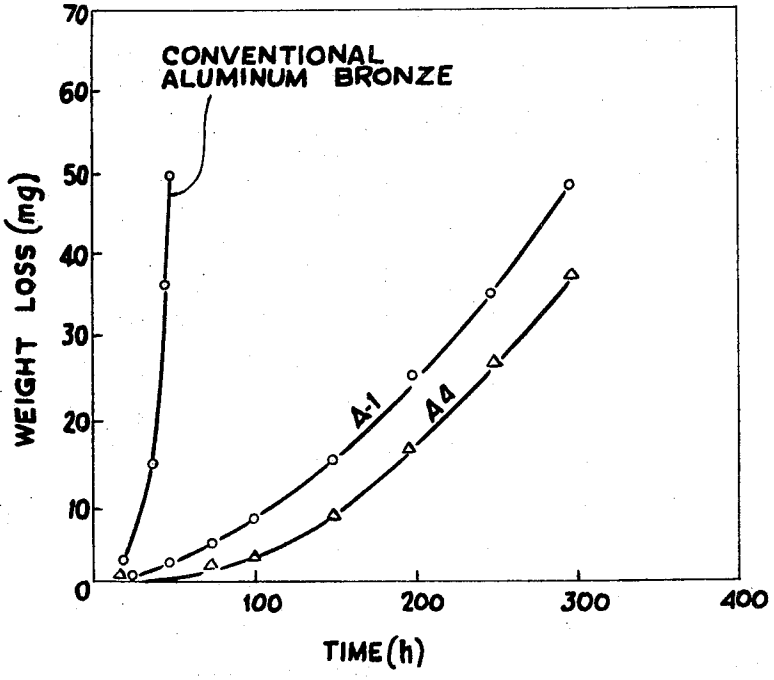
April 24, 1973 TEISHIRO ODA ET AL 3,729,345
METHOD FOR MAKING PROPELLERS OF HIGH-STRENGTH
AND HIGH-TOUGHNESS CAST STEEL
Original Filed Oct. 8, 1969



United States Patent Office 3,729,345 Patented Apr. 24, 1973

3,729,345

METHOD FOR MAKING PROPELLERS OF HIGH-STRENGTH AND HIGH-TOUGHNESS CAST STEEL

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Application Oct. 8, 1969, Ser. No. 864,898, now Patent No. 3,661,658, dated May 9, 1972, which is a division of application Ser. No. 643,679, June 5, 1967, now abandoned. Divided and this application Sept. 20, 1971, Ser. No. 182,109

Claims priority, application Japan, June 11, 1967, 42/37,570

Int. Cl. B22d *25/06;* C21d *1/78*

U.S. Cl. 148—3 5 Claims

ABSTRACT OF THE DISCLOSURE

A high strength, high toughness cast steel for marine propellers is comprised of not more than 0.25% of carbon, not more than 1% of silicon, not more than 3% of manganese, from 5–20% of chromium, from 1–8% of cobalt, and from 0.5–7% of one or both of molybdenum and tungsten, and the remainder consisting of iron. In addition, the cast steel may contain up to 8% of nickel and up to 4% of copper, depending on the conditions.

The method of making propellers of cast steel of the composition set forth above comprises the steps of after casting the propeller slowly cooling it at a rate of not more than 1° C. per minute, reheating the casting to between 800° and 1000° C. for improving its strength, ductility and toughness, cooling the casting, and then aging it at 450–700° C. In making the casting it may be cast as a single unit or in individual sections; where individual sections are cast, the method of forming the propeller includes the steps of welding the individual sections, heat treating the welded casting at 800–1000° and then slowly cooling the casting. Further, whether the casting is formed as a single unit or from individual sections, the method includes the step of annealing at 630–700°.

CROSS REFERENCE OF RELATED APPLICATION

This is a division of application Ser. No. 864,898, filed Oct. 8, 1969, now U.S. Pat. No. 3,661,658, which a division of application Ser. No. 643,679, filed June 5, 1967 and abandoned.

SUMMARY OF THE INVENTION

As ships increase in size, the propellers of ships become also larger and heavier; the weight increase of propellers requires larger amount of materials, causing an increase in the material cost and the power loss for driving propellers. Aluminum bronze has generally been used as the propeller material, but the shortage of copper resources all over the world in recent years is a serious factor which increases the material cost of marine propellers.

In order to reduce the material cost of propellers against such cost increasing tendency, it is necessary either to provide cheaper material to take the place of expensive copper alloys or to introduce materials stronger than conventional ones in order to reduce the propeller weight by making propeller blades lighter and thinner in section according to the increase of allowable stress of the used material; and the latter measure is especially desirable, because it makes possible to reduce not only the material cost but also the power loss, thus enhancing the propeller efficiency.

For the materials cheaper than copper alloys, an iron-base material, i.e. cast steel, may be considered. However, cast steel has been less frequently used as the propeller material, since its corrosion resistance against sea water as one of the requirements for propeller material is far inferior to copper alloys. Another reason why cast steel has not been widely used as a propeller material is that its mechanical properties have not been necessarily excellent as compared with conventional copper alloys.

This invention is to provide an inexpensive high-strength and high-toughness cast steel especialy suitable for the marine propeller material possessing a good combination of strength, hardness, ductility and toughness and weldability. This cast steel is expected to be put into service under the condition of electric (cathodic) protection to prevent it from being corroded by sea-water. In that condition, the high hardness ensures a good corrosion-resistance.

It is one of the most essential features of this invention to obtain satisfactory mechanical properties even at an extremely low cooling velocity, whcih is usually found not only after the casting of a large-sized casting such as a propeller but also after the austenizing treatment thereof performed again after the casting.

The cast steel of this invention is characterized by containing less than 0.25% carbon, less than 1.0% silicon, less than 3.0% manganese, 5 to 20% chromium, 1 to 8% cobalt, one or both of molybdenum and tungsten from 0.5 to 7%, the rest consisting of iron and other impurities. Further the cast steel of this invention is characterized by less than 8% nickel and less than 4% copper, besides the above-mentioned constituents, may be added independently or in combination.

And the cast steel of this invention is for the most part face-centered cubic austenite matrix at sufficiently high temperatures, and when it is cooled from the above condition to room temperature, most of the matrix changes to body-centered cubic ferrite or martensite, and yields precipitates of intermetallic compounds mainly consisting of intermetallic compound of molybdenum or tungsten, when the body-centered cubic lattice matrix is again heated to a temperature between 450 and 700° C. The purpose for precipitating the intermetallic compounds of molybdenum or tungsten is that, if the cast steel is reinforced by these intermetallic compounds ductility and toughness of this cast steel can be maintained up to higher strength than those of conventional cast steels reinforced by carbides.

There are many steels which have a similar composition to the cast steel of this invention and take advantage of the precipitation of intermetallic compound in the matrix of body-centered cubic lattice, which are classified into so-called "maraging steel" or "ferrite steel of precipitation hardening type." Each of these steels is hot forged or rolled to destroy the cast structure and is then rapidly cooled from the austenizing temperature, being further aged for use. They are not used like the cast steel of this invention which is used in the merely cast condition and, in some extreme cases, used under the condition when the cooling velocity is 0.1° C. per minute, because it has been understood according to the knowledge up to date that the excellent mechanical properties of maraging steel has been presumably derived from the fine structure obtained by forging and rolling or by subsequent heat-treatment, although it may be affected by characteristic of these intermetallic compounds.

As we have found that the above-mentioned characteristics of the intermetallic compound can be obtained in cast steel under a certain condition even if its structure

is not necessarily considered fine, this invention is designed to make the most of this fact; accordingly, the cast steel of this invention is entirely different in the essence from others although it has a chemical composition similar to some of conventional materials.

The composition of the cast steel of this invention is determined by the reasons explained as follows:

Chromium: The lower limit of its content is 5%, because if the chromium content is lower, the corrosion resistance is poor and not proper for use in sea water even when the cathodic protection against corrosion is applied. Further, if the chromium content exceeds 20%, the ferrite which does not disappear at high temperature, i.e. δ-ferrite, increases in its ratio to make the steel brittle, or the Ms-point is lowered to lose the strength of the steel because of the consequent increase of retained austenite. The upper limit of chromium content is thus determined to be 20%.

Cobalt: The lower limit of cobalt is determined to be 1%, because it desirably prevents the formation of δ-ferrite and promotes the precipitation hardening by the mutual action with molybdenum. However, excessive addition of cobalt makes this steel less economical because of its high price, thus the upper limit of cobalt content has been determined to be 8%.

Molybdenum and tungsten are required to be added to this steel in the amount of at least 0.5%, because the cast steel of this invention takes advantage of the precipitation hardening by molybdenum and tungsten; the contents of more than 7% of molybdenum or tungsten make the steel less economical because of the cost of the two metals and lower ductility and toughness of the steel although it increases the strength. Considering these effects, the upper and lower limits of the content of the two metals are determined to be 0.5% and 7%, respectively.

Nickel content of less than 8% is established for the reason that, while the content of chromium, cobalt, molybdenum, etc. in the cast steel of this invention may be changed in accordance with the applied purpose, an austenite-forming element or nickel is added for adjustment so long as its addition does not make the steel much less economical when the suppressing of δ-ferrite formation is necessary to prevent the reduction of ductility and toughness.

Copper of less than 4% is added considering that in the cast steel of this invention copper does not have markedly unfavorable influence on its mechanical properties but has rather a favorable effect on the corrosion resistance. However, it is expected in the cast steel of this invention that the corrosion by sea water is prevented by means of cathodic protection, and so the addition of copper is not necessarily required.

Carbon content is limited to less than 0.25%; it is desirable from the viewpoint of the mechanical property and the weldability of the cast steel of this invention that the carbon content is as little as possible; however, too low a content of carbon makes melting difficult and the steel less economical, since high quality raw material becomes necessary. Considering the above-mentioned factors, the content limit of carbon is set in the range where the mechanical property and weldability of this cast steel are not markedly impaired. Silicon and manganese are necessary for deoxidation and their contents are permitted in accordance with common knowledge for the steels of this type. The content of manganese is somewhat higher than that of silicon, because of our consideration that manganese can substitute for nickel as an austenite-forming element.

The cast steel of this invention contains common impurities such as phosphorus and sulphur which inevitably enter into the metal on melting; it is however, desirable to remove those impurities as much as possible so long as these impurities can be removed without any marked increase in cost.

The cast steel of this invention of which the composition is defined for the above-mentioned reasons exhibits tensile strength from 60 to or more than 120 kg./mm.^{2}, sufficiently high ductility and toughness in the as-cast condition if it is cooled at a sufficiently slow rate after casting. If the cooling rate is sufficiently high, the ductility and toughness decreases considerably. However, in this case, these properties can be improved by heating it to an appropriate temperature-above 900° C. and then cooling it slowly. Even the material which has been cooled gradually at a sufficiently slow cooling velocity can further improve its ductility and toughness after it is reheated. Further, if such material cooled sufficiently slowly as this is heated again in the temperature range f rom 450 to 700° C. for an adequate period, precipitation hardening takes place increasing the strength, particularly the yield strength. And also, if possible, the strength, ductility, and toughness are further improved by heating the material to the range from about 950 to 1050° C. after casting, subsequent rapid cooling, and then aging it at 450 to 700° C.

Among the stresses occurring in marine propellers the bending stress is dominant; consequently the cast steel of this invention may be used more effectively as propeller material if the surface property is improved by taking advantage of the above-mentioned property of this material in such a manner that the surface is rapidly heated and rapidly cooled by such a method as high-frequency induction heating and then aged.

As explained so far, the cast steel of this invention exhibits excellent properties as the material for a marine propeller.

The following is an embodiment of the cast steel of this invention. Table 1 shows typical examples of the compositions of cast steels of this invention. Each of samples was melted in a 30-kg. and a 500-kg. high frequency melting furnace and also in a 3-ton electric-arc melting furnace, and was cast into a sand mold. The cooling velocity after casting was controlled in a heat-treating furnace. Table 2 indicates mechanical properties as well as heat-treatment conditions of the materials whose compositions are listed in Table 1.

TABLE 1.—CHEMICAL COMPOSITION OF TESTED MATERIALS

[In weight percent]

Symbols of sample	C	Si	Mn	Co	Ni	Ni	Mo	W	B*	Cu	Melting furnace
A	0.03	0.32	0.53	12.19	6.93	5.92	3.23		0.003		A
B	0.04	0.40	0.55	12.23	6.08	5.56		2.93	0.003		A
C	0.13	0.36	0.53	15.24	5.55	3.72	2.97		0.003		A
D	0.05	0.36	0.56	10.32	7.29	2.57	3.55				A
E	0.04	0.17	0.32	14.37	5.75	3.72	2.97		0.003		A
F	0.05	0.38	0.59	14.35	5.73	3.53	2.99		0.003	3.42	A
G	0.04	0.38	0.61	12.34	6.12	5.62	1.52	1.42	0.003		A
H	0.03	0.34	0.52	10.13	6.83		2.53		0.003		A
I	0.07	0.36	0.40	10.14	4.18	3.53	1.97		0.003		A
J	0.08	0.45	0.34	11.51	3.56	3.14	2.05		0.003	1.80	B
K	0.05	0.05	0.17	11.44	4.11	3.63	2.00		0.003	1.60	C
L	0.06	0.29	0.40	11.89	4.15	3.94	2.00		0.003	1.66	B

* Amount of addition on steelmaking; not the actual content in the alloy.

NOTE.—30-kg. high-frequency melting furnace; B=500-kg. high-frequency melting furnace; C=3,000-kg. electric-arc melting furnace.

TABLE 2.—MECHANICAL PROPERTIES OF TEST MATERIALS

No. of test pieces	Heat-treatment	0.2% proof stress kg./mm.²	Tensile strength, kg./mm.²	Elongation, percent	Reduction of area, percent	Impact strength,[a] kg.-m./cm.²
A-1	Slowly cooled at 0.5° C./min. after casting	62.1	117.2	14.0	50.2	6.0
A-2	Slowly cooled at 10° C./min. after casting	72.7	106.0	3.8	9.7	2.1
A-3	Slowly cooled at 0.5° C./min. after casting, and aged at 500° C. for 10 hrs. after slow cooling.	96.2	132.9	12.3	45.7	3.5
A-4	Slowly cooled at 0.5° C./min. after casting, at 950° C. for 1 hr. after slow cooling, oil quenched, and aged at 500° C. for 10 hrs.	97.3	128.2	12.0	50.6	4.6
B-1	Slowly cooled at 0.5° C./min. after coating	66.5	110.0	10.6	56.7	6.9
B-2	Slowly cooled at 10° C./min. after casting	68.5	107.5	2.8	6.2	1.7
B-3	Slowly cooled at 0.5° C./min. after casting, and aged at 500° C. for 10 hrs. after slow cooling.	93.4	126.7	13.4	52.1	5.2
B-4	Slowly cooled at 0.5° C./min. after casting, at 950° C. for 1 hr. after slow cooling, oil quenched, and aged at 500° C. for 10 hrs.	94.0	127.4	14.2	53.2	6.1
C-1	Slowly cooled 0.5° C./min. after casting	80.3	125.9	10.7	41.4	4.2
D-1	Slowly cooled 0.5° C./min. after casting	65.2	118.7	13.6	50.6	6.4
E-1	do	62.1	121.4	12.3	48.2	5.8
F-1	do	63.3	116.1	14.0	51.4	5.2
G-1	do	62.1	119.3	12.7	49.9	6.8
H-1	do	64.2	111.3	10.4	45.6	4.2
I-1	Slowly cooled at 0.1° C./min. after casting	87.0	118.7	13.6	45.9	3.9
I-2	Reheated at 950° C. for 2 hrs. after casting and cooling, and cooled at 0.5° C./min.	89.4	117.4	11.0	30.9	5.3
J-1	Reheated at 850° C. for 2 hrs. after casting and cooling, and cooled at 0.5° C./min.	96.4	120.8	14.0	44.0	4.1
J-2	Softened at 650° C. for 2 hrs. after casting and cooling, at 900° C. for 2 hrs. and cooled at 0.5° C./min.	96.1	124.2	12.8	39.6	3.8
K-1	Softened at 850° C. for 4 hrs. after casting and cooling, at 850° C. for 4 hrs., and cooled at 0.1° C./min.	90.1	114.2	11.6	36.2	3.8
K-2	Slowly cooled at 5° C./min. after casting, and aged at 550° C. for 5 hrs.	104.4	114.0	16.8	51.3	5.1
K-3	Slowly cooled at 5° C./min. after casting, at 850° C. for 5 hrs., cooled at 0.5° C./min., and aged at 550° C. for 5 hrs.	103.7	108.1	19.2	54.3	4.3
K-4	Slowly cooled at 5° C./min. after casting, softened at 550° C. for 4 hrs., at 850° C. for 5 hrs., slowly cooled at 0.1° C./min., and aged at 550° C. for 5 hrs.	104.9	111.4	15.2	57.1	4.3
L-1	Slowly cooled at 1° C./min. after casting, air-cooled after at 1000° C. for 2 hrs., and aged at 550° C. for 5 hrs.	114.3	121.7	20.0	58.5	4.8

[a] 2 mm V-notch Charpy impact test.

From Table 2 it is clear that the cast steel of this invention has excellent mechanical properties as casting material for propellers.

Further a graph in the drawing illustrates the result of the erosion test by water jet of the test materials A–1 and A–4 compared with a test piece of cast aluminum bronze conventionally used as propeller material. From this graph it is seen that the cast steel of this invention possesses excellent erosion resistance. Further, the cast steel of this invention is excellent in weldability. Therefore the joining, by welding, of for example 2 to 10 pieces after the separate casting thereof is also possible. In this case, an annealing is performed at 630–700° C. so that residual stress after welding may be relieved and so that suitable hardness for the workings may be obtained. After necessary workings, said material is again austenized and slowly cooled to obtain mechanical properties required. The intermediate annealing at 630–700° C. can be performed, if necessary, prior to welding as well as in the casting in a single-body mold.

What is claimed is:

1. A method of making a marine propeller of cast steel consisting of not more than 0.25% of carbon, not more than 1% of silicon, not more than 3% of manganese, from 5–20% of chromium, from 1–8% of cobalt, and from 0.5–7% of at least one of molybdenum and tungsten and the remainder consisting of iron comprising the step of, after casting the propeller, slowly cooling it at a rate of not more than 1° C. per minute.

2. A method of making a marine propeller of cast steel, as set forth in claim 1, comprising the steps of aging the casting 450–600° to increase its strength.

3. A method of making a marine propeller of cast steel as set forth in claim 1, comprising the steps of cooling the casting, reheating the casting to between 800–1000° C.

4. A method as set forth in claim 3, comprising the further step of aging the casting at 450–600° C. to increase its strength.

5. A method of making a marine propeller of cast steel having a composition as set forth in claim 1, comprising the step of annealing the casting at 630 to 700° C. after the casting is cooled.

References Cited

UNITED STATES PATENTS

3,251,683	5/1966	Hammond	75—128 R
3,340,048	9/1967	Floreen	148—142 X
3,378,367	4/1968	Friis et al.	148—37 X

FOREIGN PATENTS

796,733	6/1958	Great Britain	75—128 R
10,980	5/1897	Great Britain	416—241
380,013	1940	Italy	416—241

OTHER REFERENCES

Metals Handbook, vol. 1, 1961, page 563.

Report of 1956 Cavitation Symposium, Rheingans Amer. Society of Mechanical Engineers, 1957, 27 pages.

CHARLES N. LOVELL, Primary Examiner

U.S. Cl. X.R.

148—142; 164—122; 416—241