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ABRASION RESISTANT ARTICLES AND ALLOYS

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The present invention relates primarily to blasting machines of the type disclosed in the patent to Keefer, No. 2,108,005, and more particularly pertains to the parts thereof which during the operation of the same are subjected to an attrition or erosive effect due to the action thereon of the abrasive medium projected by the blasting machine.

Such machines are commonly employed for the surface cleaning of articles by projecting at high velocity against the surface to be cleaned metal shot, broken shot, grit or any suitable abrasive particles. The machines have other applications, such as projecting shot or other particles at high velocity against a surface to be treated.

The attrition action of the abrasive medium on certain parts of a blasting machine, such as the propeller blades of a centrifugal blasting machine, results in such a rapid impairment or destruction of operative portions or faces thereof that the replacement expense constitutes a serious cost item in the use of the machines.

This invention resides primarily in a propeller blade for a centrifugal blasting machine, or other machine part, which is subjected in the operation to the attrition or erosive action of an abrasive medium and relates to an iron-base alloy which can readily be cast to form such propeller blade or other machine part.

The essential components of the new alloys are chromium, ranging from 7 to 30 per cent; carbon, ranging from about 2.5 to 4.5 per cent; silicon, ranging from about 0.1 to 1.25 per cent; manganese, ranging from about 0.25 to 2.5 per cent; and nitrogen amounting to from about 0.20 to 1 per cent of the chromium content; the balance of the alloy being substantially iron. The alloy advantageously contains molybdenum, varying from effective amounts up to about 7 per cent. While molybdenum additions are of benefit to alloys of 20 per cent chromium and above, such additions are more beneficial to the alloy when the chromium content is below 20 per cent.

While the above are the operative ranges of the various components which make up the alloy, it has been found that the best results are obtained when the components are restricted to the more narrow ranges of 10 to 28 per cent of chromium, 2.75 to 4.00 per cent carbon, 0.5 to 1.00 per cent of silicon, about 0.5 per cent of manganese, from 1 to 6 per cent molybdenum, and from about 0.05 to 0.25 per cent of nitrogen, with the higher nitrogen percentages in the alloys of higher chromium content. Each of these components contributes in a particular manner to the properties of the alloy.

In addition it has been found important to have the components in the alloy so proportioned that its structure, except for carbides, is largely austenitic in character, containing only sufficient martensite to make it magnetic. It is also important that the alloy consist largely of eutectic structure, no more than about 30 per cent of non-eutectic (hyper-eutectic or hypo-eutectic) structure being present. While hardness is not necessarily indicative of wear resistance, it has been found that alloys of the above composition which have hardnesses on the Rockwell "C" scale below 50 are inferior in wear resistance. It is therefore desirable that the alloys should have hardnesses on this scale within the range of about 50 to 70, while the best alloys have hardnesses falling within the narrower range of 55 to 65 on the Rockwell "C" scale. Moreover it has been found that best results are obtained with alloys having such structures that their hardnesses increase with abrasion or wear as when in service. This phenomenon is probably due to the alloy being predominantly austenitic in character as cast but being converted to martensite of increased hardness on the wearing surface by the slight cold working caused by impacts and abrasion from the hard abrasive particles.

The preferable carbon content to be used in the present alloys depends to some exent upon their chromium content for the reason that the composition of the eutectic varies with the chromium content. For example, when the alloy contains 10 per cent of chromium, the eutectic lies at a carbon content of about 3.90 per cent, while with 30 per cent of chromium present, the eutectic is at about 2.75 per cent carbon. Thus, the preferred range for carbon varies somewhat with the chromium content of the alloy, that is, slightly higher carbon contents can be used with the lower percentages of chromium than with the higher percentages of chromium. It is important to have the alloy consist principally of eutectic structure for the reason that hypo-eutectic alloys tend to be too soft while hyper-eutectic alloys contain massive carbides which tend to make them brittle with decreased wear resistance.

The chromium used in the present alloys appears to combine with the carbon present to form some type of carbide having a good wear resistance. It appears that the chromium also aids in controlling the transformation of the alloy during cooling of the casting, tending to increase its austenitic character. In addition the chromium aids in producing the desired retention of nitrogen in the alloy and the amount of nitrogen which can be retained in the alloy increases as the chromium content is increased.

The nitrogen seems to be important in increasing the wear resistance of the alloy. It also ap-

pears to modify the transformation of the austenite to martensite during the cooling of the casting, tending to make the alloy more austenitic. For this purpose the nitrogen is, in part, supplementary to the chromium.

It is usually desirable to keep the silicon content of the new alloy below 1.25 per cent, although excellent alloys have been obtained with a slightly higher content. But when the silicon is increased up to about 2 per cent the alloy tends to become too martensitic during the cooling of the casting, while still higher contents of silicon produce an alloy which is strongly ferritic and of lower hardness as cast. The wear resistance is reduced.

The manganese content of the alloy can be varied rather widely without any very definite effect upon its character. No special advantage appears to result from the use of more than 2.5 per cent of this component, while good results are obtained with 0.5 per cent.

An addition of molybdenum increases the wear resistance of the alloy. Molybdenum is, in part, supplementary to the chromium and makes it possible to employ lower contents of the latter. For example, with the molybdenum-free alloys, it has been found that for the best alloys the minimum chromium content should not be less than five times the carbon content of the alloy, while for molybdenum-containing alloys equally as good alloys are obtained with the chromium content being only three times that of the carbon content employed. Molybdenum also prevents the formation of too much martensite or ferrite during cooling of the casting. It has been found that alloys which, in the absence of molybdenum, produce castings satisfactorily austenitic in character are further improved in wear resistance by the addition of molybdenum. The addition of molybdenum also enables the carbon ccontent to be increased slightly, owing to a shift in the composition of the eutectic. In general, the addition of molybdenum to the alloy makes the composition and the casting conditions for good wear resistance somewhat less critical and more convenient for foundry practice. For example, the use of molybdenum permits the casting of some alloys against a sand core which in the absence of molybdenum would have to be cast against a cast iron chill for satisfactory results.

In addition to the components already mentioned it is possible to incorporate in the present alloys certain strong carbide forming metals, such as columbium, vanadium, titanium and tungsten. When incorporated in the present alloys they have a beneficial effect in increasing the hardness and wear resistance. Carbides of these alloys are used in high speed cutting tools and the effects produced in the present alloys are believed to be at least somewhat analogous to their effect in such tools which, of course, must withstand severe abrasion. The metals mentioned may be added in amounts ranging from about 0.25 to 1 per cent.

The effect of and relationship between the various components of the present alloys is made evident from the data which are tabulated in Table I hereinafter set forth. In this table, a few of the representative alloys are given which have been tested in actual practice and compared with "Ni-Hard" blades which have been used in the past. In the last, or the extreme right, column the relative abrasion losses (losses during abrasion) of these alloys are given in percentages, in terms of the abrasion loss of "Ni-Hard," taken as 100 per cent. The alloy designated as "Ni-Hard" in this specification and used for comparison test purposes has the following approximate composition:

	Per cent
Carbon	3.45–3.65
Silicon	1.30–1.50
Manganese	0.5 –0.65
Chromium	1.75–2.0
Nickel	4.5 –5.0

An alloy shown in Table I to have an abrasion loss of 50 per cent, loses weight upon being subjected to abrasion only half as rapidly as "Ni-Hard" or in other words it has a wear resistance twice that of "Ni-Hard." These values were determined by measuring the loss of weight of the alloys, cast in the form of propeller blades of a commercial blasting machine, during five hour periods of operation of the machine. Blades of "Ni-Hard" were incorporated in the same machine and the loss of weight of these blades during the same periods was also determined. Then the losses in weight of the blades formed of the present alloy were calculated in terms of the loss of weight of the "Ni-Hard" blades used in centrifugal blasting machines.

Table I

Alloy	Chemical composition, per cent						Percent abrasion loss
	C	N	Cr	Si	Mn	Mo	
A	3.67	0.04	10.0	0.75	0.5	------	180
B	3.33	0.03	19.8	1.00	0.5	------	80
C	3.52	0.20	20.0	0.75	0.5	------	46
D	3.66	0.04	9.9	0.75	0.5	3.0	51
E	3.58	0.11	20.0	0.75	0.5	2.9	34
F	3.21	0.03	25.6	1.0	0.5	------	108
G	3.20	0.06	25.0	0.75	0.5	------	76
H	2.65	0.13	20.0	0.75	0.5	------	80
I	2.93	0.20	20.0	0.75	0.5	------	62
J	3.22	0.14	21.0	0.75	0.5	------	53
K	3.52	0.12	20.0	0.75	0.5	------	46
L	4.16	0.06	20.5	1.24	0.5	6.6	72
M	3.55	0.14	25.0	1.0	0.5	7.0	39
N	2.94	0.23	28.0	0.75	0.5	------	76
O	3.04	0.23	29.3	0.75	0.5	3.3	72
P	3.63	0.06	15.0	0.75	0.5	6.0	37
Q	3.64	0.06	14.9	0.75	0.5	1	45
R	3.65	0.06	15.0	0.75	0.5	2.87	38
S	3.33	0.18	25.2	0.75	0.5	1.08	40
T	3.24	0.15	25.2	0.68	0.5	3.08	42
U	3.74	0.05	7.1	------	0.5	3.0	52

It will be seen that alloy A had a weight or abrasion loss which was almost double that of "Ni-Hard," owing to its low percentage (10 per cent) of chromium and the absence of molybdenum in its composition. Alloy B, in comparison, containing 19.8 per cent of chromium, showed an abrasion loss less than half as great as alloy A. But alloy D, containing only 9.9 per cent of chromium, showed an abrasion loss considerably less even than that of alloy B, owing to the presence therein of molybdenum. This would indicate that 3 per cent of molybdenum is somewhat more effective than 9.8 per cent of chromium in reducing abrasion loss.

The effect of the nitrogen content in the alloys may be seen by comparing alloys B and C and alloys F and G. The per cent abrasion losses for alloy F and G show that increasing the nitrogen content from .03 to .06 per cent materially reduced the abrasion loss, thus showing that .06 per cent nitrogen is an effective amount. Alloys N and O show that the nitrogen content can be increased considerably in alloys having high percentages of chromium.

Alloys Q, R and P show that 1 per cent of molybdenum is almost as effective as 3 or 6 per cent, when the chromium content amounts to 15

per cent. Thus, 1 per cent of molybdenum is definitely an effective amount in improving the wear resistance of the new alloy. An alloy similar in composition to alloy Q but free from molybdenum would have an abrasion loss higher than that of "Ni-Hard." But when the alloys contain over 25 per cent of chromium, the addition of even 3 per cent of molybdenum produces but little improvement, as shown by a comparison of alloys N and O. With alloys containing 3 per cent of molybdenum an increase in chromium content from 10 to 20 per cent produces a reduction in abrasion loss of from 51 to 34 as will be apparent from a consideration of alloys D and E in Table I.

Reference to Table I shows that alloy U, with 7.1 per cent of chromium and 3 per cent molybdenum, showed a per cent abrasion loss of 52, or an indicated life of approximately twice that of Ni-Hard. Thus, it is clear that a good abrasion resisting alloy can be made with only 7 per cent of chromium when the proper carbon content is used and the chromium is supplemented by an addition of molybdenum.

The effect of the carbon content can be best determined by comparing alloys H to K, which have a gradually increasing content of carbon. Alloys H and I have considerable hypo-eutectic structure, while alloy L is representative of alloys having a hyper-eutectic structure and hence a higher abrasion loss. But with alloys having lower contents of chromium, the structure with 4.16 per cent carbon would be only slightly hyper-eutectic.

The effect of surface wear on the surface hardness of 4 of the new alloys is shown in Table II. The hardness tests set forth in this table were taken with the Vickers instrument since it is capable of determining the surface hardness of relatively thin surfaces. The alloys, cast in the form of blades for a centrifugal blasting machine, were first tested for surface hardness, then the blades were operated in the machine for a period of 10 hours, after which the hardness values were again obtained. The before and after hardness values were tabulated in Table II. It has been found that alloys which are predominantly ferritic in structure or which are of very stable austenite do not show an increase in hardness during wear, this property of surface hardening being a characteristic of alloys which are predominantly austenitic but whose surfaces are at least partly transformed to martensite by the cold working obtained during service.

The advantage of using alloys having the property of increasing in hardness during use is rather evident. During test runs it has been found that the rate of weight loss of blades made with this type of alloy operating in a blasting machine actually decreases as the blade wears. This may account for the surprising results obtained in life tests of the alloys.

Table II

Alloy	Chemical composition, per cent						Vickers hardness number		
	C	N	Cr	Si	Mn	Mo	Before	After	Increase
V	3.22	0.14	21.0	0.75	0.5	----	919	1,132	213
W	3.36	0.16	25.2	0.75	0.5	----	892	1,061	169
X	3.27	0.12	20.6	0.75	0.5	3.0	928	1,096	168
Y	3.27	0.15	24.7	0.75	0.5	3.0	937	1,061	124

In life tests on several blades made of alloys having substantially the composition of the alloy S, an indicated life of 125 hours was obtained, in comparison with a life ranging from about 25 to 35 hours for blades run under the same conditions constructed of "Ni-Hard." The life of blades constructed of alloys having substantially the composition of alloy T was indicated as being about 180 hours. One of the alloys subjected to a life test contained 3.12 per cent of carbon, 0.14 per cent of nitrogen, 25 per cent of chromium, 1.0 per cent silicon, 0.5 per cent of manganese and 6.4 per cent of molybdenum. This alloy had an indicated life of no less than 270 hours. It is therefore seen that propeller blades constructed of the present alloys have operating lives ranging from 2 to 6 times that of blades constructed of "Ni-Hard." The comparative values given in Table I for abrasion loss in short-time tests appear to be over conservative with respect to operating life. The beneficial effect of substantial molybdenum additions is more clearly brought out in the life tests than in the short-time abrasion-loss test.

The present alloy, when of proper composition, does not require a special heat treatment, but it has been found advantageous to subject the castings to heat at a relatively low temperature such as about 300° to 600° F. for the purpose of relieving casting strains. This heat treatment has little or no effect on the hardness of micro-structure.

While it is believed that the more advantageous embodiments of the alloys and abrasion resistant articles have already been described, it is evident that many modifications can be made in the specific compositions which have been given without departing from the purview or scope of this invention. It has already been mentioned that the alloy compositions may include small percentages of carbide-forming metals and doubtless many other metals can be added in small proportions or may be present as impurities without substantially altering the nature and properties of the alloys. The inclusion of these extraneous metals in the alloys is included within the scope of the expression "the balance being substantially iron." It is evident, of course, that the present alloys can be used in the construction of articles of all types in which abrasion resistance is desired. Various methods of casting these articles can be employed. Other modifications of this invention will be evident to those skilled in this art and such changes may be made without departing from the spirit and scope of the invention as set forth in the appended claims.

What is claimed is:

1. A cast propeller blade for a centrifugal blasting machine comprising approximately 7 to 30 per cent chromium, about 2.5 to 4.5 per cent carbon, about 0.1 to 1.25 per cent silicon, about 0.25 to 2.5 per cent manganese, from effective amounts to about 7 per cent molybdenum, and nitrogen from effective amounts to about 1 per cent of the chromium content, the remainder of said blade being substantially iron, and said blade having a hardness as cast greater than 55 on the Rockwell "C" scale.

2. A cast propeller blade for a centrifugal blasting machine comprising approximately 7 to 30 per cent chromium, about 2.5 to 4.5 per cent carbon, about 0.1 to 1.25 per cent silicon, about 0.25 to 2.5 per cent manganese, from effective amounts to about 7 per cent molybdenum, and nitrogen from effective amounts to about 1

per cent of the chromium content, the remainder of said blade being substantially iron, said blade having a relatively high resistance to abrasion and a hardness greater than 50 on the Rockwell "C" scale as cast and having a surface principally austenitic in character.

3. A cast propeller blade for a centrifugal blasting machine comprising approximately 18 to 30 per cent chromium, about 2.75 to 4.0 per cent carbon, about 0.1 to 1.25 per cent silicon, about 0.25 to 2.5 per cent manganese, and nitrogen from effective amounts to about 1 per cent of the chromium content, and the remainder of said blade being substantially iron.

4. A cast propeller blade for a centrifugal blasting machine comprising approximately 18 to 30 per cent chromium, about 2.75 to 4.0 per cent carbon, about 0.1 to 1.25 per cent silicon, about 0.25 to 2.5 per cent manganese, and nitrogen from effective amounts to 1 per cent of chromium content, the remainder of said blade being substantially iron, said blade having a relatively high resistance to abrasion and a hardness greater than 50 on the Rockwell "C" scale as cast and having a surface principally austenitic in character.

5. An abrasion resistant alloy having the composition of about 7 to 30 per cent chromium, about 2.5 to 4.5 per cent of carbon, about 0.1 to 1.25 per cent of silicon, about 0.25 to 2.5 per cent of manganese, from effective amounts to 7 per cent molybdenum, and nitrogen from effective amounts to about 1 per cent of the chromium content, the balance of said composition being substantially iron, said alloy being characterized by having a high resistance to abrasion, a hardness in excess of 50 on the Rockwell "C" scale as cast and being principally austenitic in character.

6. An abrasion resistant alloy having the composition of about 18 to 30 per cent chromium, about 2.75 to 4.0 per cent of carbon, about 0.1 to 1.25 per cent of silicon, about 0.25 to 2.5 per cent of manganese, and nitrogen from effective amounts to about 1 per cent of the chromium content, the balance of said composition being substantialy iron, said alloy being characterized by having a high resistance to abrasion, a hardness in excess of 50 on the Rockwell "C" scale as cast and being principally austenitic in character.

7. An abrasion resistant alloy having the composition of about 7 to 30 per cent chromium, about 2.75 to 4.0 per cent of carbon, about 0.1 to 1.25 per cent of silicon, about 0.25 to 2.5 per cent of manganese, from effective amounts to about 7 per cent molybdenum, and nitrogen from effective amounts to about 1 per cent of the chromium content, the balance of said composition being substantially iron, said alloy being characterized by having a high resistance to abrasion, a hardness in excess of 50 on the Rockwell "C" scale as cast and being principally austhenitic in character.

8. An abrasion resistant alloy having the composition of about 10 to 28 per cent chromium, about 2.75 to 4.0 per cent of carbon, about 0.1 to 1.25 per cent of silicon, about 0.25 to 2.5 per cent of manganese, from effective amounts to 7 per cent molybdenum, and nitrogen from effective amounts to about 1 per cent of the chromium content, the balance of said composition being substantially iron, said alloy being characterized by having a high resistance to abrasion, a hardness in excess of 50 on the Rockwell "C" scale as cast and being principally austenitic in character.

9. An abrasion resistant alloy having the composition of about 20 to 27 per cent chromium, about 2.75 to 4.0 per cent of carbon, about 0.1 to 1.25 per cent of silicon, about .25 to 2.5 per cent of manganese, and nitrogen from effective amounts to about 1 per cent of the chromium content, the balance of said composition being substantially iron, said alloy being characterized by having a high resistance to abrasion, a hardness in excess of 50 on the Rockwell "C" scale as cast and being principally austenitic in character.

10. An alloy according to claim 5 wherein the structure is principally eutectic and having not more than 30 per cent of hypoeutectic structure or 30 per cent of hypereutectic structure.

11. An alloy according to claim 5 wherein at least one strong carbide forming metal is also present, selected from the group consisting of titanium, tungsten, columbium and vanadium, in quantity ranging from about 0.25 to 1 per cent.

12. Abrasion resistant alloys having compositions of from about 15 to 25 per cent of chromium, from about 2.75 to 4.0 per cent of carbon, from about 0.5 to 1.0 per cent of silicon, from about 0.25 to 2.5 per cent of manganese, from about 0.05 to 0.25 per cent of nitrogen, and a small quantity of molybdenum ranging from a small but effective amount up to about 7 per cent, the balance of the composition being substantially iron, said alloys being characterized by having a high resistance to abrasion, a hardness in excess of 50 on the Rockwell "C" scale as cast and being principally austenitic in character.

13. A machine part subject to abrasion constructed of a casting having substantially the composition of about 7 to 30 per cent chromium, about 2.5 to 4.5 per cent of carbon, about 0.1 to 1.25 per cent of silicon, about 0.25 to 2.5 of manganese, from effective amounts to 7 per cent molybdenum, and nitrogen from effective amounts to about 1 per cent of the chromium content, the balance of said machine part being substantially iron, said machine part being characterized by having a high resistance to abrasion, a hardness in excess of 50 on the Rockwell "C" scale and having a surface principally austenitic in character.

14. A machine part subject to abrasion constructed of a casting having substantially the composition of about 18 to 30 per cent chromium, about 2.75 to 4.00 per cent of carbon, about 0.1 to 1.25 per cent of silicon, about 0.25 to 2.5 per cent of manganese and nitrogen from effective amounts to about 1 per cent of the chromium content, the balance of said machine part being substantially iron, said machine part being characterized by having a high resistance to abrasion, a hardness in excess of 50 on the Rockwell "C" scale and having a surface principally austenitic in character.

15. A machine part subject to abrasion constructed of a casting having substantially the composition of about 7 to 30 per cent chromium, about 2.75 to 4.00 per cent of carbon, about 0.1 to 1.25 per cent of silicon, about 0.25 to 2.5 per cent of manganese, from effective amounts to about 7 per cent molybdenum, and nitrogen from effective amounts to about 1 per cent of the chromium content, the balance of said machine part being substantially iron, said machine part being characterized by having a high resistance

to abrasion, a hardness in excess of 50 on the Rockwell "C" scale and having a surface principally austenitic in character.

16. A machine part subject to abrasion constructed of a casting having substantially the composition of about 10 to 28 per cent chromium, about 2.75 to 4.0 per cent of carbon, about 0.1 to 1.25 per cent of silicon, about 0.25 to 2.5 per cent of manganese, from effective amounts to 7 per cent molybdenum, and nitrogen from effective amounts to about 1 per cent of the chromium content, the balance of said machine part being substantially iron, said machine part being characterized by having a high resistance to abrasion, a hardness in excess of 50 on the Rockwell "C" scale and having a surface principally austenitic in character.

17. A machine part subject to abrasion constructed of a casting having substantially the composition of about 20 to 27 per cent chromium, about 2.75 to 4.0 per cent of carbon, about 0.1 to 1.25 per cent of silicon, about .25 to 2.5 per cent of manganese, and nitrogen from effective amounts to about 1 per cent of the chromium content, the balance of said machine part being substantially iron, said machine part being characterized by having a high resistance to abrasion, a hardness in excess of 50 on the Rockwell "C" scale and having a surface principally austenitic in character.

18. A machine part according to claim 13 wherein the structure is principally eutectic and having not more than 30 per cent of hypoeutectic structure or 30 per cent of hypereutectic structure.

19. A machine part according to claim 13 wherein at least one strong carbide forming metal is also present, selected from the group consisting of titanium, tungsten, columbium and vanadium, in quantity ranging from a small but effective amount up to about 1 per cent.

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