(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 602 742 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
07.12.2005 Bulletin 2005/49

(51) Int Cl.7: **C22C 38/46**, C22C 38/44, C21D 9/30

(21) Application number: **05011252.3**

(22) Date of filing: **24.05.2005**

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

(30) Priority: **01.06.2004 JP 2004163638**

(71) Applicant: **KABUSHIKI KAISHA KOBE SEIKO SHO**
Kobe-shi, Hyogo 651-8585 (JP)

(72) Inventors:
- **Fukaya, Shogo**
Takasago-shi Hyogo 676-8670 (JP)
- **Kagawa, Yasunori**
Takasago-shi Hyogo 676-8670 (JP)
- **Fujitsuna, Nobuyuki**
Takasago-shi Hyogo 676-8670 (JP)

(74) Representative: **Müller-Boré & Partner**
Patentanwälte
Grafinger Strasse 2
81671 München (DE)

(54) High-strength steel for large-scaled forging, and crankshaft

(57) A high-strength steel for a large-scaled forging consists essentially of, by mass, C: 0.30 to 0.50 %, Si: more than 0.15 %, but not more than 0.40 %, Mn: 0.80 to 1.20 %, Ni: 0.80 to 2.5 %, Cr: 1.0 to 3.0 %, Mo: 0.35 to 0.70 %, V: 0.10 to 0.25 %, and balance: Fe and unavoidable impurities. The high-strength steel is low in cost as compared to 3.5NiCrMo steel proposed as high-strength Ni-Cr-Mo steel for large forgings such as a rotor shaft of a generator, and has excellent strength and toughness as compared to 34CrNiMo6.

Printed by Jouve, 75001 PARIS (FR)

Description

[0001] The present invention relates to high-strength steels for large-scaled forgings, such as for manufacturing an integrated type of forged steel assembled large-scaled crankshaft, which is suitable for use in a diesel engine or the like used in a ship or generator, and to crankshafts using the same. More particularly, the invention relates to a high-strength steel for a large-scaled forging with the small content of Ni, which is an expensive alloying element, and having high strength at low cost, and to a large-scaled crankshaft which exhibits such properties.

[0002] To improve outputs from diesel engines of ships or generators, and to achieve downsizing of these engines, it is required to strengthen steels, which is to be used for components thereof. Such components are generally produced by forged steels. This kind of steel for crankshafts has the maximum tensile strength of about 950 N/mm^2, while steels for crankshafts having the strength of 1000 N/mm^2 or more are required in order to meet such a requirement.

[0003] As the steel for large-scaled forgings with the strength of 1000 N/mm^2 or more, 3.5NiCrMo steel or the like is known which is used in rotors (see, for example, "Tetsu to Hagane", vol. 89 (2003) No. 6) . This steel has the most excellent strength, toughness, and the like, and is used as a rotor (rotating shaft) for a generator which is put under high load.

[0004] The above type of steel, however, contains the large amount of Ni, which is very expensive, as an alloying element for strengthening and toughing the steel, and is preferably subjected to a two-stage tempering process to ensure toughness, or to a specific prehardening process to minimize the grain size, resulting in a problem of high cost.

[0005] On the other hand, Cr-Mo steels, notably 34CrNiMo6 as defined in a DIN specification, 32CrMo12 as defined in the same, 42CrMo4 as defined in an ISO specification, have been hitherto used as steels for large-scaled crankshafts, which are used for parts of an engine and a transmission mechanism in the ships or the like. These types of steels have the advantage of relatively low cost because they have less content of Ni compared to the above-mentioned 3.5NiCrMo steel. In fact, however, these steels do not meet the recent requirements in terms of strength and toughness, as compared to the above type of steel.

[0006] The present invention has been accomplished in view of the above-mentioned problems, and it is an object of the invention to provide a high-strength steel for a large-scaled forging which is low in cost as compared to the 3. SNiCrMo steel proposed as the steel for the high-strength Ni-Cr-Mo steel, and which has excellent strength and toughness as compared to the 34CrNiMo6 as defined in the DIN specification which has been put to practical use. Alternatively, it is an object of the invention to provide a low-cost large-scaled crankshaft with excellent strength and toughness, utilizing the same.

[0007] A high-strength steel for a large-scaled forging according to the invention, which has solved the above-mentioned problems, has the principle that the steel consists essentially of, by mass, (the contents of the following components being expressed in mass % in the same manner) C: 0.30 to 0.50 %, Si: more than 0.15 %, but not more than 0.40 %, Mn: 0.80 to 1.20 %, Ni: 0.80 to 2.5 %, Cr: 1.0 to 3.0%, Mo: 0.35 to 0.70 %, V: 0.10 to 0.25%, and balance: Fe and unavoidable impurities.

[0008] In the high-strength steel for a large-scaled forging of the invention, a grain size in a metal structure of the steel is preferably an ASTM grain size number ranging from 2 to 6. Further, the high-strength steel for a large-scaled forging of the invention is preferably produced by quenching under 200 °C from austenitizing-temperature and then tempering.

[0009] By forging the above-mentioned high strength steel for a large-scaled forging, a large-scaled crankshaft with desired properties is obtained. Such a crankshaft is useful as a crankshaft for a diesel engine used in a ship or generator.

[0010] In the high-strength steel for a large-scaled forging according to the invention, the Ni content is reduced as compared to that of the 3.5NiCrMo steel which has been proposed as steel for a high-strength Ni-Cr-Mo forging, leading to reduction in cost, while predetermined contents of Si, Mn, Cr, and the like are contained therein, enhancing the strength. Thus, the invention can provide the steel for forgings of high quality at low cost. Further, this steel for forgings has very excellent hardenability (quenching ability). That is, this steel has an excellent property that the microstructure can be controlled to that consisting only of bainite and martensite. Using the excellent hardenability, the steel can be effectively utilized as material for large-scaled forged products. In particular, the steel is extremely useful as material for large-scaled crankshafts, including a crankshaft for a diesel engine used in a ship or generator.

Fig.1 is a graph showing a relation between an absorbed energy at the strength of 1000 N/mm^2, into which the determined absorbed energy is converted, and the Ni content.

Fig.2 is a graph showing a relation between the Ni content and the grain size number.

Fig. 3 is a graph showing a relation between the tempering start temperature and the tensile strength TS.

Fig. 4 is a graph showing a relation between the tempering start temperature and the impact value (absorbed energy).

[0011] Under these problems, the inventors have been dedicated themselves to studying the development of steel for a forging in which the amount of Ni contained as an alloying element is reduced as compared to, in particular, 3.5NiCrMo steel known as the high-strength steel for forgings, leading to reduction in cost, and further which has the strength and toughness equivalent to those of the known steel, while being capable of exhibiting excellent hardenability, which is important in manufacturing the large-scaled high-strength forgings.

[0012] As a result, the inventors have found that the amount of Ni serving as a strengthening element in the above-mentioned steel for Ni-Cr-Mo based steels should be reduced as much as possible, while the elements including Si, Mn, Cr, and the like, should be added in appropriate amounts, thereby providing the steel for forgings with extremely excellent hardenability and with the improved strength and toughness to compensate for the shortage of strength caused by the decreased Ni amount, so that the invention has been accomplished.

[0013] That is, Ni is a very useful element for enhancing the strength and toughness of the Cr-Mo based steel, which has been used as the steel for forgings for multipurpose applications as mentioned above, and for improving the hardenability. For this reason, the Ni is the extremely useful element to the high-class Cr-Mo based steel for forging. However, since the Ni is the expensive element, an excessive increase in the Ni content would lead to an increase in cost of the steel, whereby the consumer' s requirements regarding prices cannot be satisfied. Accordingly, the invention has been developed to achieve the following most important aims: to reduce the Ni content as much as possible, and to be capable of ensuring the strength and quenching properties equivalent to those of the conventional steel for Ni-Cr-Mo based steels. In order to accomplish the object of reducing cost by decreasing the amount of Ni, the Ni content is desirably reduced to not more than 2.5 %.

[0014] The steel for forgings according to the invention is characterized by that the Ni content is restricted as mentioned above, and that instead the alloying elements including Si, Mn, Cr, and the like are added in appropriate amounts. The reasons for restriction of a chemical component composition defined by the invention, including the above-mentioned elements, are as follows:

<u>C: 0.30 to 0.50 %</u>

[0015] C is an element contributing to enhancement of the hardenability and improvement of the strength. To ensure enough strength and hardenability, the C needs to be contained in an amount of 0. 30 % or more. The excessive C content, however, extremely decreases the toughness, while enhancing formation of an inverse V-segregation in a large-scaled ingot. Accordingly, the C content is preferably reduced to not more than 0.50 %.

<u>Si: more than 0.15 %, but not more than 0.40 %</u>

[0016] The element Si acts as a strength improving element, and needs to be contained in an amount exceeding 0.15 % in order to ensure enough strength. The excessive amount of Si, however, results in formation of the significant inverse V-segregation, making it difficult to obtain clean ingots. Accordingly, the Si content should be not more than 0.40 %.

<u>Mn: 0.80 to 1.20 %</u>

[0017] The element Mn is an element contributing to enhancement of the hardenability and improvement of the strength. To ensure enough strength and hardenability, the Mn needs to be contained in an amount of 0.80 % or more. The excessive Mn content, however, enhances the tempering embrittlement. Accordingly, the Mn content needs to be not more than 1.20 %.

<u>Cr: 1.0 to 3.0 %</u>

[0018] The element Cr is an element which is useful for enhancement of the hardenability and improvement of the toughness. To sufficiently exhibit these effects, the Cr needs to be contained in an amount of 1.0% or more. The excessive Cr content, however, forms inhomogeneous solidification, making it difficult to manufacture the clean steel. Accordingly, the Cr content needs to be not more than 3.0 %.

<u>Mo: 0.35 to 0.70 %</u>

[0019] The element Mo is an element which effectively acts to improve all of the hardenability, strength, and toughness. To sufficiently exhibit these effects, the Mo needs to be contained in an amount of 0.35 % or more. If the Mo content is less than the above-mentioned amount, the inverse V-segregation is formed, which is not desirable. In contrast, since the excessive Mo content promotes micro-segregation in the ingots, and the Mo is a heavy element, gravity segregation tends to occur. Accordingly, the Mo content needs to be not more than 0.70 %.

V: 0.10 to 0.25 %

[0020] The element V is an element which effectively acts to improve the hardenability and strength even in a small amount. To exhibit these effects, the V needs to be contained in an amount of 0.10% or more. However, since the element V has a low equilibrium distribution coefficient, the excessive V content tends to cause the micro-segregation (normal segregation). Accordingly, the V content needs to be not more than 0.25 %.

[0021] In the steel for forgings used in the invention, preferable basic components are as mentioned above. The balance consists essentially of Fe, but the minute amounts of unavoidable impurities (including, for example, P, O, N, Al, or the like) may be allowed to be contained in the steels. It should be noted that the steel for forgings positively containing another element within a range that does not adversely affect the effects of the invention can be employed. The other elements that are allowed to be included in the steel are, for example, Ti, Ca, Mg, S, and the like. From a viewpoint of prevention of formation of rough inclusions, these elements are desirably reduced to not more than about 0.5 % in total.

[0022] It is well known that minimizing the grain size improves the toughness of the steel material. To minimize the grain size, it is necessary to perform an austenitizing process as a precondition. That is, the austenitizing process is carried out for fining and uniforming the grain size, preceding the quenching. In the austenitizing process of the large-scaled forging, a holding time becomes long so that austenite transformation can take place inside the steel. Thus, the larger the product, the larger the difference in grain size between inside and outside tends to be, where a special process, such as multi-stage, namely, two or more stage, austenitizing process is often carried out to minimize the grain size.

[0023] On the other hand, it is well known that inclusion of the element Ni is effective in improving the toughness of the steel. The excessive Ni content, however, tends to increase the grain size, and austenite tends to remain in quenching. If the large amount of remaining austenite exists in quenching, then it is transformed into martensite in tempering, resulting in a hard and brittle structure mixed in, thus leading to deterioration in the toughness. This needs to temper again the martensite which has already been produced in the first tempering process, in a case where the certain toughness is strictly required. This is why the two-stage tempering process is often carried out.

[0024] From this viewpoint, the inventors have fully considered aiming for development of the steel which can ensure enough toughness even in coarse grains, and which suppresses the formation of the remaining austenite in quenching, without needing the special process, such as the two-stage tempering process, for the purpose of ensuring the toughness. As a result, it has been clearly found that the high-strength steel for forgings with the above chemical composition ensures enough toughness even in the metal structure having the grain size of the ASTM grain size No.6 or less, and has only to be subjected to only one-time tempering process. Note that the steel with the ASTM grain size number less than two, the grain size is significantly increased, resulting in degradation in toughness of the forged steel. Accordingly, the ASTM grain size number is preferably at least two.

[0025] A crankshaft for a diesel engine used in a ship or generator has a journal diameter of at least about 150 mm, which is extremely large as compared to that of the vehicle (for example, about 15 mm). Since water quenching leads to a danger of cracking and breaking down in manufacturing the large-scaled forging, quenching of the large-scaled crankshaft is generally performed by oil quenching, polymer quenching, air cooling or the like. In manufacturing the large-scaled crankshaft of interest in the invention, although cooling rate in the quenching depends on a diameter of the crankshaft, it is not more than 50 °C/min in the oil quenching. More specifically, for a crankshaft with a diameter of 500 mm grade, the cooling rate is about 20 °C/min. For a crankshaft with a larger diameter than this (for example, 1000 mm), the cooling rate is much lower.

[0026] To obtain the high-strength steel for large-scaled forgings with both excellent strength and toughness, the microstructure is preferably controlled to consist of bainite and martensite. As a result of studying a condition in which such a structure is achieved even at the quenching cooling rate of about 20 °C/min (in the case of oil quenching) so as to apply the steel to the large-scaled crankshaft with a diameter of 150 mm or more, the inventors have found out the aforesaid chemical composition.

[0027] Note that since, for a crankshaft with a much larger diameter, the desired cooling rate (20 °C/min) in the oil quenching is not often reached, the above "polymer quenching" is recommended to be carried out in this case. This polymer quenching involves cooling the steel by use of cooling solution which is produced by dissolving organic solvent, such as glycols (for example, diethylene glycol, polyethylene glycol, or the like), into water. Such polymer quenching is capable of achieving cooling rate higher than that in the oil quenching. Therefore, the polymer quenching is a cooling system useful for prevention of cracks, which might occur in the water quenching, and for achieving the higher cooling rate, for example, the cooling rate of more than 20 °C/min for the relatively large-scaled forgings.

[0028] In the quenching, preferably, the austenitized steel is subjected to quenching to under 200 °C, and then tempering from a viewpoint of completion of the transformation. If the quenching temperature (namely, tempering start temperature) exceeds 200 °C, partially austenite remains without transformation to bainite and martensite, which causes variations in properties.

[0029] A method of manufacturing the steel for the forging according to the invention is not particularly limited. The steel has only to be adjusted to predetermined chemical compositions, and then to be cast using a high-frequency melting furnace, an electric furnace, a converter, or the like in a normal manner. Performing a vacuum process after adjustment of the compositions is also effective. In the case of the steel for the large-scaled forging, ingot casting is mainly employed, while, in the case of the relatively small-scaled forging, a continuous casting method can be employed.

[0030] Further, a method of manufacturing, for example, a crankshaft or the like, using the steel for forgings, is not particularly limited. For example, the method may comprise the following steps of: melting steel with a predetermined composition in the electric furnace; removing an impurity element, such as S, and a gas component, such as O, by vacuum refining; ingot-making; forging to a bar after heating the ingot; heating the forged bar after an intermediate inspection and forging it into a shape of a crankshaft; performing heat treatment for obtaining required properties such as quench-hardening and tempering; and finish machining, wherein these steps are carried out in this order.

[0031] It should be noted that a free forging method (which involves forging a crank arm and a crank pin into one block, and finishing the forged block into the crankshaft shape by gas cutting and machining), and RR and TR forging methods (which involves performing forge processing in such a manner that the center axis of an ingot is aligned with a center axis of a crankshaft) are exemplified as a forge processing method for forging the material into the crankshaft. Inparticular, the latter is more preferable because high cleanness level without segregation can be obtained in the near surface region where high stress is loaded in operation, easily obtaining the crankshaft with excellent strength and fatigue property. The thus-obtained crankshaft is very useful as a crankshaft for a diesel engine used in a ship or generator.

[0032] Now, the effects and advantages of the invention will be hereinafter described more specifically by way of examples. It is understood that the invention is not to be limited to the following specific examples, and that various appropriate modifications can be devised and carried out within the applicable scope of the invention mentioned above and below, and are intended to be included in the technical scope of the invention.

[Example]

Example 1

[0033] Steels with chemical compositions given in the following Table 1 were melted using a high-frequency melting furnace, and then cast into ingots (40 kg) each having a diameter of 132 to 158 mm and a length of 323 mm. A feederhead part of each of the obtained ingots was cut off, and then the ingot was heated at 1230 °C for five to ten hours. Thereafter, the ingot was pressed into one second in height using an open-die forging press, and stretched to 90 mm x 90 mm x 600 mm after changing the forging direction to the transversal direction against the center line of the ingot. The thus-obtained billet was cooled in air.

[Table 1]

[0034] After the steel was cooled to room temperature, a quenching process was carried out which simulated respective heating and cooling rates at a point located 50 mm (which is one tenth of the diameter) below the surface of the crankshaft having the diameter of 500 mm. More specifically, the steel was heated up to 870 °C at a rate of temperature increase of 40 °C/hr using a small-scaled simulate furnace, and kept at the temperature for one hour. (austenitizing process) Then, the steel was cooled at an average cooling rate of 20 °C/min to a temperature ranging from 500 to 870 °C to perform a quenching process. A tempering process was carried out at a temperature ranging from 580 to 630 °C for 13 hours, and cooling was performed by furnace cooling. Thereafter, mechanical properties of each of the thus-obtained steels were evaluated in the following manner. The grain size of the steel was measured based on the ASTM (grain size number).

[Measurement Method of Mechanical Properties]

[0035]

(A) Tensile tests were performed for each of the steels based on JIS Z2241, wherein the shape of a test piece, which is the JIS Z2201 No.14 specimen, is $\Phi 6 \times$ G.30. The mechanical properties [yield stress (YS), tensile stress (TS), elongation (EL), reduction of area (RA)] of the steel were measured.

(B) A Charpy impact test was performed for the type of steel with a tensile strength TS of not less than 1000 N/mm^2 . The Charpy impact test was carried out based on JIS Z2242 to measure its absorbed energy vE, wherein the shape of a test piece employed is 2 mm V-notch based on JIS Z2202. In order to evaluate toughness at the same strength, the absorbed energy vEat (1000 N/mm^2) at the strength of 1000 N/mm^2 was calculated by the following calculation method to evaluate the toughness.

[0036] The absorbed energies at tempering temperatures which brought about the strength of around 1000 N/mm^2 are designated as Eu and Ed, and the respective tensile strengths as Su and Sd.

Eu: Absorbed energy at an tempering temperature (Td) at which the strength of not less than 1000 N/mm^2 was obtained
Su: Tensile strength on the above condition
Ed: Absorbed energy at an tempering temperature (Td) at which the strength of not more than 1000 N/mm^2 was obtained
Sd: Tensile strength on the above condition

$$\text{vEat}\ (1000\ \text{N/mm}^2)$$

$$= Eu + (Ed - Eu) / (Su - Sd) \times (Su - 1000)$$

[0037] These results were given in the following Table 2, together with the quenching and tempering temperatures. From the results, the following can be shown. First, it has shown that in samples of tests No.1 to 3, 13, and 14, any of chemical components thereof deviates from a range specified by the invention, and that the tensile strength TS of each of these samples does not reach 1000 N/mm^2 (unachievable strength).

[0038] In contrast, it has shown that samples of tests No. 4 to 12, which meet the range specified by the invention, have the tensile strength of not less than 1000 N/mm^2. Moreover, it has found that a Charpy absorbed energy of each of these samples vE tends to depend on the Ni content.

[0039] Note that, after the austenitizing, quenching and tempering processes, a cross section of each sample was etched by natal, and then two or more views thereof were photographed by an optical microscope with a magnification of 100 times. From the photographs, area fractions of respective areas classified into ferrite and pearlite were determined to examine the metal structure of each sample. It has found that the area fractions of ferrite and pearlite in each sample are substantially zero, and the structure thereof consists essentially of bainite and martensite.

[Table 2]

[0040] Based on such results, a relation between an absorbed energy at the strength of 1000 N/mm^2, into which the determined absorbed energy is converted, and the Ni content is shown in Fig.1. Further, a relation between the Ni content and the grain size number is shown in Fig.2. Fig.1 shows clearly that the steel with the Ni content of not less than 0.80 % and not more than 2.5 % has good impact property. It is generally known that increase in the Ni content improves the toughness of the steel. That is, it has shown that the effect of Ni is not exhibited markedly until the Ni content reaches 0.80 % or more. In contrast, it has shown that when the Ni content is more than 2.5 %, the toughness is lowered. This indicates, as shown in Fig.2, that the grain size increases with increase in the Ni content, and that such increase in the grain size lowers the toughness. Further, as can be seen from Figs. 1 and 2, the steel with the grain size number of two or more can ensure the good toughness. In a steel for forging in general, toughness improves monotonously as Ni content increases. However, in a combination of a composition and conditions of heat treatment, a suitable range of Ni content exists so as to maintain high toughness, as shown in this example. And the upper limit of the range of Ni content 2.5% equals by chance the aforementioned upper limit of Ni content to be considered in terms of cost.

<u>Example 2</u>

[0041] Generally, in manufacturing a large-scaled forging, the steel is cooled not to room temperature, but to a temperature ranging from 200 to 300 °C, and then a tempering process is successively carried out, from a viewpoint of preventing cracking, which might be caused by deforming and thermal stresses in the quenching and tempering processes.

[0042] From this viewpoint, in the samples of the tests No. 1 and 9 as shown in Table 2 (the steels of the types A and I as shown in Table 1), influences of the tempering start temperature (quenching end temperature) on the mechanical properties [tensile strength (TS), 0.2 % proof strength (0.2PS), elongation (EL), reduction of area (RA), absorbed energy (vE)] were examined (other conditions being the same as those of the inventive examples). The results are shown in the following Table 3. Further, based on the results, a relation between the tempering start temperature and the tensile strength TS is shown in Fig. 3, and a relation between the tempering start temperature and the impact value (absorbed energy) is shown in Fig.4.

[Table 3]

[0043] From these results, the following can be shown. In the sample of the test No.1, the tempering start temperature does not have so much influence on the mechanical properties, while in the sample of the test No.9, the tempering start temperature has significant influence on the properties. Such results have shown that setting the tempering start temperature (quenching end temperature) to not more than 200 °C can ensure the stabilized strength without degradation in toughness.
[0044] A cause of the influence of the tempering start temperature on the tensile strength in the chemical compositions specified by the invention is not clearly known, but it is considered that the chemical compositions limited within a range specified by the invention form a partial martensitic structure, and not a complete bainitic structure, and that the tempering start temperature has the influence on formation of such a transformed structure.

Table 1

Type of steel	Chemical composition (mass %)										
	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V	Al
A	0.35	0.24	0.62	0.004	0.003	0.03	1.51	1.49	0.22	0.081	0.003
B	0.28	0.23	1.05	0.005	0.003	0.03	1.52	2.03	0.52	0.21	0.004
C	0.38	0.26	0.77	0.003	0.003	0.03	1.54	2.03	0.53	0.19	0.006
D	0.36	0.22	0.99	0.005	0.003	0.03	0.22	2.92	0.47	0.1	0.005
E	0.36	0.24	0.94	0.005	0.003	0.03	3.05	0.21	0.49	0.11	0.026
F	0.36	0.23	0.98	0.005	0.003	0.03	1.63	1.58	0.48	0.11	0.022
G	0.39	0.2	0.94	0.008	0.003	0.04	0.52	2.9	0.48	0.15	0.018
H	0.38	0.21	1.02	0.008	0.003	0.05	0.82	2.8	0.47	0.16	0.030
I	0.34	0.22	0.98	0.007	0.003	0.04	1.58	1.59	0.49	0.16	0.020
J	0.36	0.25	1.03	0.006	0.003	0.05	2.01	1.55	0.48	0.17	0.022
K	0.37	0.23	0.99	0.007	0.003	0.04	2.41	1.62	0.51	0.17	0.023
L	0.34	0.22	0.97	0.007	0.003	0.04	2.98	1.6	0,49	0.11	0.023
M	0.39	0.2	0.94	0.008	0.003	0.04	0.52	2.9	0.27	0.15	0.018
N	0.39	0.2	0.94	0.008	0.003	0.04	0.52	2.9	0.48	0.88	0.018

Table 2

Test No.	Type of steel	Quenching temperature	Tempering temperature	Grain size No.	YS (N/mm^2)	TS (N/mm^2)	EL (%)	RA (%)	vE Ave.	vE at (1000N/ mm^2)	Remarks
1	A	870	590	5	885	988	17.8	65.1	Unadvevable strength		Conventional steel 34CrNiMo6
			610	5	804	948	18.6	65.7			
			630	5	718	873	19.9	69.4			
2	B	870	590	3.3	829	982	17.1	63.6	Unachievable strength		Influence of C
			610	3.3	769	917	20	70.2			
			630	3.3	709	860	20.5	71.1			
3	C	870	590	3.9	817	992	17.7	65.9	Unachievable strength		Influence of Mn
			610	3.9	720	886	20.1	70.6			
			630	3.9	683	853	19.9	70.8			
4	D	870	580	6.2	959	1122	16.9	61.8	22.5	40.5	Influences of Ni and Cr
			600	6.2	840	987	16.6	65.9	42.4		
			620	6.2	776	923	19.5	70.3	82.1		
5	E	870	580	1.15	986	1122	17.6	58.6	21.7	39.0	Ni,Cr
			600	1.15	939	1067	17.3	58.7	23.1		
			620	1.15	898	1016	17.9	61.4	35.2		
6	F	870	580	2.6	1048	1190	16.3	59.3	20.4	87.3	-
			600	2.6	915	1060	16.9	61.1	57.6		
			620	2.6	848	998	19.3	65.6	86.3		
7	G	870	580	5.15	976	1133	14.8	60.7	31.5	66.7	-
			600	5.15	874	1033	17.1	63.4	62.3		
			620	5.15	741	897	21.1	69.5	83.3		

Table 2 (continued)

Test No.	Type of steel	Quenching temperature	Tempering temperature	Grain size No.	YS (N/mm^2)	TS (N/mm^2)	EL (%)	RA (%)	vE Ave.	vE at ($1000N/mm^2$)	Remarks
8	H	870	580	4.05	994	1138	15.4	59.5	36.7	86.4	-
			600	4.05	877	1041	17.7	64.5	78.7		
			620	4.05	740	901	19.3	68.9	105		
9	I	870	580	4.1	1083	1214	16.9	60.4	25.7	103.1	-
			600	4.1	988	1111	17	61.7	79.7		
			620	4.1	860	986	19.9	66.1	106		
10	J	870	580	2.8	984	1103	15.4	59.5	33.4	86.6	-
			600	2.8	867	1061	17.7	64.5	70.7		
			620	2.8	733	931	19.3	68.9	105		
11	K	870	580	2.4	989	1152	15.4	59.5	28.7	76.2	-
			600	2.4	876	1053	17.7	64.5	64.7		
			620	24	743	923	19.3	68.9	93		
12	L	870	580	1.5	1106	1218	15.4	50.6	19	45.0	Influence of Ni
			600	1.5	1001	1125	16.5	57.7	27.3		
			620	1.5	861	998	19.2	62.7	45.3		
13	M	870	580	7.85	976	993	14.8	60.7	Unachievable strength		Influence of Mo
			600	7.85	874	936	17.1	63.4			
			620	7.85	741	897	21.1	69.5			
14	N	870	580	7.85	976	975	14.8	60.7	Unachievable strength		Influence of V
			600	7.85	874	923	17.1	63.4			
			620	7.85	741	885	21.1	69.5			

Table 3

No.	Cooling rate (°C/min)	Tempering start temperature (°C)	TS (N/mm^2)			0.2%PS (N/mm^2)			EL (%)			RA (%)			vE (J)					
			1	2	ave.	1	2	ave.	1	2	ave.	1	2	ave.	1	2	3	4	5	ave.
1 34CrNi Mo6)	21.4	100	991	992	992	853	856	855	17.9	18.4	18.2	65.9	66.2	66.1	41	38	34	48	58	44
		200	995	995	995	864	864	864	17.9	17.7	17.8	66.4	66.5	66.5	51	41	31	43	51	43
		250	988	988	988	849	852	851	18.3	18.1	18.2	65.4	66.0	65.7	38	46	43	48	48	45
9	21.4	23	1111		1111	988		988	17.0		17.0	61.7		61.7	88	85	66	-	-	80
		100	1082	1094	1088	960	968	964	16.8	14.9	15.9	55.6	49.6	52.6	80	69	77	-	-	75
		150	1072	1067	1070	950	944	947	17.4	16.1	16.8	58.8	58.6	58.7	85	91	56	-	-	77
		200	1061	1053	1057	937	935	936	17.0	16.8	16.9	61.0	58.4	59.7	77	78	77	-	-	77
		250	1060	1050	1055	937	935	936	17.6	17.7	17.7	61.6	61.8	61.7	82	85	84	-	-	84

Claims

1. A steel for a forging, consisting essentially of, by mass, (the contents of the following components being expressed in mass % in the same manner)

   C: 0.30 to 0.50 %,
   Si: more than 0.15 %, but not more than 0.40 %,
   Mn: 0.80 to 1.20 %,
   Ni: 0.80 to 2.5 %,
   Cr: 1.0 to 3.0 %,
   Mo: 0.35 to 0.70 %,
   V: 0.10 to 0.25 %, and
   balance: Fe and unavoidable impurities.

2. A crankshaft obtained by forging the steel for a forging according to claim 1.

3. The crankshaft according to claim 2, wherein the crankshaft is a crankshaft for a diesel engine used in a ship or generator,

4. The crankshaft according to claim 2 or 3, wherein a grain size of a metal structure of the steel is an ASTM grain size number ranging from 2 to 6.

5. The crankshaft according to claim 2, 3 or 4 wherein the crankshaft is produced by quenching after austenitizing steel material under 200 °C, and then tempering the material.

FIG.1

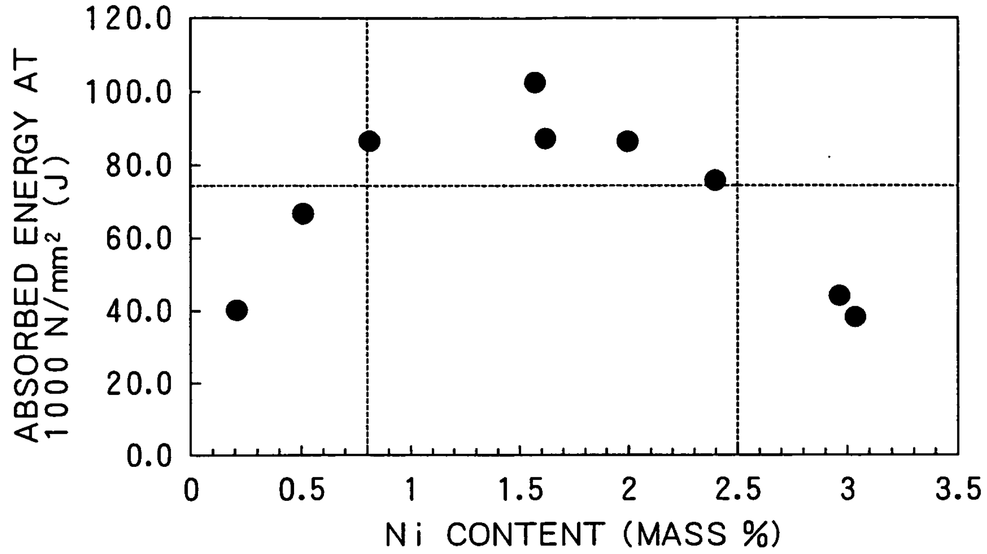

120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
0.5
1
1.5
2
2.5
3
3.5
ABSORBED ENERGY AT 1000 N/mm² (J)
Ni CONTENT (MASS %)

FIG.2

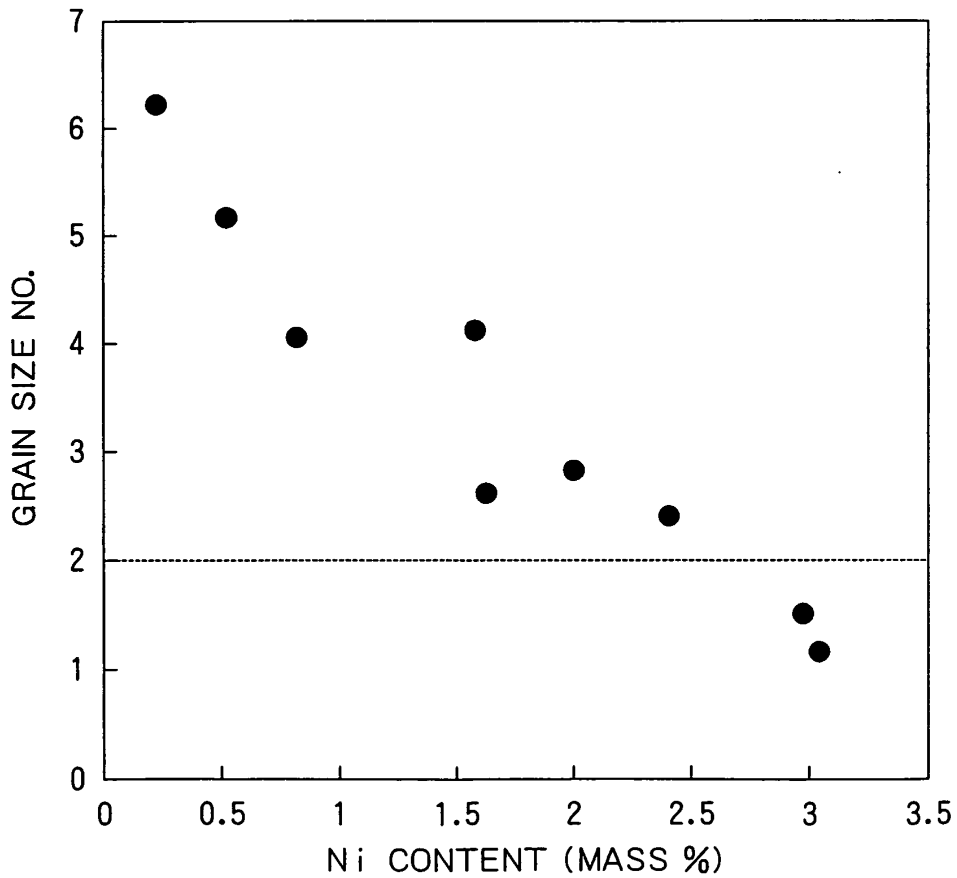

7
6
5
4
3
2
1
0
0
0.5
1
1.5
2
2.5
3
3.5
GRAIN SIZE NO.
Ni CONTENT (MASS %)

FIG.3

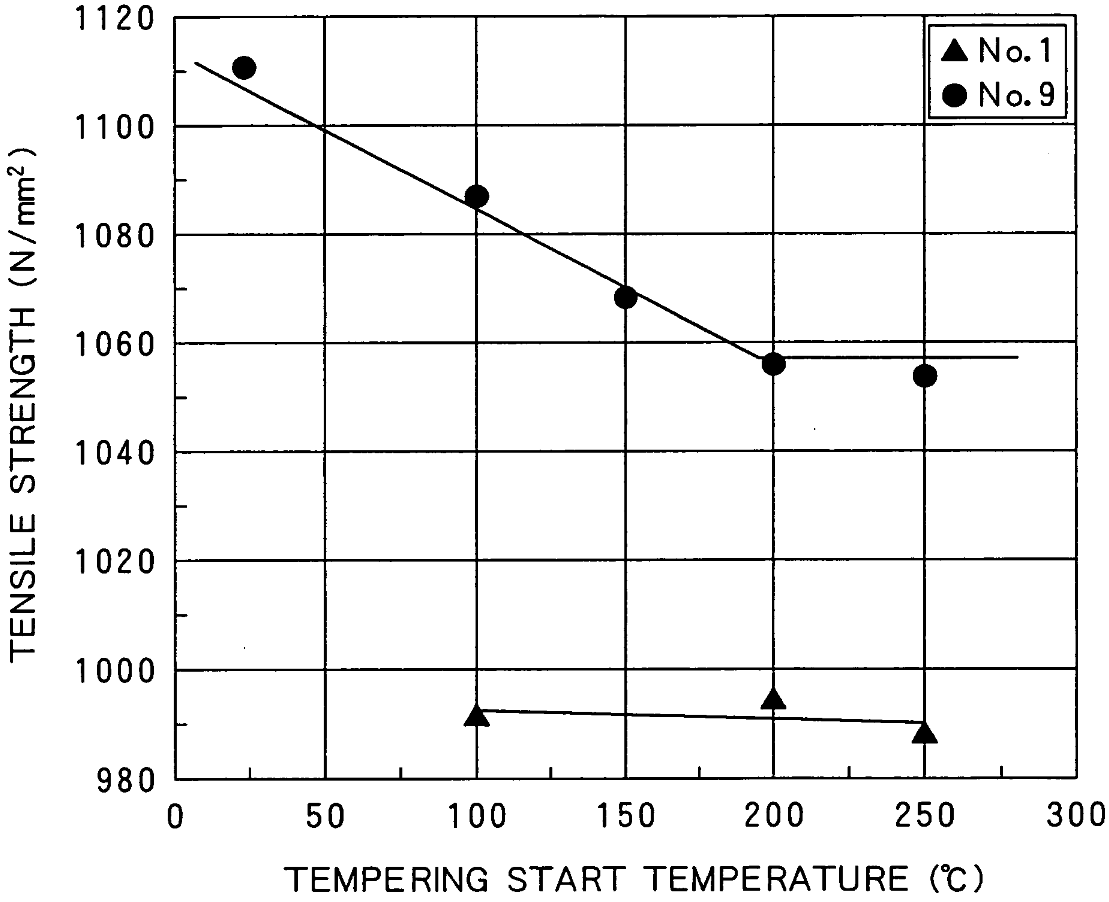
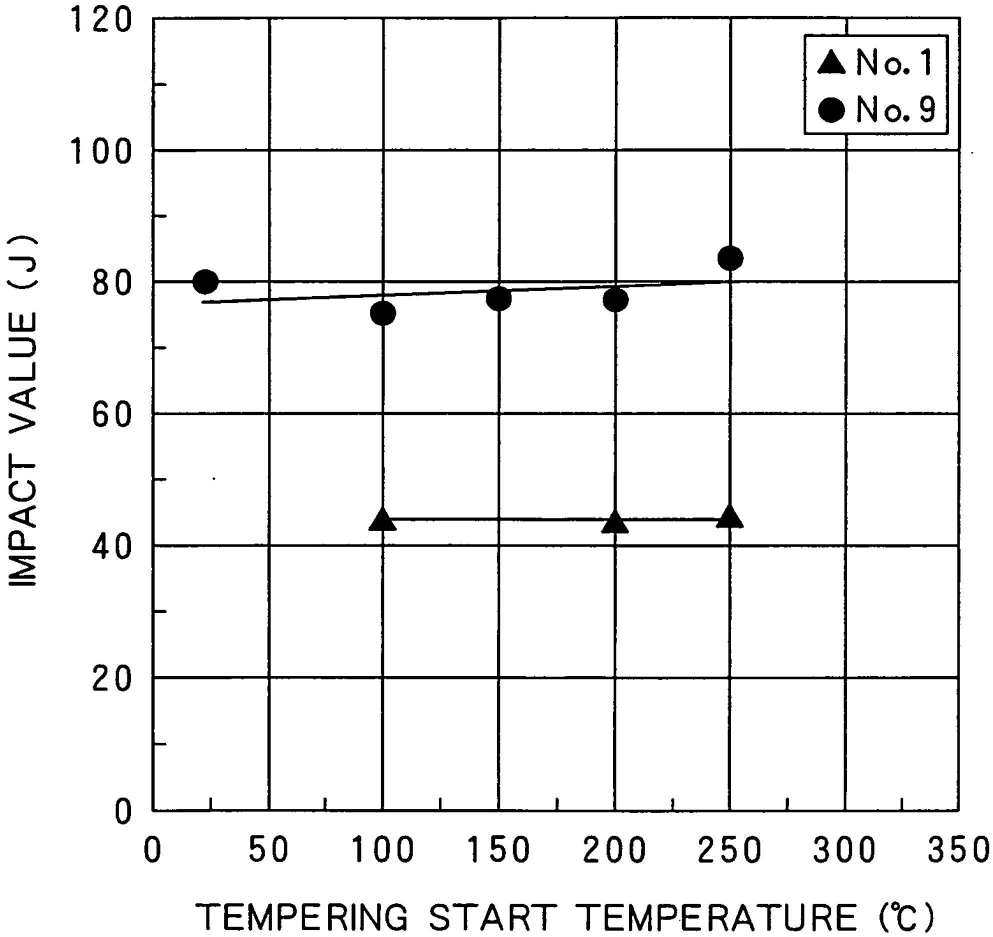

No.1
No.9
TENSILE STRENGTH (N/mm²)
1120
1100
1080
1060
1040
1020
1000
980
0
50
100
150
200
250
300
TEMPERING START TEMPERATURE (℃)

FIG. 4


No. 1
No. 9
IMPACT VALUE (J)
120
100
80
60
40
20
0
0
50
100
150
200
250
300
350
TEMPERING START TEMPERATURE (℃)

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 05 01 1252

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	GB 2 302 334 A (* A FINKL & SONS CO; * A. FINKL & SONS CO) 15 January 1997 (1997-01-15) * claims *	1,2	C22C38/46 C22C38/44 C21D9/30
X	EP 0 247 415 A (UDDEHOLM TOOLING AKTIEBOLAG) 2 December 1987 (1987-12-02) * claims *	1,5	
A	EP 1 087 030 A (SUMITOMO METAL INDUSTRIES, LTD) 28 March 2001 (2001-03-28)		
A	US 2002/124716 A1 (GRIMM WALTER ET AL) 12 September 2002 (2002-09-12)		
A	US 5 888 450 A (FINKL ET AL) 30 March 1999 (1999-03-30)		
A	US 5 496 516 A (FINKL ET AL) 5 March 1996 (1996-03-05)		

TECHNICAL FIELDS SEARCHED (Int.Cl.7)
C21D

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	13 September 2005	Mollet, G

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

1

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 05 01 1252

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

13-09-2005

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB 2302334 A	15-01-1997	NONE	
EP 0247415 A	02-12-1987	AU 599105 B2	12-07-1990
		AU 7346387 A	03-12-1987
		BR 8702687 A	01-03-1988
		CA 1324513 C	23-11-1993
		DE 3781203 D1	24-09-1992
		DE 3781203 T2	11-03-1993
		DK 270887 A	29-11-1987
		ES 2033723 T3	01-04-1993
		FI 872357 A	29-11-1987
		IN 169997 A1	25-01-1992
		JP 63057746 A	12-03-1988
		NO 871859 A	30-11-1987
		US 4673433 A	16-06-1987
EP 1087030 A	28-03-2001	DE 60021670 D1	08-09-2005
		US 6478898 B1	12-11-2002
US 2002124716 A1	12-09-2002	AT 280938 T	15-11-2004
		DE 10111304 A1	19-09-2002
		EP 1239257 A1	11-09-2002
		ES 2230400 T3	01-05-2005
US 5888450 A	30-03-1999	NONE	
US 5496516 A	05-03-1996	NONE	

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82