorized officer
Facsimile No.		Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2007/061004

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 8-319516 A (Sumitomo Metal Industries, Ltd.), 03 December, 1996 (03.12.96), Par. Nos. [0031] to [0033]; Figs. 5, 6 (Family: none)	1,2
Y	JP 11-269548 A (Sumitomo Metal Industries, Ltd.), 05 October, 1999 (05.10.99), Par. No. [0008] (Family: none)	1,2
P,X	JP 2006-152393 A (Sumitomo Metal Industries, Ltd.), 15 June, 2006 (15.06.06), Claims; Par. Nos. [0001], [0024] to [0030]; Fig. 3 (Family: none)	1,2

Form PCT/ISA/210 (continuation of second sheet) (April 2005)

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP H027372 B [0004] [0006]
- JP S614896 B [0005] [0007] [0037]