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(54) NON-HEAT-TREATED HOT-FORGING STEEL EXCELLENT IN TENSILE STRENGTH, FATIGUE STRENGTH AND MACHINABILITY.

(57) A non-heat-treated ferritic-bainitic steel to be used as hot-forged, wherein the following relation holds between the bainitic structure fraction f and the carbon content C(%): $1.4C + 0.4 \geqq f \geqq 1.4C$ in the metal structure after hot forging a steel material containing the following elements on the weight basis: C: 0.10~0.35 %; Si: 0.15~2.00 %; Mn: 0.40~2.00 %; S: 0.03~0.10 %; Al: 0.0005~0.05 %; Ti: 0.003~0.05 %; N: 0.0020~0.0070 %; V: 0.30~0.70 % and further containing at least one of Cr, Mo, Nb, Pb and Ca in a specified amount and cooling the forged steel to room temperature. It is possible to produce a non-heat-treated hot-forging steel having high tensile strength, fatigue strength and machinability.

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TECHNICAL FIELD

The present invention relates to a non-thermal refined steel, having excellent tensile strength, fatigue strength and machinability simultaneously, and usable as hot forged, without thermal refining process such as quench hardening and tempering after hot forging.

BACKGROUND ART

Non-thermal refined steels have been widely used for structural machine parts such as an automobile parts from the standpoint of elimination of steps and reduction of production cost.

These non-thermal refined steels have been developed mainly for their high tensile strength (or hardness), yield strength and toughness. In this regard, as disclosed in Laid-Open Japanese Patent Application No. Sho 62-205245, for example, non-thermal refined steels have been proposed that employ V, a typical precipitation strengthening element. In application of such non-thermal refined steels having high strength and toughness as machine parts, however, the real problem is the fatigue strength and machinability.

Fatigue strength is generally understood to depend on the tensile strength and increases as the tensile strength increases. However, enhancement of tensile strength makes the machinability extremely deteriorated: with a tensile strength exceeding 120 kgf/mm^2, production with normal efficiency will be impossible. There has been made thus eager demand to develop a non-thermal refined steel by improving fatigue strength without sacrificing the machinability.

For this purpose, it is an effective means to improve durability ratio that is the ratio of the fatigue strength to the tensile strength. In this connection, a process to reduce the high carbon martensite island and the retained austenite in structure is proposed, for example in Laid-Open Japanese Patent Application No.Hei 4-176842, by transforming the metallographic structure into a structure mainly composed of bainite.

However, despite such effort and other development trials the the durability ratio has been improved to 0.55 at most; and the machinability has been improved only twice or so compared with conventional type bainite non-thermal refined steels having extremely poor machinability.

Previously, the present inventors noted a structure that includes pearlite, having good machinability and made an invention relating to a non-reinforced refined steel for hot forging excellent in fatigue strength and machinability by combination of two steps to get a metallographic structure that contains fine and precipitation-enriched perlite throughout the structure, the two steps comprising: (1) first step wherein, TiN and VN are compositely precepitated on MnS to refine austenite crystal grains formed when heated for forging and the composite precipitates are utilized as nucleus generating sites for precipitating ferrite very finely; and (2) second step wherein perlite is precipitated and V carbide or V nitride is simultaneously finely precipitated in the ferrite in the precipitated pearlite. However, the non-thermal refined steel of this type has tensile strength of 100 kgf/mm^2 at best; thus there has been a limit in fatigue strength even if the durability ratio was improved.

The present invention is to provide a non-thermal refined steel for hot forging having high fatigue strength, tensile strength and machinability, which has been difficult to realize by the conventional non-thermal refining steel.

DISCLOSURE OF THE INVENTION

The easiest way to attain high fatigue strength is to enhance the tensile strength (hardness). This may be realized by introducing structures, such as martensite or bainite, that are transformed at lower temperatures; however, such methods deteriorate the machinability significantly as explained in the description of the prior art.

The present inventors have studied the fatigue characteristic and machinability for several kinds of hot forging materials that have metallographic structures containing the ferrite structure mixed with an adequate quantity of the bainite structure. As a result, a non-thermal refined steel, of ferrite-bainite type, for hot forging has been invented that improves the tensile strength and fatigue strength and also maintains the machinability allowable in the current machining practices on the basis of the following three points: (1) to use composite precipitates of MnS + TiN + VN as precipitation nuclei for the purpose of making the structure fine; (2) to make a two-phase ferrite-bainite structure that contains an adequate quantity of bainite structure with controled hardness by lowering carbon and nitrogen contents; and (3) to precipitate V carbide in the bainite structure.

The first invention of the present invention is to provide a ferrite-bainite type, non-thermal refined steel usable as hot forged, characterized by: having a composition by weight of C: 0.10 - 0.35%, Si: 0.15 - 2.00%, Mn: 0.40 - 2.00%, S: 0.03 - 0.10%, Al: 0.0005 - 0.050%, Ti: 0.003 - 0.050%, N: 0.0020 - 0.0070%, V: 0.30 - 0.70%, with the balance being Fe and impurities; and having a structure ratio f of bainite structure in the metallographic structure after cooling down to room temperature from the hot forging, the structure ratio f being, on the basis of the carbon content C (%), represented by: $1.4C + 0.4 \geqq f \geqq 1.4C$. The second invention contains, in addition to the components of the first invention steel, one or two or more elements selected from Cr: 0.02 - 1.50%, Mo: 0.02 - 1.00%, Nb: 0.001 - 0.20%, Pb: 0.05 - 0.30%, and Ca: 0.0005 - 0.010%, for the purpose of making the crystal grains finer, adjusting the ratio of bainite structure, and improving the machinability further.

Now, the reasons, according to the present invention, for limiting the chemical components in the ferrite-bainite type non-thermal refined steel are explained below together with the reasons for limiting the metallographic structure after cooling down to room temperature from the hot forging.

C: This element is important for adjusting the structure ratio of bainite structure and accordingly increases tensile strength of the final product. However, too high contents of this element increase the strength excessively and deteriorate the machinability significantly. Thus contents less than 0.10% make both tensile strength and fatigue strength too low, and the contents exceeding 0.35% make the tensile strength too high causing the machinability significantly to deteriorate. Thus, the range of 0.10 - 0.35% is specified.

Si: This element adjusts deoxidization and the ratio of bainite structure. Si contents less than 0.15% do not give enough effect; the contents exceeding 2.00% lower both durability ratio and machinability. Thus, the range of 0.15 - 2.00% is specified.

Mn: This element adjusts the ratio of bainite structure and turns to MnS that brings a base of composite precipitates giving the precipitation site for ferrite. Mn contents less than 0.40% do not give enough effect; the contents exceeding 2.00% bring too much formation of bainite causing both durability ratio and machinability to lower. Thus, the range of 0.40 - 2.00% is specified.

S: This element turns to MnS, bringing a base of composite precipitates which provides the precipition site for ferrite and improves the machinability. The specified range is 0.03 - 0.10%.

Al: This element is effective for deoxidizing and making the crystal grains finer. Its contents less than 0.0005% do not give enough effect, and the contents exceeding 0.050% form hard inclusion causing both durability ratio and machinability to lower. Thus, the range of 0.0005 - 0.050% is specified.

Ti: This element turns to a nitride precipitating on MnS forming the composite precipitates which provides the precipitation site for ferrite. Ti contents less than 0.003% do not give enough effect; the contents exceeding 0.050% promote formation of coarse hard inclusion causing both the durability ratio and machinability to lower. Thus, the range of 0.003 - 0.050% is specified.

N: This element forms nitrides and carbon nitrides with Ti and V. Its contents less than 0.0020% do not give enough effect, and the contents exceeding 0.070% cause both durability ratio and machinability to lower. Thus, the range of 0.0020 - 0.0070% is specified.

V: This element forms the composite precipitates with MnS and TiN and enforce the precipitation strengthening of matrix ferrite in bainite. Its contents less than 0.30% do not give enough effect; the contents exceeding 0.70% cause both durability ratio and machinability to lower. Thus, the range of 0.30 - 0.70% is specified.

The above are the reasons for limiting the chemical components in the steel according to the first present invention. In the second invention of the present invention, one or two or more elements selected from Cr, Mo, Pb and Ca are contained in addition to the components of the first invention steel for the purpose of making the crystal grains finer, adjusting the ratio of bainite structure, and improving the machinability further. The reasons for specifying the chemical components are explained below.

Cr: This element adjusts the ratio of bainite structure in an almost same way as Mn. Its contents less than 0.02% do not give enough effect, and the contents exceeding 1.50% bring too much formation of bainite causing both durability ratio and machinability to lower. Thus, the range of 0.02 - 1.50% is specified.

Mo: This element has effect similar to Mn and Cr. Its contents less than 0.02% do not give enough effect, and the contents exceeding 1.00% bring too much formation of bainite, causing both durability ratio and machinability to lower. Thus, the range of 0.02 - 1.00% is specified.

Nb: This element has effect similar to Mn and Cr. Its contents less than 0.001% do not give enough effect, and the contents exceeding 0.20% bring too much formation of bainite causing both durability ratio and machinability to lower. Thus, the range of 0.001 - 0.20% is specified.

Pb: This element improves the machinability. Its contents less than 0.05% do not give enough effect; the contents exceeding 0.30% saturate such effect and decrease the fatigue strength and durability ratio.

Thus, the range of 0.05 - 0.30% is specified.

Ca: This element has effect similar to Pb. Its contents less than 0.0005% do not give enough effect, and the contents exceeding 0.010% saturate such effect and decreases the fatigue strength and durability ratio. Thus, the range of 0.0005 - 0.010% is specified.

The above are the reasons for specifying the chemical components that are added in the second present invention. Now, the reason for specifing the metallographic structure after cooling down to room temperature from the hot forging is explained below.

As explained above, the two phase structure of ferrite - bainite and the contents of adequate quantity of bainite bring high tensile strength, high fatigue strength and machinability. The structure ratio of bainite can be controlled by the C content of the steel, the hardening characteristic and the cooling rate from the austinite zone. For the purpose of using the bainite structure effectively, its structure ratio f is required to be more than 1.4C where C is the carbon content (%). On the other hand, when the structure ratio f exceeds 1.4C + 0.4, the machinability deteriorates significantly. Thus, the structure ratio f of bainite is specified as 1.4C or more and 1.4C + 0.4 or less on the basis of the carbon content C (%). While the cooling method after hot forging is not limited as long as the metallographic structure containing such bainite structure, natural cooling is preferable in view of facilities and production cost as a matter of course. The structure ratio f of bainite is determined by observing an etching test piece by optical microscope or the like, and by measuring the structure hardness by a micro-Vickers hardness meter; finally the structure ratio f is determined by measuring the area percentage.

The effects of the present invention are shown more specifically by way of Examples.

BEST MODE FOR CARRYING OUT THE INVENTION

Examples

In the tables below, the conditions enclosed by the bold lines are embodying examples satisfying the present invention and the others are comparative examples.

(1) Influence of chemical components of steel product

Each steel having chemical components shown in Table 1 was melted in a high frequency furnace to make a steel ingot of 150 kg. From this ingot, a material for forging was cut out, normalized once with heating followed by allowing to cool down, heated up to 1100 - 1250 °C and subjected to hot forging at a temperature of 1050 - 1200 °C, and thereafter allowed to cool down. From the center part of this material, a JIS No. 4 tensile test piece and a JIS No. 1 rotary bending test piece were sampled and subjected to the tensile test and rotating bending fatigue test respectively. A specimen for observation by an optical microscope was etched with 5% nital, and observed with a magnification of X200 to determine the structure ratio of bainite. A specimen for machinability test was further sampled from the material, and a blind hole of 30 mm depth was bored therein by a 10 mm$^{\varnothing}$ straight shank drill made of SKH9. Total length of the boring was measured until the drill was broken with life. Machinability was evaluated by the relative total boring length supposing the total boring length of conventional No steel 1.00. The cutting speed was 50 m/min, feed speed was 0.35 mm/rev, and the cutting oil was 7 L/min.

Table 1 (Part 1)

No		C	Si	Mn	S	Al	Ti	N	V	Cr	Mo	Nb	Pb	Ca
1	Embodying Example of the first invention	0.12	1.55	1.96	0.036	0.031	0.011	0.0051	0.55	–	–	–	–	–
2	〃	0.18	1.15	1.98	0.045	0.032	0.012	0.0062	0.45	–	–	–	–	–
3	〃	0.26	0.98	1.99	0.054	0.035	0.015	0.0065	0.41	–	–	–	–	–
4	〃	0.31	0.55	1.96	0.064	0.041	0.016	0.0065	0.35	–	–	–	–	–
5	〃	0.34	0.25	1.95	0.075	0.046	0.014	0.0066	0.31	–	–	–	–	–
6	Embodying Example of the second invention	0.25	0.35	1.97	0.056	0.038	0.016	0.0056	0.42	0.35	–	–	–	–
7	〃	0.27	0.29	1.98	0.057	0.035	0.012	0.0055	0.35	–	0.21	–	–	–
8	〃	0.31	0.22	1.99	0.056	0.025	0.014	0.0057	0.35	–	–	0.031	–	–
9	〃	0.28	0.26	1.95	0.055	0.026	0.016	0.0051	0.31	0.31	0.18	–	–	–
10	〃	0.31	0.27	1.96	0.052	0.028	0.017	0.0042	0.32	0.25	–	0.025	–	–
11	〃	0.25	0.31	1.96	0.051	0.031	0.012	0.0048	0.33	–	0.15	0.021	–	–
12	〃	0.26	0.35	1.97	0.018	0.025	0.014	0.0057	0.35	0.22	0.12	0.021	–	–
13	〃	0.25	0.26	1.96	0.044	0.041	0.015	0.0056	0.31	–	–	–	0.22	–
14	〃	0.31	0.35	1.98	0.033	0.042	0.011	0.0058	0.36	–	–	–	–	0.0018
15	〃	0.27	0.20	1.95	0.035	0.043	0.013	0.0059	0.42	–	–	–	0.12	0.0014
16	〃	0.25	0.38	1.96	0.037	0.044	0.016	0.0061	0.39	0.31	–	–	0.11	–
17	〃	0.19	1.36	1.96	0.041	0.035	0.017	0.0061	0.33	0.21	0.12	–	–	0.0016
18	〃	0.29	1.12	1.97	0.046	0.038	0.014	0.0059	0.32	–	0.11	0.012	0.12	–
19	〃	0.27	0.25	1.96	0.044	0.035	0.013	0.0060	0.37	–	0.33	–	0.11	0.0013
20	〃	0.31	0.33	1.96	0.046	0.038	0.011	0.0055	0.33	0.32	–	0.011	0.11	0.0013
21	Comparative Example	0.09	0.24	1.95	0.076	0.046	0.014	0.0066	0.32	–	–	–	–	–
22	〃	0.45	0.25	1.96	0.075	0.048	0.015	0.0065	0.31	–	–	–	–	–
23	〃	0.28	0.07	1.95	0.045	0.033	0.012	0.0062	0.45	–	–	–	–	–
24	〃	0.18	2.21	1.95	0.042	0.032	0.012	0.0063	0.44	–	–	–	–	–
25	〃	0.26	0.86	0.30	0.054	0.036	0.016	0.0065	0.41	–	–	–	–	–
26	〃	0.25	0.91	2.15	0.054	0.035	0.015	0.0066	0.43	–	–	–	–	–
27	〃	0.31	0.55	1.95	0.015	0.041	0.016	0.0065	0.35	–	–	–	–	–
28	〃	0.30	0.56	1.96	0.121	0.043	0.015	0.0063	0.34	–	–	–	–	–

TABLE 1(Part 2)

No		C	Si	Mn	S	Al	Ti	N	V	Cr	Mo	Nb	Pb	Ca
29	Comparative Example	0.35	0.26	1.96	0.077	0.0002	0.013	0.0064	0.34	–	–	–	–	–
30	//	0.34	0.28	1.97	0.075	0.053	0.014	0.0066	0.38	–	–	–	–	–
31	//	0.25	0.34	1.97	0.056	0.041	0.001	0.0056	0.41	–	–	–	–	–
32	//	0.26	0.35	1.95	0.056	0.038	0.061	0.0056	0.42	–	–	–	–	–
33	//	0.28	0.31	1.95	0.057	0.036	0.013	0.0015	0.35	–	–	–	–	–
34	//	0.27	0.33	1.96	0.058	0.035	0.012	0.0078	0.35	–	–	–	–	–
35	//	0.31	0.22	1.96	0.057	0.026	0.014	0.0055	0.24	–	–	–	–	–
36	//	0.30	0.21	1.96	0.056	0.025	0.016	0.0057	0.75	–	–	–	–	–
37	//	0.30	0.29	1.95	0.052	0.028	0.015	0.0042	0.32	1.61	–	–	–	–
38	//	0.24	0.32	1.96	0.051	0.031	0.012	0.0048	0.33	–	1.15	–	–	–
39	//	0.24	0.35	1.97	0.032	0.025	0.014	0.0057	0.34	–	–	0.320	–	–
40	//	0.26	0.33	1.98	0.044	0.041	0.015	0.0055	0.31	–	–	–	0.33	–
41	//	0.28	0.34	1.96	0.033	0.042	0.011	0.0058	0.36	–	–	–	–	0.0115
42	Comparative Example: Conventional thermal refined steel	0.43	0.23	1.64	0.024	0.030	–	0.0048	–	–	–	–	–	–

Table 2 shows the structure ratio of bainite and results of performance evaluation for each sample.

At first, in contrast with No. 42 that is a thermal refined steel having the durability ratio of 0.47 and machinability of 1.00, all of the Nos. 1 through 20 that are Embodying Examples of the present invention are excellent, having the durability ratio of 0.57 or more and two or three times machinability.

No. 21, a Comparative Example, has a low tensile strength and low fatigue strength since the C content is low. No. 22, a Comparative Example, has martensite generated due to the excessive C content and does not satisfy the required range for structure ratio of bainite according to the present invention; although the tensile strength is high, the durability ratio is low compared with Embodying Examples and the machinability is also poor.

No. 23, a Comparative Example, has a low degree of deoxidation since the Si content is low, and the durability ratio is low compared with Embodying Examples. No. 24, a Comparative Example, has martensite formed due to the excessive Si content and does not satisfy the required range for structure ratio of bainite according to the present invention; the durability ratio is low compared with Embodying Examples and the machinability is also poor.

No. 25, a Comparative Example, has a low composite precipitation since the Mn content is low, and has a poor durability ratio compared with Embodying Examples. No. 26, a Comparative Example, has martensite formed due to the excessive Mn content and does not satisfy the required range for structure ratio of bainite according to the present invention; the durability ratio is low compared with Embodying Examples and the machinability is also poor.

No. 27, a Comparative Example, has a low composite inclusion since the S content is low and has a poor durability ratio compared with Embodying Examples; the machinability is also poor since the effect of MnS for improving the machinability is not realized. No. 28, a Comparative Example, has an excessive precipitates of Mns since the S content is high, and has a lower durability ratio compared with the Embodying Examples.

No. 29, a Comparative Example, has a low degree of deoxidation and a smaller effect of making crystals fine since the Al content is low, and has a lower durability ratio compared with the Embodying

Examples. No. 30, a Comparative Example, has hard inclusion formed due to the high Al content, and has a lower durability ratio compared with the Embodying Examples; the machinability is also poor.

No. 31, a Comparative Example, has a small composite precipitates as the Ti content is low, and has a lower durability ratio compared with the Embodying Examples. No. 32, a Comparative Example, has hard inclusions formed due to the high Ti content, and has a lower durability ratio compared with the Embodying Examples; the machinability is also poor.

No. 33, a Comparative Example, has small composite precipitates since the N content is low, and has a lower durability ratio compared with the Embodying Examples. No. 34, a Comparative Example, has the matrix hardened due to the high N content, and has a lower durability ratio compared with the Embodying Examples; the machinability is also poor.

No. 35, a Comparative Example, has small composite precipitates and has a smaller effect of precipitation strengthening of matrix ferrite due to the low V content; thus, the durability ratio is low compared with the Embodying Examples and the durability ratio is also poor. No. 36, a Comparative Example, has a lower durability ratio compared with the Embodying Examples due to the high V content, and the machinability is also poor.

No. 37, a Comparative Example, has martensite formed due to the excessive Cr content and does not satisfy the required range for structure ratio of bainite according to the present invention; the durability ratio is low compared with Embodying Examples and the machinability is also poor.

No. 38, a Comparative Example, has martensite formed due to excessive Mo content and does not satisfy the required range for structure ratio of bainite according to the present invention; the durability ratio is low compared with Embodying Examples and the machinability is also poor.

No. 39, a Comparative Example, has a poor durability ratio since the Nb content is high and the machinability is also poor.

No. 40, a Comparative Example, has a poor durability ratio although the machinability is good due to the high Pb content.

No. 41, a Comparative Example, has a poor durability ratio although the machinability is good due to the high Ca content.

TABLE 2 (Part 1)

No		Bainite Structure Ratio		Mechanical Property			Machineability
		Inventive Range	Observed	Tensile Strength	Fatigue Strength	Durability Ratio	
1	Embodying Example of the First Invention	0.168 ~ 0.568	0.65	123.7	73.1	0.59	2.02
2	″	0.252 ~ 0.652	0.67	116.0	68.1	0.59	2.16
3	″	0.364 ~ 0.764	0.71	117.7	69.3	0.59	2.12
4	″	0.434 ~ 0.834	0.73	109.3	63.8	0.58	2.29
5	″	0.476 ~ 0.876	0.74	103.3	60.0	0.58	2.42
6	Embodying Example of the Second Invention	0.350 ~ 0.750	0.70	109.5	64.0	0.58	2.28
7	″	0.378 ~ 0.778	0.71	100.2	58.0	0.58	2.49
8	″	0.434 ~ 0.834	0.73	102.4	59.4	0.58	2.44
9	″	0.392 ~ 0.792	0.72	104.1	60.5	0.58	2.40
10	″	0.434 ~ 0.834	0.73	106.5	62.0	0.58	2.35
11	″	0.350 ~ 0.750	0.70	97.6	56.3	0.58	2.56
12	″	0.364 ~ 0.764	0.71	104.7	60.9	0.58	2.39
13	″	0.350 ~ 0.750	0.70	95.6	55.0	0.58	2.88
14	″	0.434 ~ 0.834	0.73	105.6	61.5	0.58	2.60
15	″	0.378 ~ 0.778	0.71	100.8	58.4	0.58	2.73
16	″	0.350 ~ 0.750	0.70	107.9	62.9	0.58	2.55
17	″	0.266 ~ 0.666	0.68	119.9	70.7	0.59	2.29
18	″	0.406 ~ 0.806	0.72	119.2	70.2	0.59	2.31
19	″	0.378 ~ 0.778	0.71	99.9	57.8	0.58	2.75
20	″	0.434 ~ 0.834	0.73	109.6	64.0	0.58	2.51
21	Comparative Example	0.168 ~ 0.568	0.65	83.7	41.9	0.50	2.99
22	″	0.630 ~ 1.030	0.30	130.1	62.4	0.48	0.70
23	″	0.392 ~ 0.792	0.72	100.1	45.8	0.46	2.50
24	″	0.252 ~ 0.652	0.20	138.8	64.3	0.46	0.76
25	″	0.364 ~ 0.764	0.71	84.6	42.3	0.50	2.96
26	″	0.350 ~ 0.750	0.70	119.0	57.1	0.48	0.88
27	″	0.434 ~ 0.834	0.73	109.1	50.0	0.46	0.71

TABLE 2 (Part 2)

No		Bainite Structure Ratio		Mechanical Property			Machinability
		Inventive Range	Observed	Tensile Strength	Fatigue Strength	Durability Ratio	
28	Comparative Example	0.420~0.820	0.72	108.2	51.1	0.47	3.05
29	〃	0.490~0.890	0.75	105.9	50.1	0.47	2.36
30	〃	0.476~0.876	0.74	107.5	46.5	0.43	0.85
31	〃	0.350~0.750	0.70	102.1	50.2	0.49	2.45
32	〃	0.364~0.764	0.71	103.3	50.1	0.49	0.75
33	〃	0.392~0.792	0.72	101.0	46.7	0.46	2.47
34	〃	0.378~0.778	0.71	110.4	55.2	0.50	0.90
35	〃	0.434~0.834	0.73	96.9	43.2	0.45	2.58
36	〃	0.420~0.820	0.38	122.5	55.5	0.45	0.68
37	〃	0.420~0.820	0.35	121.5	52.4	0.43	0.75
38	〃	0.336~0.736	0.20	131.5	55.3	0.42	0.71
39	〃	0.336~0.736	0.70	98.2	48.5	0.49	0.85
40	〃	0.364~0.764	0.71	98.4	46.5	0.47	2.79
41	〃	0.392~0.792	0.72	102.3	46.1	0.45	2.69
42	〃	(QT Structure)		98.3	46.2	0.47	1.00

(2) Influence of the cooling method after the hot forging to the ratio of bainite structure

Each steel having chemical components shown in Table 1 was melted in a high frequency furnace to make a steel ingot of 150 kg. From this ingot, a material for forging was cut out, normalized once with heating at a temperature of 950°C followed by allowing to cool down, heated up to 1100 - 1250°C and subjected to hot forging at a temperature of 1050 - 1200°C, and thereafter allowed to cool down in a way as shown in Table 3. From the center part of this material, the tensile strength, fatigue strength, machinability and ratio of bainite structure were determined in the same procedures as Embodying Example 1. Table 4 shows the ratio of bainite structure and results of performance evaluation for each sample.

Nos. 45, 46, 47 and 48 are Embodying Examples satisfying the requirement for structure ratio of bainite according to the present invention, that is, the structure ratio f is, on the basis of the carbon content C (%), represented by: $1.4C + 0\ 4 \geqq f \geqq 1.4C$; all have good machinability nearly 2.5 times as high as No. 42, a conventional thermal refined steel, while the durability ratio is kept 0.55 or more.

Nos. 43 and 44, produced with a smaller cooling rate, have a smaller structure ratio of bainite; majority of the structure is ferrite or bainite + spherical cementite. Thus, the tensile strength itself is low, furthermore, the effect by the two phase structure of ferrite + bainite disappears and the durability ratio is as low as 0.54 or less; the machinability is poor compared with the Embodying Examples.

No. 49, on the other hand, has a structure mainly composed of martensite by increasing the cooling rate; while the tensile strength is enhanced, the durability ratio is extremely low and the machinability is poor with short tool life.

TABLE 3

No	Sample Steel	Cooling Method After Forging	Average Cooling Speed at 800-500 °C
43	No.20 of Table 1	Air cooled after 30min. charge into the furnace at 700 °C	ca.0.10 °C/sec.
44	"	Cooled in the furnace kept at 200 °C	ca.0.15 °C/sec.
45	"	Gradually cooled in glass wool insulating material	ca.0.30 °C/sec.
46	"	Nature cooling	ca.0.80 °C/sec.
47	"	Cooling in air blast	ca.1.40 °C/sec.
48	"	Quenching by water mist injection	ca.4.00 °C/sec.
47	"	Thrown into oil hardening bath, quench hardening	ca.30.00 °C/sec.
48	No.42 of Table 1 Control Steel:Conventional thermal refined steel	Oil hardening at 900 °C, tempering at 500 °C, then water cooling	- - -

TABLE 4

No	Sample Steel	Bainite Structure Ratio		Mechanical Property			Machineability
		Inventive Range	Observed	Tensile Strength	Fatigue Strength	Durability Ratio	
43	Comparative Example	0.434 ~ 0.834	0.10	88.5	46.5	0.53	3.11
44	"	0.434 ~ 0.834	0.33	93.4	50.5	0.54	2.94
45	Embodying Example	0.434 ~ 0.834	0.55	105.5	60.5	0.57	2.61
46	"	0.434 ~ 0.834	0.73	109.6	64.0	0.58	2.51
47	"	0.434 ~ 0.834	0.65	112.3	62.5	0.56	2.45
48	"	0.434 ~ 0.834	0.40	114.5	63.1	0.55	2.40
49	Comparative Example	0.434 ~ 0.834	0.05	125.2	64.3	0.51	1.15
50	"	(QT Structure)	0.00	98.3	46.2	0.47	1.00

As described above, the steel according to the present invention provides high tensile strength while keeping the machinability by making a ferrite-bainite two phase structure, and, further, is able to have improved durability ratio, namely fatigue strength, without sacrificing the machinability by realization of fine metallographic structure by use of composite precipitates formed by MnS, Ti nitride and V nitride and by simultaneous realization of strengthening of the ferrite matrix in bainite by V carbide (or carbon nitride); thus, a non-thermal refined steel for hot forging, which has been eagerly demanded, is now provided, satisfying both high fatigue strength with high tensile strength and machinability and bringing great industrial advantages.

Claims

1. A ferrite-bainite type non-thermal refined steel usable as hot forged, characterized by:
having a composition by weight of

C : 0.10 - 0.35%,

Si: 0.15 - 2.00%,
Mn: 0.40 - 2.00%,
S : 0.03 - 0.10%,
Al: 0.0005 - 0.050%,
Ti: 0.003 - 0.050%,
N : 0.0020 - 0.0070%,
V : 0.30 - 0.70%, and
with the balance being Fe and impurities; and having a structure ratio f of bainite structure in the metallographic structure after cooling down to room temperature from the hot forging, the structure ratio f being, on the basis of the carbon content C (%), represented by:

$$1.4C + 0.4 \geqq f \geqq 1.4C.$$

2. A ferrite-bainite type non-thermal refined steel usable as hot forged according to CLAIM 1 characterized by: further containing one or two or more elements selected from
Cr: 0.02 - 1.50%,
Mo: 0.02 - 1.00%,
Nb: 0.001 - 0.20%,
Pb: 0.05 - 0.30%, and
Ca: 0.0005 - 0.010%.

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP94/01693

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl[6] C22C38/14, 38/28, 38/60

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int. Cl[5] C22C38/00-38/60

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

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, A, 4-210449 (Toa Steel K.K.), July 31, 1992 (31. 07. 92), Tables 1, 2, lines 2 to 24, column 1, page 2, (Family: none)	1, 2
A	JP, A, 61-261464 (Daido Steel Co., Ltd.), November 19, 1986 (19. 11. 86), Page 1, line 6, upper left column, page 2, page 5, (Family: none)	1, 2
A	JP, A, 61-104049 (Daido Steel Co., Ltd.), May 22, 1986 (22. 05. 86), Lower left column to line 14, lower right column, page 1, (Family: none)	1, 2

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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
December 12, 1994 (12. 12. 94)	January 10, 1995 (10. 01. 95)
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Facsimile No.	Telephone No.