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(54) LOW ALLOY STEEL

(57) A low alloy steel for a heat-resisting structural member being improved in long time creep ductility at high temperatures and temper softening resistance, **characterized by** comprising, by mass percent, C: 0.03 to 0.10%, Si: not more than 0.30%, Mn: not more than 1.0%, Cr: more than 1.5% to not more than 2.5%, Mo: 0.01 to 1.0%, V: 0.04 to 0.30%, Nb: 0.001 to 0.10%, Ti: 0.001 to 0.020%, B: 0.0001 to 0.020%, Al: 0.001 to 0.01% and Nd: 0.0001 to 0.050%, with the balance being Fe and impurities, wherein the content of P is not more than 0.020%, the content of S is not more than 0.003%, the content of N is less than 0.0050% and the content of O (oxygen) is not more than 0.0050% among the impurities, in which the value of BSO represented by the following formula (1) is 0.0001 to 0.010:

$$\mathrm{BSO} = \mathrm{B} - (11/14)\mathrm{N} - (11/32)\mathrm{S} - (11/16)\mathrm{O} \cdots\cdots (1),$$

wherein each element symbol in the formula (1) represents the content (by mass %) of the element concerned. The steel may further contain one or more element selected from among W, Cu, Ni, Co, Mg, Ca, La, Ce, Y, Sm and Pr.

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Description

TECHNICAL FIELD

[0001] The present invention relates to a low alloy steel excellent in high temperature creep characteristics and toughness. The low alloy steel of the present invention is suitable for heat-resisting structural members such as electric power plant boilers, turbines, nuclear power plant facilities, chemical industry facilities and other facilities or apparatus, which are used at high temperatures.

BACKGROUND ART

[0002] Electric power plant boilers, turbines, nuclear power plant facilities, chemical industry facilities and the like are used at high temperature and high pressure conditions for a long time. Therefore, the heat-resisting materials to be used in such facilities and the like are generally required to be excellent in strength, corrosion resistance and oxidation resistance at high temperatures as well as toughness and the like at room temperature. In those fields of application, austenitic stainless steels (for example, JIS SUS321H and SUS347H steels), low alloy steels (for example, JIS STBA24 steel, namely 2.25Cr-1Mo steel) and further, 9-12Cr type high-Cr ferritic steels (for example, JIS STBA26 steel, namely 9Cr-1Mo steel, and JIS STBA28 steel, namely improved 9Cr-1Mo steel) have been used in the past.

[0003] Recently, in the thermal power plants, attempts have been made to reduce the discharge of CO_2 and so forth for the prevention of global warming. Therefore, it is essential to improve the thermal efficiency and, regarding the boilers, new type plants have been built to be operated under high temperature and high pressure steam conditions (for example, 300 atmospheres at temperatures over 600˚C). On the other hand, a number of existing plants which were built during the period of rapid economic growth, are each nearing the end of their scheduled life span one after another and it is becoming a great social problem whether they should be replaced with new advanced plants or their lives should be prolonged by partial mending. This is also a problem which involves the energy policy of Japan.

[0004] On the other hand, advanced liberalization in the electric power business field in compliance with the request for deregulation inside and outside the country, has now made it possible for an enterprise outside the electric power industry to go into that field. This has resulted in increased price competition and therefore economical efficiency in electric power plants has become more important as well.

[0005] Therefore due to a need to reduce the cost of new power plants, a trend is growing toward improving the strength of the heat-resisting structural materials used in the power plants and also reduce the steel consumption in order to meet this requirement, new high strength materials are under development.

[0006] In the relatively low temperature region up to about 500˚C, Cr-Mo type low alloy steels such as JIS STBA22 steel (1Cr-0.5Mo steel), STBA23 steel (1.25Cr-0.5Mo steel) and the above-mentioned STBA24 steel (2.25Cr-1Mo steel) and the like, have so far been used. Also a steel containing W in substitution for a part of Mo in order to increase the high temperature strength more is disclosed in the Patent Document 1. Further, a steel improved in hardenability by adding Co is also disclosed in the Patent Document 2.

[0007] In such new steels as referred to above, the high temperature softening resistance is improved by W or Co, and especially the creep strength at 500˚C or above is markedly improved as compared with the conventional multipurpose steels. However, there is a problem in that increases in strength result in a deterioration in toughness and marked decreases in long time creep ductility (that is, elongation and reduction of area).

[0008] In the Patent Documents 3 and 4, as steels prevented from deterioration in toughness and also improved in reheat cracking resistance, steels resulting from the addition of a very small amount of Ti to the Cr-Mo steels, with a nitrogen content suppressed to a very low level, are disclosed. The steels are definitely improved in toughness but fail to simultaneously attain high creep strength and creep ductility. Further, in regions subjected to repeated SR treatment following welding, reheat cracking may occur and, in addition, marked decreases in creep strength may be sometimes encountered due to reheat softening.

[0009] In the Patent Document 5, a low and medium Cr type heat-resisting steel characterized by a regulated density of occurrence of precipitates within a specific range of size is disclosed. This steel is high in creep strength but the composition design is not always made in consideration of long time creep ductility or reheat softening resistance characteristics.

[0010] In the Patent Document 6, a low alloy steel with a Cr content of 0.40 to 1.50% is disclosed. However, the Cr content is too low, therefore the resistance to high temperature corrosion in the temperature range above 500˚C is not always sufficient and the temperature range for its use is restricted.

Patent Document 1: Japanese Laid-open Patent Publication No. 08-134584,
Patent Document 2: Japanese Laid-open Patent Publication No. 09-268343,
Patent Document 3: Japanese Laid-open Patent Publication No. 08-144010,
Patent Document 4: Japanese Laid-open Patent Publication No. 2001-234276

Patent Document 5: Japanese Laid-open Patent Publication No. 2001-342549
Patent Document 6: Japanese Laid-open Patent Publication No. 2004-107719

DISCLOSURE OF THE INVENTION

PROBLEMS TO BE SOLVED BY THE INVENTION

[0011] The objective of the present invention is to provide a steel which is markedly improved in long time creep ductility at high temperatures and in temper softening resistance and is capable of being used even in a temperature range up to about 550˚C by improving low alloy steels for heat-resisting structural members which have so far been in a temperature range of up to about 500˚C in electric power plants and so forth.

MEANS FOR SOLVING THE PROBLEM

[0012] The present inventors made detailed investigations concerning the effects of the chemical composition of each material and the metallurgical structure (that is, microstructure) on the creep deformation properties, namely creep strength, creep ductility and reheat softening characteristics, in various heat-resisting low alloy steels. As a result, the following new findings were obtained.

[0013]

(a) When, in the Cr-Mo steels, a part of Mo is substituted with W, the carbides become stable for a longer time and the creep strength increases but, contrariwise, the toughness and creep ductility markedly decrease. For example the said carbides occurred in the form of M_3C, M_7C_3, $M_{23}C_6$ and M_6C. M mainly comprises Fe and Cr and some quantities of Mo, W and the like are dissolved in the said M. With the increase in the amount of Cr, M_3C changes into M_7C_3, $M_{23}C_6$ and M_6C.

[0014]

(b) When Co is added to the Cr-Mo steels, the hardenability is markedly improved with the increase of the amount of Co. However, the addition of Co in large amounts, like W, leads to increases in susceptibility to creep embrittlement.

[0015]

(c) On the other hand, when V, Nb and the like are added to the Cr-Mo steels, MC carbides (M comprising mainly V and Nb, and a part of Mo is dissolved in the said M) precipitate out finely and dispersedly and a more significant precipitation hardening effect is obtained compared with the single addition of Mo; the high temperature creep strength is thus improved. However, the susceptibility to creep embrittlement also increases markedly.

[0016]

(d) The addition of B to the Cr-Mo steels is effective in increasing the hardenability, and so the strength and toughness are improved. Although such a phenomenon is already known, the investigations made by the present inventors revealed that when excessive B is added, the toughness markedly decreases.

[0017]

(e) Further research works made by the present inventors revealed that the creep ductility and reheat softening resistance are both markedly improved when the contents of B, N, S and O (oxygen) are respectively optimized and the value of BSO represented by the formula (1) given below is adjusted to 0.0001 to 0.010. It was also revealed that it becomes possible to add W and B, for instance, in large amounts.

[0018] The present invention has been accomplished on the basis of the above-mentioned findings. The gists of the present invention are the following low alloy steels.

[0019]

(1) A low alloy steel, which comprises by mass percent, C: 0.03 to 0.10%, Si: not more than 0.30%, Mn: not more than 1.0%, Cr: more than 1.5% to not more than 2.5%, Mo: 0.01 to 1.0%, V: 0.04 to 0.30%, Nb: 0.001 to 0.10%, Ti: 0.001 to 0.020%, B: 0.0001 to 0.020%, Al: 0.001 to 0.01% and Nd: 0.0001 to 0.050%, with the balance being Fe

and impurities, wherein the content of P is not more than 0.020%, the content of S is not more than 0.003%, the content of N is less than 0.0050% and the content of O (oxygen) is not more than 0.0050% among the impurities, in which the value of BSO represented by the following formula (1) is 0.0001 to 0.010:

$$\mathrm{BSO} = \mathrm{B} - (11/14)\mathrm{N} - (11/32)\mathrm{S} - (11/16)\mathrm{O} \ \cdots\cdots (1),$$

wherein each element symbol in the formula (1) represents the content (by mass %) of the element concerned.

[0020]

(2) A low alloy steel according to the above (1), which further contains W: not more than 2.0% by mass in lieu of part of Fe.

[0021]

(3) A low alloy steel according to the above (1) or (2), which further contains one or more elements selected from among Cu, Ni and Co each at a level not more than 0.50% by mass in lieu of part of Fe.

[0022]

(4) A low alloy steel according to any one of the above (1) to (3), which further contains one or more elements selected from among Mg: not more than 0.005% by mass, Ca: not more than 0.005% by mass, La: not more than 0.02% by mass, Ce: not more than 0.02% by mass, Y: not more than 0.05% by mass, Sm: not more than 0.05% by mass and Pr: not more than 0.05% by mass.

[BEST MODE FOR CARRYING OUT THE INVENTION

[0023] The working-effect of the each component constituting the low alloy steel of the present invention and the reasons for restricting the contents thereof will next be explained. In the following description, the symbol "%" for the content of each component represents "% by mass".

[0024] C: 0.03 to 0.10%

C serves as an austenite-stabilizing element and stabilizes the bainite phase (lower bainite phase) or martensite phase, which is the basic parent phase of the Cr-Mo steels. It also forms various carbides and contributes toward increasing strength. If the content of C is less than 0.03%, however, the extent of carbide precipitation is small; hence a sufficient level of strength cannot be obtained. On the other hand, if the content of C exceeds 0.10%, the steel is markedly hardened and the weldability and workability are deteriorated. A more preferable lower and the upper limit of C are 0.04% and 0.08%, respectively.

[0025] Si: not more than 0.30%

Si is used as a deoxidizer in the steelmaking process and inevitably remains in the steel. Conventionally, Si is positively added as an element necessary for securing the oxidation resistance in the steels used for heat-resisting structural members. However, according to the study made by the present inventors, it was revealed that reductions in the amount of Si contained as an impurity can produce the effects of reducing not only the creep embrittlement but also the reheat embrittlement and the reheat cracking susceptibility. When the content of Si is suppressed to 0.30% or less, the effects become significant. Even when the content of Si is suppressed to 0.30% or below, the Cr captures oxygen and therefore causes no harmful effect on the oxidation resistance. From the reasons mentioned above, the content of Si is set to not more than 0.30%. A more preferable content of Si is not more than 0.15%.

[0026] Mn: not more than 1.0%

Like C, Mn is an austenite-stabilizing element and important for the stabilization of the bainite phase. However, higher levels of the addition of Mn cause a lower Ac_1 transformation point of the steel and further, cause reheat embrittlement. Therefore, the content of Mn is set to not more than 1.0%. If the content of Mn is not more than 0.30%, the creep ductility is further improved. The lower limit content of Mn may be an ordinary impurity level.

[0027] Cr: more than 1.5% to not more than 2.5%

Cr is essential for the stabilization of the low carbon type bainitic parent phase. In order to obtain the said effect, the content of Cr is set to more than 1.5%. A more preferable lower limit content of Cr is more than 1.6%. On the other hand, if the content of Cr exceeds 2.5%, the precipitation of M_7C_3 and $M_{23}C_6$ type carbides increases remarkably, and it causes a decrease in creep strength.

[0028] Mo: 0.01 to 1.0%

Mo is an element which produces solid solution hardening and contributes to the stabilization of M_3C, M_7C_3 and $M_{23}C_6$ type carbides and further, it forms Mo_2C and, in addition, contributes to the stabilization of MC type carbides and improves the creep strength. In order to obtain the said effects, the content of Mo is set to not less than 0.01%. However, if there is an excessive addition of Mo, the bainitic or martensitic parent phase becomes unstable, and therefore, the upper limit content of Mo is set to 1.0%.

[0029] V: 0.04 to 0.30%

V, together with Nb which will be mentioned later herein, forms MC type carbides and remarkably contributes to improvement in creep strength. In order to obtain the said effect, the content of not less than 0.04% of V is needed. Since, at excessive additional levels, it markedly reduces the long time creep ductility, the upper limit content of V is set to 0.30%.

[0030] Nb: 0.001 to 0.10%

Like V, Nb forms fine carbides which contribute toward increasing the creep strength. In order to obtain the said effect, the content of not less than 0.001% of Nb is needed. However, if the content of Nb exceeds 0.10%, the toughness deteriorates due to the excessive formation of carbonitrides. A more preferable lower and the upper limit of Nb are 0.020% and 0.060%, respectively.

[0031] Ti: 0.001 to 0.020%

Ti forms fine carbides and contributes toward increasing the strength. Therefore, the content of not less than 0.001% of Ti is needed. In particular, it is effective in improving the creep ductility and in preventing embrittlement and cracking during reheating, so that the content of not less than 0.010% of Ti is more preferable. Excessive addition, however, adversely affects the toughness; hence the upper limit content of Ti is set to 0.020%.

[0032] B: 0.0001 to 0.020%

B is effective in increasing the hardenability. The said effect is obtained if the content of B is not less than 0.0001%. On the other hand, at excessive additional levels, it adversely affects the toughness and therefore, the upper limit content of B should be set to 0.020%. It is noted that the upper limit content of B is preferably 0.015% and more preferably 0.012%. It is necessary that the content of B is set so that the value of BSO represented by the formula (1) given above may fall within the range of 0.0001 to 0.010.

[0033] Nd: 0.0001 to 0.050%

Nd is an element which improves long time creep ductility In order to obtain the said effect, the content of not less than 0.0001% of Nd is needed. Excessive Nd, however, forms coarse inclusions unfavorable to the toughness and therefore, the upper limit content of Nd is set to 0.050%. A more preferable content of Nd is more than 0.010% and not more than 0.050%.

[0034] Al: 0.001 to 0.01%

Al is an element which is important as a steel deoxidizer for steels. In order to obtain the deoxidizing effect, the content of not less than 0.001% of A1 is needed. On the other hand, the content of A1 levels exceeding 0.01% is unfavorable to simultaneously securing both the strength and toughness which is an aim of the present invention.

[0035] One of low alloy steels according to the present invention comprises the components mentioned above with the balance being Fe and impurities. It is necessary, however, to suppress the contents of P, S, N and O (oxygen) among the impurities in the following manner.

[0036] P: not more than 0.020%, S: not more than 0.003%, O: not more than 0.0050%

These elements are unfavorable impurities which deteriorate the toughness of the steel. The contents thereof should be not more than the respective upper limits given above and are preferably as low as possible.

[0037] N: less than 0.0050%

N is an element which produces solid solution hardening and forms carbonitrides therefore sometimes contributes to the high temperature strength. However, in the practice of the present invention, the content of N is suppressed to less than 0.0050% in order to obtain both the creep strength and toughness, and also to obtain the improved creep ductility. Further, it is necessary that the content of N is adjusted so that the value of BSO represented by the formula (1) given above may fall within the range of 0.0001 to 0.010.

[0038] BSO: 0.0001 to 0.010

As mentioned hereinabove, the BSO is expressed in terms of the formula (1) given below. In order to improve the creep ductility and the reheat softening resistance, it is necessary that the value of BSO is 0.0001 to 0.010:

$$BSO = B - (11/14)N - (11/32)S - (11/16)O \quad \cdots\cdots (1).$$

[0039] The technical meaning of the BSO is to secure an amount of B which is effective in preventing the carbonitrides from becoming coarse and also effective in preventing grain boundary embrittlement when the steel of the present invention is used at high temperatures. If the value of BSO is smaller than 0.0001, no effective amount of B is secured. And when it is greater than 0.010, coarse inclusions which are harmful to the toughness are formed. Therefore, the value of BSO is set to 0.0001 to 0.010. A more preferable lower limit value of BSO is 0.001.

[0040] The low alloy steel according to the present invention also contains the components mentioned above and further one or more components selected from among W, Cu, Ni, Co, Mg, Ca, La, Ce, Y, Sm and Pr. The working-effects of these components and the reasons for restricting the contents thereof are described below.

[0041] W: not more than 2.0%

W is added when a further improvement in the long time creep strength at high temperatures is desired. As mentioned hereinabove, high addition levels of W have so far been regarded as causing reheat embrittlement and also increase cracking susceptibility. However, in the steels having a value of BSO within the range of 0.0001 to 0.010, the content of 2.0% or less of W does not produce these above harmful effects. W also contributes to improvement in creep ductility. In order to definitely obtain these effects, a content of W of not less than 0.20% is preferable.

[0042] Cu, Ni, Co: each not more than 0.50%

All of these elements are austenite-stabilizing elements and contribute to the stabilization of the bainite phase or martensite phase. In order to definitely obtain this effect, the content of each element is preferably not less than 0.01%. However, if the content of each element is above 0.50%, the steel sometimes becomes too high in strength, making it necessary for example to carry out excessive softening heat treatment and the like. Therefore, when these components are added, the content of each should be suppressed to not more than 0.50%.

[0043] Mg, Ca: each not more than 0.005%, La, Ce: each not more than 0.02%, Y, Sm, Pr: each not more than 0.05%

All of these elements have an effect of preventing solidification cracking during steel casting, and therefore they are added according to necessity. At levels exceeding the respective upper limit values described above, they adversely affect the toughness. In order to secure the effect of their addition, the content of each is preferably not less than 0.0001%.

[0044] The steel of the present invention, after processing into pipes, plates and so forth, is subjected to "normalizing-tempering" heat treatment and then used. The microstructure after the said heat treatment is mainly composed of tempered bainite or tempered martensite.

EXAMPLES

[0045] In the following, the effects of the present invention are explained concretely in reference to examples.

Steels having chemical compositions shown in Table 1 were melted by use of a 150 kg vacuum induction melting furnace, followed by ingot making and hot forging, to give plate-like test materials, 25 mm in thickness × 100 mm in width. Then, they were subjected to normalizing treatment, namely they were maintained at 950˚C for 1 hour and water cooled, and then reheated and maintained at a tempering temperature varying within the range of 720 to 760˚C for 1 hour and then air cooled. The microstructure of each steel was tempered bainite or tempered martensite.

[0046] A portion of the said test materials after the above heat treatment, was further reheated at 730˚C for 10 hours in order to examine the changes in hardness and for reheat softening resistance evaluation.

[0047] Creep rupture test specimens, 6 mm in diameter and 30 mm in GL and Charpy test specimens 10 mm × 10 mm × 5 mm in size, having a 2 mm V notch were cut out from each test material obtained. The creep rupture test was carried out under the condition of a temperature of 550˚C and an applied stress of 200 MPa, and the Charpy impact test was carried out within a temperature range of-60˚C to 60˚C. The results of these tests are shown in Table 2.

[0048] In Table 2, in the column "toughness", the mark "o o" indicates that the vTrs was lower than -40˚C; the mark "o" indicates that the vTrs was within the range of -40˚C to -20˚C; the mark "∆" indicates that the vTrs was within the range exceeding -20˚C and not higher than 0˚C; and the mark "x" indicates that the vTrs was higher than 0˚C. In the column "reheat softening resistance", the mark "o" indicates that the decrease in Vickers hardness (Hv) after the reheating mentioned above (that is, 10 hours of heating at 730˚C) was smaller than 20% and the mark "×" indicates 20% or larger.

[0049]

[Table 1]

Table 1

Division	No.	Chemical compositions (mass %) Balance: Fe and impurities																			
		C	Si	Mn	P	S	Cr	Mo	V	Nb	Ti	B	Al	N	Nd	O	BSO	W	Cu	Ni	Co	Others
Inventive	1	0.06	0.15	-	0.003	0.001	1.81	0.35	0.19	0.048	0.016	0.0048	0.0018	0.0017	0.0461	0.0015	0.0021	1.46	-	-	-	-
	2	0.07	0.07	0.11	0.013	0.002	2.11	0.71	0.11	0.039	0.017	0.0036	0.0072	0.0027	0.0252	0.0009	0.0002	-	-	-	-	-
	3	0.06	0.09	0.20	0.011	0.002	2.29	0.72	0.27	0.032	0.009	0.0060	0.0077	0.0002	0.0195	0.0010	0.0045	-	-	-	-	-
	4	0.07	0.07	0.04	0.019	0.002	1.93	0.19	0.22	0.028	0.018	0.0060	0.0093	0.0027	0.0223	0.0011	0.0024	1.63	-	-	-	-
	5	0.06	0.06	0.21	0.015	0.002	2.07	0.10	0.05	0.046	0.009	0.0068	0.0037	0.0041	0.0168	0.0015	0.0019	1.55	-	-	-	-
	6	0.07	0.06	0.13	0.005	0.002	2.07	0.96	0.23	0.039	0.008	0.0064	0.0046	0.0020	0.0169	0.0013	0.0032	0.86	-	-	-	-
	7	0.06	0.13	0.29	0.010	0.003	1.69	0.76	0.10	0.043	0.016	0.0071	0.0020	0.0019	0.0286	0.0019	0.0033	-	0.16	-	-	-
	8	0.08	0.03	0.24	0.013	0.002	2.32	0.94	0.26	0.034	0.014	0.0073	0.0013	0.0030	0.0239	0.0039	0.0016	-	-	0.36	-	-
	9	0.06	0.11	0.28	0.016	0.002	2.41	0.16	0.18	0.028	0.012	0.0046	0.0040	0.0038	0.0486	0.0009	0.0003	-	-	-	0.44	-
	10	0.07	0.07	0.07	0.014	0.003	2.20	0.35	0.23	0.028	0.012	0.0071	0.0032	0.0037	0.0178	0.0002	0.0030	1.42	-	-	-	Mg:0.0034
	11	0.07	0.04	0.05	0.018	0.002	2.02	0.32	0.04	0.058	0.020	0.0096	0.0081	0.0028	0.0137	0.0031	0.0046	-	-	-	-	Ca:0.0032
	12	0.06	0.12	0.16	0.006	0.002	2.13	0.06	0.20	0.023	0.011	0.0069	0.0046	0.0047	0.0185	0.0020	0.0011	-	-	-	-	La:0.0058
	13	0.05	0.21	0.27	0.009	0.001	2.28	0.67	0.08	0.034	0.010	0.0041	0.0053	0.0030	0.0342	0.0012	0.0006	-	-	-	-	Ce:0.0164
	14	0.05	0.02	0.23	0.009	0.002	2.02	0.82	0.07	0.039	0.006	0.0059	0.0041	0.0044	0.0255	0.0023	0.0002	-	-	-	-	Y:0.0122
	15	0.04	0.06	0.28	0.008	0.001	2.47	0.04	0.19	0.038	0.012	0.0072	0.0090	0.0032	0.0119	0.0028	0.0024	-	-	-	-	Sm:0.0050
	16	0.06	0.11	0.10	0.004	0.001	2.08	0.88	0.09	0.058	0.007	0.0051	0.0092	0.0021	0.0144	0.0041	0.0003	-	-	-	-	Pr:0.0426
	17	0.06	0.03	0.22	0.016	0.001	2.40	0.27	0.29	0.050	0.017	0.0082	0.0056	0.0004	0.0124	0.0041	0.0047	1.44	0.37	0.14	0.25	-
	18	0.07	0.09	0.14	0.001	0.003	2.30	0.27	0.12	0.057	0.013	0.0073	0.0076	0.0043	0.0488	0.0034	0.0006	-	-	-	-	Mg:0.0031,La:0.0026
	19	0.07	0.12	0.16	0.019	0.001	1.56	0.98	0.15	0.022	0.007	0.0082	0.0018	0.0010	0.0375	0.0016	0.0060	1.88	0.21	-	-	-
	20	0.05	0.05	0.17	0.002	0.002	2.17	0.98	0.10	0.054	0.009	0.0049	0.0031	0.0032	0.0106	0.0014	0.0007	1.97	-	-	-	Mg:0.0024
	21	0.07	0.13	0.30	0.005	0.002	1.59	0.80	0.20	0.041	0.015	0.0050	0.0048	0.0009	0.0136	0.0038	0.0010	-	-	-	-	Mg:0.0005
	22	0.06	0.06	0.23	0.019	0.003	2.36	0.43	0.19	0.047	0.013	0.0056	0.0038	0.0009	0.0369	0.0010	0.0032	1.36	-	0.12	-	Sm:0.0441
Comparative	30	0.07	0.21	0.11	0.014	0.002	1.89	0.07	0.10	0.047	0.019	0.0033	0.0020	0.0024	0.0178	0.0037	-0.0018	-	-	-	-	-
	31	0.05	0.25	0.07	0.004	0.001	1.56	0.03	0.19	0.038	0.015	0.0121	0.0046	0.0005	0.0218	0.0004	0.0111	-	-	-	-	-
	32	0.07	0.08	0.30	0.005	0.001	2.11	0.23	0.15	0.046	0.013	0.0078	0.0058	0.0029	0.0583	0.0041	0.0024	-	-	-	-	-
	33	0.07	0.27	0.10	0.017	0.001	1.15	1.12	0.17	0.027	0.012	0.0055	0.0001	0.0022	0.0354	0.0032	0.0012	-	-	-	-	-
	34	0.04	0.15	0.01	0.015	0.002	2.30	0.96	0.35	0.051	0.019	0.0092	0.0048	0.0002	0.0443	0.0043	0.0054	-	-	-	-	-
	35	0.06	0.29	0.11	0.020	0.002	1.70	0.26	0.25	-	0.013	0.0063	0.0089	0.0014	0.0415	0.0025	0.0028	-	-	-	-	-
	36	0.05	0.07	0.17	0.015	0.001	2.02	0.97	0.20	0.057	0.025	0.0053	0.0012	0.0008	0.0304	0.0048	0.0010	-	-	-	-	-
	37	0.08	0.11	0.20	0.010	0.002	0.56	0.81	0.15	0.026	0.013	0.0068	0.0038	0.0055	0.0481	0.0025	0.0001	-	-	-	-	-
Conventional	51	0.05	0.26	0.20	0.014	0.002	1.03	0.50	0.06	0.031	0.015	0.0022	0.0046	0.0058	-	0.0025	-0.0048	-	-	-	-	-
	52	0.07	0.35	0.26	0.013	0.002	1.22	0.47	0.05	0.033	0.014	0.0018	0.0047	0.0047	-	0.0026	-0.0044	-	-	-	-	-
	53	0.06	0.40	0.11	0.010	0.005	1.24	0.50	0.06	0.025	0.015	0.0015	0.0035	0.0043	-	0.0025	-0.0053	-	-	-	-	-
	54	0.03	0.29	0.20	0.018	0.002	1.27	0.50	0.07	0.033	0.012	0.0010	0.0033	0.0020	-	0.0023	-0.0028	-	-	-	-	-

[0050] [Table 2]

Table 2

Division	No.	Creep rupture test (550˚C, 200MPa)			Toughness	Reheat softening resistance
		Rupture time (h)	Elongation (%)	Reduction of area (%)		
Inventive	1	14204	17.4	74.8	OO	O
	2	12916	16	77.4	O	O
	3	11934	17.6	71.6	O	O
	4	12092	17.7	76.1	O	O
	5	13822	17.3	80.0	O	O
	6	11749	16.7	74.5	O	O
	7	14260	15.6	82.0	O	O
	8	13185	16.2	80.6	O	O
	9	13960	17.8	79.1	O	O
	10	13200	15.0	72.9	O	O
	11	13239	17.7	76.5	O	O
	12	12137	15.7	75.6	O	O
	13	13074	17.6	82.8	O	O
	14	13807	17.8	86.7	O	O
	15	13724	17.1	71.4	O	O
	16	11974	17.8	70.7	O	O
	17	13575	15.6	86.1	O	O
	18	13318	15.1	79.3	O	O
	19	13923	16.2	83.1	O	O
	20	11666	16.2	75.2	O	O
	21	12196	17.9	81.0	O	O
	22	13523	18.0	84.4	O	O
Comparative	30	12242	6.3	47.8	×	×
	31	5166	11.1	44.9	×	×
	32	7628	10.1	57.1	×	×
	33	11979	6.3	47.9	×	×
	34	7286	12.2	52.6	×	×
	35	5969	12.8	41.1	×	×
	36	11255	7.9	55.3	×	×
	37	7325	6.1	57.3	×	×
Conventional	51	6413	5.3	6.7	○	×
	52	3988	6.7	5.3	○	×
	53	5012	10.2	7.3	○	×
	54	8139	8.6	22.7	△	×

[0051] As shown in Table 2, all of the inventive steels Nos. 1 to 22 showed a creep rupture time exceeding 10000 hours and were superior to the conventional steels (Nos. 51 to 54) in this respect. As regards the toughness as well, the vTrs was not higher than -20˚C and was very excellent.

[0052] On the other hand, the comparative steels Nos. 30 to 37 had a composition outside the range specified in accordance with the present invention or had a value of BSO represented by the formula (1) outside the range of 0.0001 to 0.010. These were inferior in the reduction of area in the said creep rupture test and reheat softening resistance to the inventive steels and further, they were unsatisfactory in the toughness as well.

INDUSTRIAL APPLICABILITY

[0053] The steel of the present invention is a low alloy steel usable in a high temperature range up to about 550˚C and excellent in long time creep ductility, reheat softening resistance and toughness. This steel is useful as a structural material for high temperature, high pressure operation-aimed electric power plants and the like.

Claims

1. A low alloy steel, which comprises by mass percent, C: 0.03 to 0.10%, Si: not more than 0.30%, Mn: not more than 1.0%, Cr: more than 1.5% to not more than 2.5%, Mo: 0.01 to 1.0%, V: 0.04 to 0.30%, Nb: 0.001 to 0.10%, Ti: 0.001 to 0.020%, B: 0.0001 to 0.020%, Al: 0.001 to 0.01% and Nd: 0.0001 to 0.050%, with the balance being Fe and impurities, wherein the content of P is not more than 0.020%, the content of S is not more than 0.003%, the content of N is less than 0.0050% and the content of O (oxygen) is not more than 0.0050% among the impurities, in which the value of BSO represented by the following formula (1) is 0.0001 to 0.010:

$$\mathrm{BSO} = \mathrm{B} - (11/14)\mathrm{N} - (11/32)\mathrm{S} - (11/16)\mathrm{O} \quad \cdots\cdots (1),$$

wherein each element symbol in the formula (1) represents the content (by mass %) of the element concerned.

2. A low alloy steel according to claim 1, which further contains W: not more than 2.0% by mass in lieu of part of Fe.

3. A low alloy steel according to claim 1 or 2, which further contains one or more elements selected from among Cu, Ni and Co each at a level not more than 0.50% by mass in lieu of part of Fe.

4. A low alloy steel according to any one of claims 1 to 3, which further contains one or more elements selected from among Mg: not more than 0.005% by mass, Ca: not more than 0.005% by mass, La: not more than 0.02% by mass, Ce: not more than 0.02% by mass, Y: not more than 0.05% by mass, Sm: not more than 0.05% by mass and Pr: not more than 0.05% by mass.

INTERNATIONAL SEARCH REPORT

International application No.
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A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01), *C22C38/32*(2006.01), *C22C38/54*(2006.01)

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C38/00(2006.01), *C22C38/32*(2006.01), *C22C38/54*(2006.01)

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

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 05-269590 A (Sumitomo Metal Industries, Ltd.), 19 October, 1993 (19.10.93), Claims; table 1 (Family: none)	1-4
Y	JP 2004-107719 A (Sumitomo Metal Industries, Ltd.), 08 April, 2004 (08.04.04), Claims; Par. No. [0036] (Family: none)	1-4
A	JP 09-296249 A (NKK Corp.), 18 November, 1997 (18.11.97), Claims; Par. Nos. [0023] to [0031] (Family: none)	1-4

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
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"&" document member of the same patent family

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