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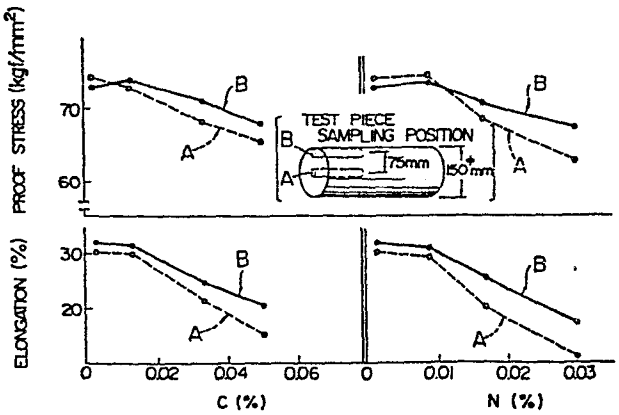
(54) Non-magnetic steel having high corrosion resistance and high strength for use as material of drill collar, and drill collar made of the steel.

(57) A non-magnetic steel alloy having high corrosion resistance and high strength suitable for use as the material of a drill collar which operates under corrosive conditions, particularly under the conditions which cause stress corrosion cracking, and a drill collar made of the steel alloy. The steel alloy has a composition which essentially consists of: not greater than 0.02% of C, not greater than 2.0% of Si, not greater than 2.0% of Mn, 25 to 40% of Ni, 18 to 30% of Cr, 0.1 to 1.5% of A1, 1.5 to 3.0% of Ti, 0.0005 to 0.020% of Ca, not greater than 0.020% of N and the balance Fe and incidental impurities, and a drill collar made of the steel.

FIG. 2



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NON-MAGNETIC STEEL HAVING HIGH CORROSION RESISTANCE AND HIGH STRENGTH FOR USE AS MATERIAL OF DRILL COLLAR, AND DRILL COLLAR MADE OF THE STEEL

BACKGROUND OF THE INVENTION

The present invention relates to a non-magnetic steel alloy having high resistance to stress corrosion cracking, suitable for use as the material of drill collars, and relates to the drill collars made of the steel.

In recent years, the petroleum drilling operation is conducted under severe conditions such as in greater depth into the earth or in submarine oil fields, as a result of exhaustion of the petroleum resources. Drill collars made of high-strength, non-magnetic steels are used in the petroleum drilling operation under such severe conditions. The drill collar is a member which is provided on the upper side of a drill bit so as to load the drill bit thereby enhancing the drilling efficiency. The drill collar is constituted by a thick-walled steel pipe of, for example, 250 mm in outside diameter, 70 mm in thickness and 10 m in length. The drill collar is required to have a considerable strength and toughness, e.g., a proof stress of about 60 to 80 kgf/mm^2 and elongation of about 25% or greater.

The drilling under the severe condition encounters problems such as stress corrosion cracking of the drill collar. More specifically, the drill collar driven deeper into the earth is inevitably subjected to a surrounding atmosphere containing greater amount of chlorides and higher temperature. The chlorine ions at high temperature cause stress corrosion cracking of steel. It is, therefore, necessary to take a suitable countermeasure for preventing the stress corrosion cracking.

Hitherto, some high Mn-steels and Ni-Cr steels have been used as high-strength non-magnetic steels. An example of such steels is X50MnCrV20 14 (1.3819) specified by DIN. Among these steels, the high Mn steel has a lower corrosion resistance than Ni-Cr steels, although the corrosion resistance of the high Mn steel can be increased by addition of Cr. In particular, the high Mn steel is undesirable for the usage of drilling under the condition rich in colorine ions, because the resistance to stress corrosion cracking is impaired by the presence of Mn. The strength of the high Mn steel relies mainly upon strengthening effect of precipitation of carbides. When a round bar of the high Mn steel of about 200 mm in diameter used as the blank of the drill collar is subjected to a solution heat treatment, precipitation of carbides takes place particularly in the core portion of the bar where the cooling rate is inevitably small. Consequently, in the subsequent aging for reinforcement, the strengthening effect occurs non-uniformly in the radial direction, thus impairing homogeneousness of the material.

On the other hand, precipitation strengthened austenitic stainless steels have been known as a kind of the high-strength Ni-Cr austenitic steels. An example of such austenitic stainless steel is A 286 (AISI 660) which makes use of the precipitation strengthening due to intermetallic compound γ': [$Ni_3(Al,Ti)$], or is described in Metal Science Journal, 1970, Vol. 4, Page 122 and in Metallurgical Transactions A, Vol. 7A, November 1976, Pages 1743 to 1746. However, this steel does not exhibit satisfactory corrosion resistance because the Cr content thereof is as small as 15% or so. In addition, this stainless steel is apt to cause carbides of Ti, due to containment of about 0.05% of C. In the case of a round bar of 200 mm diameter used as the blank material of the drill collar, the Ti carbides of large sizes are formed during solidification of an ingot or billet. Such large-sized carbides cannot be removed completely even by subsequent heating and rolling. The large Ti carbides tend to initiate cracks of the material and to promote propagation of cracks, thus impairing ductility and toughness of the material. The distribution of the large Ti carbides, which adversely affect the properties of the material, varies in the radial direction as well as in the longitudinal direction of the round bar. It is, therefore, not possible to obtain satisfactory homogeneousness of the round bar steel as the blank material of the drill collar.

Thus, the conventional high-strength non-magnetic steels are unsatisfactory in their properties such as corrosion resistance, particularly stress corrosion cracking, ductility and toughness, and do not have required homogeneousness, thus impairing the life and durability of drill collars.

SUMMARY OF THE INVENTION

Accordingly, an object of the invention is to provide a non-magnetic steel having high corrosion resistance as well as high strength suitable for use as the material of drill collars, thereby overcoming the above-described problems of the prior art.

Another object of the invention is to provide the use of the non-magnetic steel described above as the material of a drill collar.

Still another object of the invention is to provide a drill collar having superior resistance to stress corrosion cracking and high strength used in petroleum drilling operation effected under severe conditions such as atmosphere containing greater amount of chlorides and high temperature.

Through an intense study on the defects of the prior arts, the present inventors have found that satisfactory resistance to stress corrosion cracking can be obtained if Cr and Ni contents in the steel are sufficiently high. The inventors have found also that the ductility, toughness and homogeneousness can be remarkably improved by extremely reducing the contents of C and N both of which are apt to form compounds in association with carbide formers and nitride formers such as Ti, Cr, Mo, Nb and V.

With these knowledges, the present invention makes it possible to obtain a non-magnetic steel having high corrosion resistance and high strength suitable for use as the material of a drill collar, which steel essentially consists, by weight %, of: not greater than 0.02% of C, not greater than 2.0% of Si, not greater than 2.0% of Mn, 25 to 40% of Ni, 18 to 30% of Cr, 0.1 to 1.5% of Al, 1.5 to 3.0% of Ti, 0.0005 to 0.020% of Ca, not greater than 0.020% of N and the balance Fe and incidental impurities.

The steel in accordance with the invention may further contain one or two kinds or more selected from the group consisting of not greater than 3.0% of Mo, not greater than 0.5% of Zr, not greater than 0.5% of Nb and not greater than 0.5% of V.

The drill collar of the invention, which is adapted to be attached to a drill bit through a near bit stabilizer, comprises a cylindrical main body made of an alloy consisting essentially, by weight, of not greater than 0.020% of C, not greater than 2.0% of Si, not greater than 2.0% of Mn, 25 - 40% of Ni, 18 to 30% of Cr, 0.1 to 1.5% of Al, 1.5 to 3.0% of Ti, 0.0005 to 0.020% of Ca, not greater than 0.020% of N and the balance Fe and incidental impurities.

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1a and 1b are graphs which show, respectively, how time to rupture in stress corrosion test is changed in accordance with change in Cr and Ni contents; and

Fig. 2 is a chart showing the influences of C and N contents on the mechanical property of a steel of the invention.

Fig. 3 is a front view of a drill collar embodying the invention which drill collar (1) is attached to drill bit (2) through a near bit stabilizer (3).

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A description will be made hereinunder as to the reasons of limitation of the contents of constituent elements.

In the composition of the steel embodying the invention, Si and Mn are elements which are essential as deoxidation agents. However, an excessively large Si content impairs the hot workability of the material, while the presence of Mn in excess of 2.0% reduces the resistance to stress corrosion cracking. Therefore, the Si and Mn contents are limited to be not greater than 2.0%, respectively.

Ni and Cr are fundamental elements in the steel of the invention. Referring first to Ni, this element is the major constituent necessary for maintaining, in combination with Cr which will be mentioned later, a stable austenitic phase which is essential for the non-magnetic property of the steel. Ni serves also as a strengthening element, because the steel of the invention is a so-called precipitation-hardened steel in which the strength has been increased as a result of precipitation of intermetallic compound γ'-phase: [Ni_3(Al,Ti)] through aging treatment. In order that the drill collar for deep oil well drilling exhibits the required resistance to stress corrosion cracking under operating condition rich in chlorine ions, the Ni content should be not less than 25%. The Ni content, however, need not exceed 40% because the effect for improving the resistance to stress corrosion cracking is saturated at 40%.

In order to ensure the necessary corrosion resistance, the Cr content should not be less than 18%. A Cr content exceeding 30%, however, impairs the hot workability and makes austenitic phase unstable. Therefore, the upper limit of Cr content is set at 30%.

The appropriate ranges of Ni and Cr contents have been determined in accordance with the following experiment. Figs. 1a and 1b show, how time to rupture in stress corrosion test is varied in accordance with change in the Cr content and Ni content, respectively. The experiment was conducted by using two types of test pieces: namely, a first type test pieces obtained from steels each of which basically contains 0.010% of C, 0.5% of Si, 1.2% of Mn, 0.5% of Al, 2.0% of Ti, 0.0010% of Ca and 0.005% of N and further containing 30% of Ni and variable amount of Cr; and a second type test pieces obtained from steels each containing, in addition to the above-mentioned basic elements, 20% of Cr and variable amount of Ni. The test pieces each having a diameter of 6 mm at its parallel portion were subjected to a constant load type stress corrosion cracking test conducted in a boiling, saturated salt water at a stress of 80 kgf/mm^2.

From these Figures, it will be understood that the stress corrosion rupture time can be remarkably improved when Cr content and Ni content exceed 18% and 25%, respectively. It will be also clear that this effect is saturated when the Ni content has reached 40%. Although the effect of Cr is further increased if Cr content increases beyond 30%, the upper limit of Cr content is set at 30% because such Cr content exceeding 30% impairs the hot workability of the alloy.

Al is the element which forms the precipitates for strengthening the steel of the invention: namely, an intermetallic compound γ': [Ni_3(Al, Ti)]. Al also has an effect for suppressing the precipitation of η-phase which is precipitates of grain boundary reaction type adversely affecting the ductility and toughness of the steel. An excessively large Al content, however, reduces the precipitation hardening effect because it decreases the matching strain occarring between the austenite phase and the γ' phase. For these reasons, the Al content is selected to range between 0.1 and 1.5%. Ti is a major element which forms the intermetallic compound γ': [Ni_3(Al, Ti)], and the strength of the alloy is increased as the Ti content is increased. In order that the drill collar can withstand the large ground pressure encountered during drilling, the drill collar has to have a high strength. To keep this high strength, the Ti content has to be at least 1.5%. The addition of Ti in excess of 3% seriously impairs the hot workability of the alloy. For these reasons, the Ti content should range between 1.5% and 3%.

Ca as an element for improving the hot workability should be contained by an amount not less than 0.0005%. A Ca content exceeding 0.020%, however, impairs the hot workability, so that the Ca content is determined to range between 0.0005 and 0.020%.

According to the invention, the formation of carbides or nitrides of Ti, Cr, Mo, Nb, Zr and V is reduced by limiting the C and N contents, thereby ensuring high ductility, toughness and homogeneousness required for the steel used for drill collar. Referring to C, this element forms large Ti carbides through reaction with Ti in the course of solidification. The solid-solution of such large Ti carbide is difficult to be effected in the subsequent heating, rolling or solid-solution heat treatment. On the other hand, drill collars are inevitably subjected to impacts due to change in the driving torque or change in the nature of the earth during drilling. The drill collar, therefore, should have high ductility, toughness and homogeneousness, in order to prevent breakage by such impacts. The large carbides which remain without being changed into solid solution not only impairs the ductility and toughness but also make the material heterogeneous. In order to prevent such large carbides from remaining, therefore, the C content has to be not greater than 0.02%. Preferably, the carbon content is not more than 0.015%.

N has a tendency of forming large compounds through reaction with Ti, i.e., Ti nitrides. This tendency is greater than the tendency of formation of large Ti carbides exhibited by C. In order to ensure the ductility, toughness and homogeneousness which are necessary for the drill collars, therefore, the N content should be limited suitably. In view of the greater tendency of N to form nitrides than the tendency of formation of carbides by C, the upper limit of N content should be selected to be less than 0.020% which is lower than the upper limit of C content. The preferable range of nitrogen is of not more than 0.010%. The adequate ranges of C and N contents are determined in view of the following effects.

Fig. 2 shows the results of an experiment which was conducted for the purpose of investigation of the relationship between the mechanical properties and

C and N contents. The experiment was carried out as follows. Two types of material were prepared. The first type of alloy basically containing 0.5% of Si, 1.2% of Mn, 20% of Cr, 34% of Ni, 0.5% of Al, 2% of Ti and 0.0010% of Ca, with the addition of 0.006% of N and variable amount of C. The second type of alloy was prepared by adding 0.010% of C and variable amount of N to the basic composition described above. The melts of these materials were solidified and rolled or forged into round bars of 150 mm in diameter which were then subjected to a solution treatment effected at a temperature of 950 to 1100°C in 30 to 90 min and an aging treatment effected at a temperature of 700 - 850°C in 1 to 10 hours. Then, tensile test pieces in accordance with the tensile test piece No. 4 in JIS were provided at the sampling positions shown in Fig. 2. The thus obtained test pieces were then subjected to a tensile test conducted under JIS Z 2241. The results of the tensile test are shown in Fig. 2.

From this Figure, it will be understood that high proof stress and large elongation are obtainable when C content is not greater than 0.015% and when N content is not greater than 0.010%. In addition, no fluctuation of proof stress and elongation according to the sampling position was observed. This means that the material is substantially homogeneous. More specificaly, the proof stress was not less than 70 kgf/mm^2 and the elongation was not less than 25% both of which values are sufficient for ensuring the required mechanical strength. As stated before, the ductility and toughness are impaired due to formation of Ti carbides and Ti nitrides, when C and N contents exceed the above-mentioned limit values, respectively, and this is the reason why the upper limits of C and N contents are set at these limit values.

Basic components of the composition of the invented steel have been described above. Besides these basic components, the steel of the invention can further contain limited amount of one, two or more elements selected from the group consisting of Mo, Zr, Nb and V, in order to improve the proof stress of the drill collar.

More specifically, Mo is an element which produces a solid solution strengthening effect, and is important for attaining high proof stress. An Mo content exceeding 3%, however, seriously increases the hot deformation resistance of the material, so that the processing such as rolling and forging is made difficult. The Mo content, therefore, should be not greater than 3.0%.

Zr, Nb and V can be in the state of the solid-solution in the intermetallic compound γ' which brings about the precipitation strengthening effect. The addition of these elements increases the amount of precipitation of γ', thus enhancing the proof stress. Since the excessive addition of these elements impairs the ductility and toughness, the content of each of these elements is limited to 0.5% at the greatest.

The steel of the invention having the described composition are produced by a steel making process using, for example, an electric furnace, and is changed into an ingot or billet by a subsequent ingot-making, blooming or by a continuous casting. The billets are formed into round bars through rolling or forging, and, after a subsequent solution heat treatment effected at a temperature in the range of 950 to 1100°C for a period of time of 30 to 90 min followed by water-cooling and an aging treatment effected at a temperature of 700 to 850°C for a period of time of 1 to 10 hours, it becomes a blank material available for the drill collars having austenitic structure in which γ' intermetallic compounds are uniformly precipitated. Alternatively, in the steel of the invention the solid-solution treatment and aging treatment may be omitted if temperature of the rolling or forging is appropriate.

The advantage of the invention will be more fully realized from the following description of Examples.

(Example 1)

Each of molten alloys of about 1000 kg having the chemical compositions shown in Table 1 prepared by a vacuum melting furnace was cast at about 1500°C into an ingot having a square cross section of about

400 mm in one side and a length of about 700 mm, the ingot being then forged at a temperature of about 1150°C into a rounded bar having a size shown in Table 1. The rounded bar was then subjected to a solution heat treatment in which the bar is held at a temperature in the range of 1050°C for a period of time of 60 min and was water-cooled, the rounded bar being then subjected to an aging treatment in which the bar was held at a temperature in the range of 800°C for a period of time of 2 hours. The rounded bars thus heat-heated were used in tests for researching the properties of each alloy. Table 2 shows the properties of the materials as observed at positions 20 mm and 60 mm below the surface of the rounded bars. From the result of the investigation of the properties, it was seen that the steel of the invention exhibited superior resistance to stress corrosion cracking, as well as high homogeneousness of the material, as compared with known steels which were shown by way of comparison.

As has been described, the steel in accordance with the invention has high strength and superior corrosion resistance, particularly the resistance to stress corrosion cracking, as well as a high degree of homogeneousness and, therefore, can be used very effectively as the blank material of high-performance drill collars for use in drilling of oil well under severe working conditions.

Table 1

	Alloy No.	Chemical Composition (wt %)						
		Si	Mn	Ni	Cr	Al	Ti	Ca
Steel of Invention	1	0.51	1.25	29.4	19.5	0.52	1.72	0.0007
	2	0.42	0.82	35.2	19.3	0.73	1.89	0.0017
	3	0.39	0.75	34.7	22.4	1.17	1.75	0.0014
	4	1.27	1.42	37.8	27.4	1.32	2.10	0.0018
	5	0.77	1.73	28.7	18.5	0.51	2.05	0.0054
	6	1.04	0.80	35.7	24.7	0.54	2.74	0.0104
	7	1.62	0.65	38.8	27.8	0.49	2.61	0.0171
	8	0.35	0.99	30.7	20.4	0.32	2.11	0.0067
	9	0.37	0.84	35.1	22.0	0.21	1.98	0.0047
	10	0.32	0.84	34.8	20.7	0.52	20.8	0.0051
	11	0.35	0.78	34.1	21.4	0.64	2.12	0.0049
	12	0.45	0.91	35.2	20.5	0.55	23.4	0.0040
Comparison Steel	13	0.36	24.3	3.7	2.2	0.03	-	-
	14	0.42	25.0	2.5	15.0	0.02	-	-
	15	0.32	1.4	35.2	19.8	0.42	2.12	0.008
	16	0.47	1.6	35.9	21.2	0.61	1.89	0.007
	17	0.35	1.5	34.9	20.2	0.53	2.04	0.009
	18	0.34	1.4	30.7	17.2	0.49	2.07	0.002

(to be continued)

Table 1 (Cont'd)

C	N	Mo	Zr	Nb	V	Diameter of Rounded Bar (mm)
0.012	0.007	-	-	-	-	220
0.008	0.006	-	0.10	-	-	200
0.013	0.008	-	-	-	-	240
0.011	0.008	-	-	-	-	200
0.012	0.007	-	0.14	-	-	200
0.007	0.005	-	-	-	-	180
0.009	0.009	-	0.04	-	-	180
0.010	0.009	-	-	0.17	-	220
0.010	0.006	-	-	-	0.42	220
0.014	0.008	-	0.07	0.29	-	220
0.006	0.007	0.5	-	-	-	200
0.007	0.009	2.5	-	-	-	200
0.183	0.065	-	-	0.09	1.18	200
0.205	0.052	-	-	0.12	1.32	220
0.051	0.005	-	-	-	-	180
0.013	0.047	-	-	-	-	180
0.062	0.027	-	-	-	-	180
0.011	0.008	-	-	-	-	180

Table 2

	Alloy No.	Test piece sampling position: 20 mm below round bar surface					
		Tensile properties			Charpy absorption energy (kg·m)	Constant-load type stress corrosion cracking test. Time to Rupture (h)*	
		Proof stress (kgf/mm^2)	Tensile strength (kgf/mm^2)	Elongation (%)		Saturated Nacl boiled	Pre-NACE boiled
Steel of Invention	1	66	104	34	10.5	565	1000NF
	2	67	106	35	11.4	670	1000NF
	3	62	101	38	13.4	711	1000NF
	4	72	110	28	8.7	817	1000NF
	5	75	113	29	8.2	544	1000NF
	6	81	117	26	7.3	889	1000NF
	7	80	118	27	7.6	970	1000NF
	8	78	114	31	7.4	700	1000NF
	9	84	121	25	7.2	820	1000NF
	10	83	120	26	6.9	750	1000NF
	11	74	114	30	8.4	980	1000NF
	12	77	115	29	9.1	1000NF	1000NF

(to be cont'd)

Table 2 (Cont'd)

Comparison Steel	13	76	113	29	4.8	0.2	0.1
	14	81	122	27	4.5	20.5	12.7
	15	68	108	21	4.5	520	1000NF
	16	69	110	18	4.2	635	1000NF
	17	64	105	19	4.3	580	1000NF
	18	75	114	31	8.7	275	757

* Stress = 1.0 x proof stress   NF: No Failure

Table 2 (Cont'd)

Test piece sampling position: 20 mm below round bar surface					
Tensile properties			Charpy absorption energy (kg·m)	Constant-load type stress corrosion cracking test. Time to Rupture (h)*	
Proof stress (kgf/mm^2)	Tensile strength (kgf/mm^2)	Elongation (%)		Saturated Nacl boiled	Pre-NACE boiled
65	105	34	10.2	590	1000NF
67	106	36	11.1	652	1000NF
63	104	37	13.6	700	1000NF
75	112	29	8.9	835	1000NF
74	112	30	8.6	521	1000NF
81	118	25	7.7	890	1000NF
79	116	27	7.2	920	1000NF
76	115	30	7.1	756	1000NF
85	120	26	8.0	815	1000NF
83	123	26	7.4	659	1000NF
76	115	32	8.2	1000NF	1000NF
75	110	27	8.9	1000NF	1000NF

(to be cont'd)

Table 2 (Cont'd)

74	112	26	4.2	0.2	0.1
79	118	25	3.9	18.7	11.5
66	105	17	3.8	570	1000NF
65	107	15	3.7	620	1000NF
59	100	16	3.9	557	1000NF
76	112	33	8.8	290	807

(Example 2)

A molten steel alloy having chemical composition No. 1 in Table 1 was prepared through a conventional vacuum oxygen carburization process (VOD process) by use of an electric arc furnace of 50 to 100 ton in capacity and was casted into an ingot of 600 x 600 mm in cross section and 2500 mm in length at a temperature of about 1500°C. The ingot was hot-rolled at 1150°C into a bloom of 320 x 340 mm in cross-sectional size, which bloom was again hot-rolled into a rounded bar of 90 to 290 mm in diameter. The rounded bar was subjected to rough turning to prepare a sized rounded bar of 80 to 280 mm in diameter. The rounded bar was then subjected to a solution heat treatment in which the bar was held at about 1050°C for a period of time of 60 min and was then water-cooled. The solution-heat-treated round bar was subjected to a trepanning to prepare a cylindrical main body of 32 to 90 mm in inner diameter and of 600 to 900 mm in length. The cylindrical main body was subjected to aging heat treatment in which it was held at 800°C for 2 hours, which main body was then subjected to a threading step to prepare a threaded portion therein. Thus, there was obtained a drill collar 1 having the main body and the threaded portion adapted to be engaged with a near bit stabilizer 3, through which the drill collar is connected to the drill bit 1 used in petroleum drilling operation, which drill collar had such high strength, high toughness and superior resistance to stress corrosion cracking as shown in Table 2.

WHAT IS CLAIMED IS

1. A non-magnetic steel having high corrosion resistance and high strength suitable for use as the material of a drill collar, said steel essentially consisting, by weight, of: not greater than 0.02% of C, not greater than 2.0% of Si, not greater than 2.0% of Mn, 25 to 40% of Ni, 18 to 30% of Cr, 0.1 to 1.5% of Al, 1.5 to 3.0% of Ti, 0.0005 to 0.020% of Ca, not greater than 0.020% of N and the balance Fe and incidental impurities.

2. A non-magnetic steel having high corrosion resistance and high strength suitable for use as the material of a drill collar, said steel essentially consisting, by weight, of: not greater than 0.02% of C; not greater than 2.0% of Si; not greater than 2.0% of Mn; 25 to 40% of Ni; 18 to 30% of Cr; 0.1 to 1.5% of Al; 1.5 to 3.0% of Ti; 0.0005 to 0.020% of Ca; not greater than 0.020% of N; at least one selected from the group consisting of not greater than 3.0% of Mo, not greater than 0.5% of Zr, not greater than 0.5% of Nb and not greater than 0.5% of V; and the balance Fe and incidental impurities.

3. Use of a non-magnetic steel as the material of a drill collar, said steel consisting essentially, by weight, of: not greater than 0.02% of C, not greater than 2.0% of Si, not greater than 2.0% of Mn, 25 to 40% of Ni, 18 to 30% of Cr, 0.1 to 1.5% of Al, 1.5 to 3.0% of Ti, 0.0005 to 0.020% of Ca, not greater than

0.020% of N and the balance Fe and incidental impurities.

4. Use of a non-magnetic steel as the material of a drill collar, said steel consisting essentially, by weight, of: not greater than 0.02% of C; not greater than 2.0% of Si; not greater than 2.0% of Mn; 25 to 40% of Ni; 18 to 30% of Cr; 0.1 to 1.5% of Al; 1.5 to 3.0% of Ti; 0.0005 to 0.020% of Ca; not greater than 0.020% of N; at least one selected from the group consisting of not greater than 3.0% of Mo, not greater than 0.5% of Zr, not greater than 0.5% of Nb and not greater than 0.5% of V; and the balance Fe and incidental impurities.

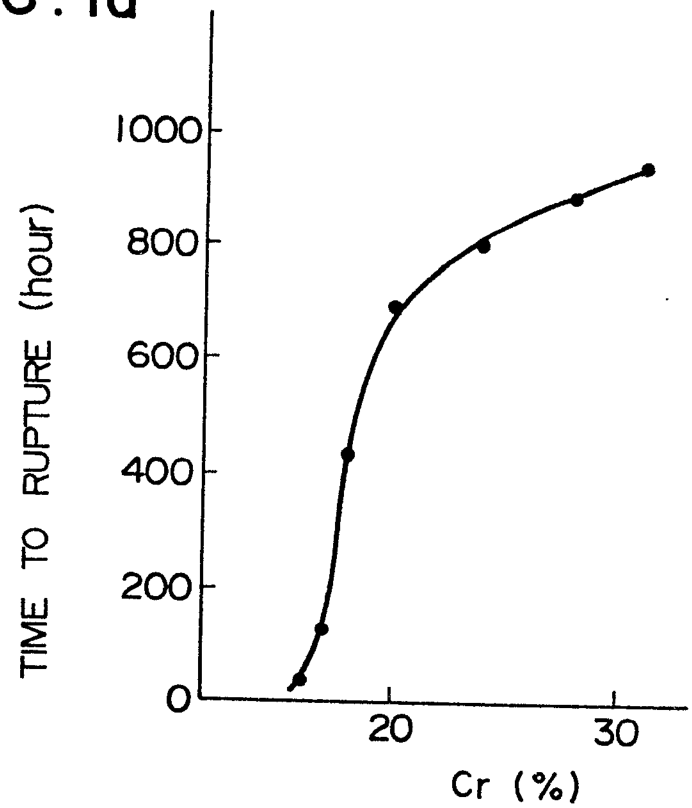
5. A drill collar having superior resistance to stress corrosion cracking and high strength adapted to be attached to a drill bit used in petroleum drilling operation, comprising a cylindrical main body made of an alloy consisting essentially, by weight, of not greater than 0.02% of C, not greater than 2.0% of Si, not greater than 2.0% of Mn, 25 to 40% of Ni, 18 to 30% of Cr, 0.1 to 1.5% of Al, 1.5 to 3.0% of Ti, 0.0005 to 0.020% of Ca, not greater than 0.020% of N and the balance Fe and incidental impurities.

6. A drill collar as claimed in claim 5, said main body having an outer diameter in the range of 80 to 280 mm, an inner diameter in the range of 32 to 90 mm and a length in the range of 600 to 9600 mm, said drill collar having an austenitic structure in which fine γ' intermetallic compound particles are uniformly dispersed.

7. A drill collar adapted to be attached to a drill bit used in petroleum drilling operation, comprising a cylindrical main body made of an alloy consisting essentially, by weight, of not greater than 0.02% of C; not greater than 2.0% of Si; not greater than 2.0% of Mn; 25 to 40% of Ni; 18 to 30% of Cr; 0.1 to 1.5% of Al; 1.5 to 3.0% of Ti; 0.0005 to 0.020% of Ca; not greater than 0.020% of N; at least one selected from the group consisting of not greater than 3.0% of Mo, not greater than 0.5% of Zr, not greater than 0.5% of Nb and not greater than 0.5% of V; and the balance Fe and incidental impurities.

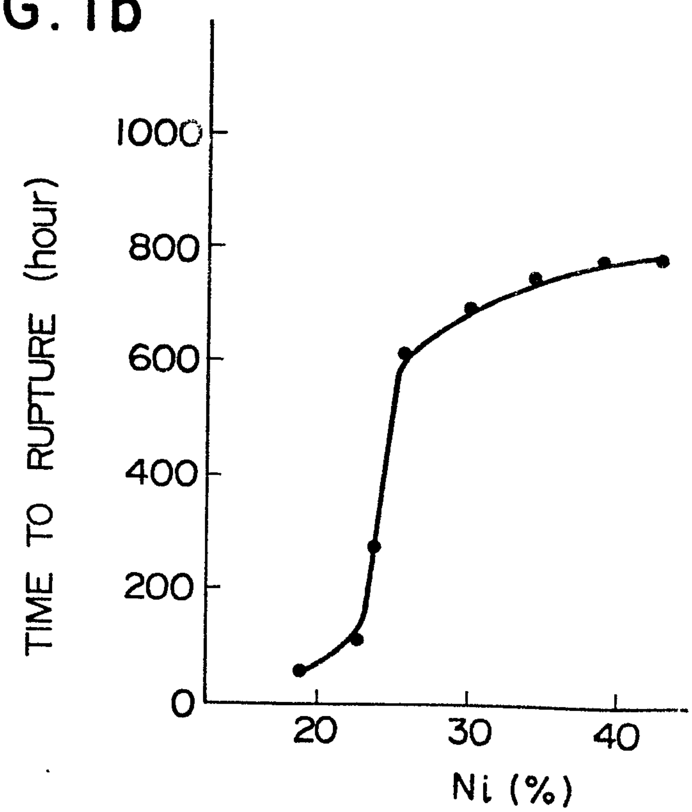
8. A drill collar as claimed in claim 5, said main body having an outer diameter in the range of 80 to 200 mm, an inner diameter in the range of 32 to 90 mm and a length in the range of 600 to 9600 mm, said drill collar having an austenitic structure in which fine γ' intermetallic compound particles are uniformly dispersed.

FIG. 1a



TIME TO RUPTURE (hour)
1000
800
600
400
200
0
20
30
Cr (%)

FIG. 1b



TIME TO RUPTURE (hour)
1000
800
600
400
200
0
20
30
40
Ni (%)

FIG. 2

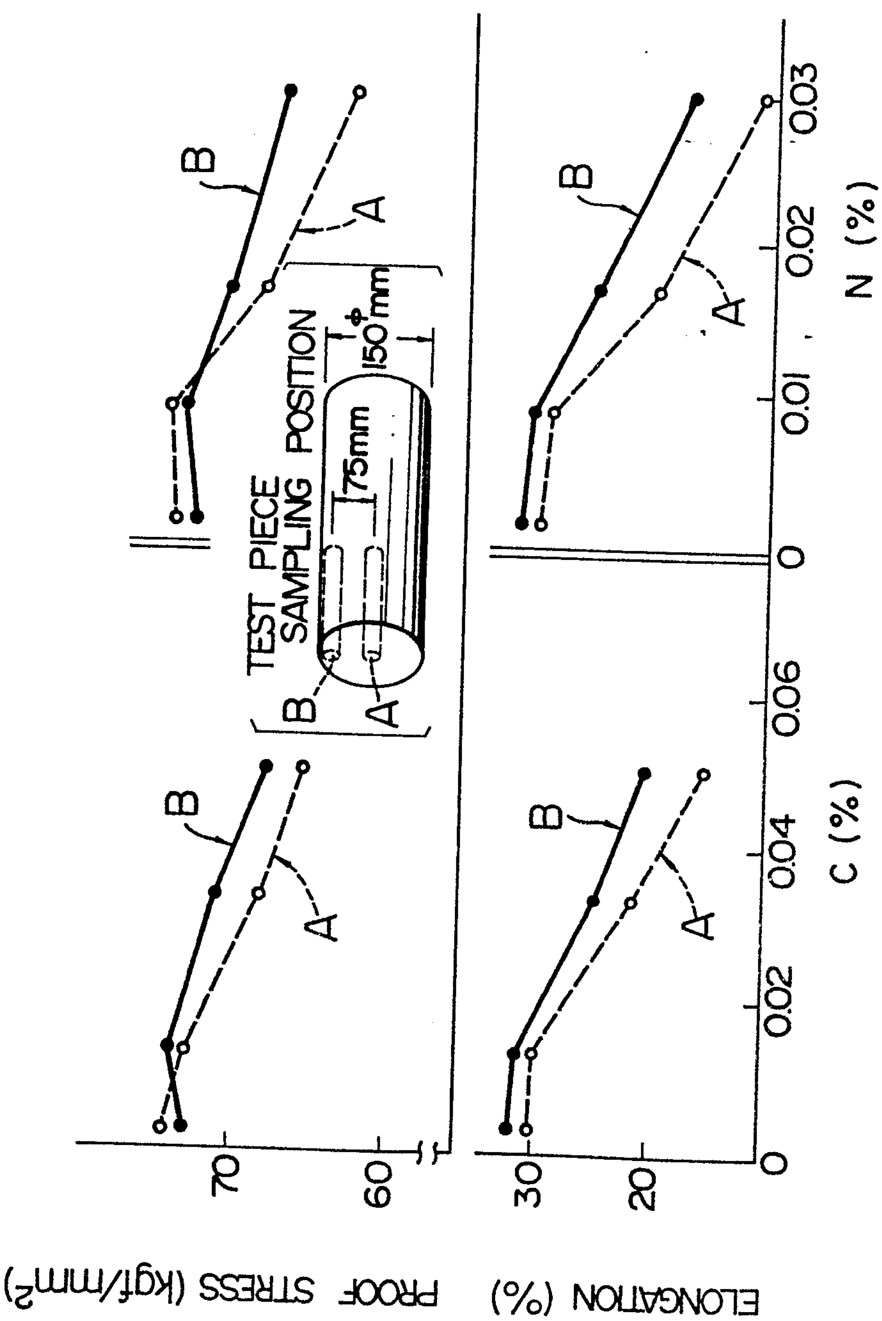

PROOF STRESS (kgf/mm²)
ELONGATION (%)
70
60
30
20
0
0.02
0.04
0.06
0.01
0.03
C (%)
N (%)
A
B
TEST PIECE SAMPLING POSITION
75mm
φ150mm

FIG.3