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LOW ALLOY, HIGH HARDNESS, TEMPER RESISTANT STEEL

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The present invention relates to a novel alloy that is particularly useful for applications where high strength at elevated temperatures is required, as well as for the preparation of dies for use in the aluminum die casting industry and for use in hot work forging die applications.

It is a major object of the present invention to provide alloy steels especially useful in aluminum die casting and hot work forging die applications, that have all the advantages of prior alloys for those applications but are further advantageous in that they exhibit superior resistance to tempering and heat checking.

Another object of the present invention is to provide dies for use in the aluminum die casting industry as well as in hot work forging die applications, which are highly resistant to tempering and to heat checking.

Still another object of the present invention is to provide improved steel for use in such applications as solid fuel rocket cases and structural members of aircraft that are subject to aerodynamic heating.

The present invention is based on the discovery that the advantageous characteristics of prior art die alloys can be provided in a steel along with a superior resistance to tempering and heat checking in a composition consisting essentially, by weight, of about 0.25 to 0.50 percent of carbon, up to 1 percent of manganese, 0.50 to 2 percent of silicon, 2 to 10 percent of chromium, 1.5 to 5 percent of molybdenum, 0.25 to 2 percent of vanadium, 1 to 6 percent of cobalt and the remainder iron. Elements such as sulfur and phosphorus can be present either in normal amounts resulting from standard steel melting practices or can be present in quantities sufficient to provide for free machining. Lead and selenium can also be present to enhance free machining characteristics where these are desirable. In addition, other alloying constituents can be included in such amounts as desirable to attain a given characteristic as long as the advantages of this invention are not deleteriously affected. For example, nickel might be used in the alloy for specific property requirements.

Within the foregoing broad range, superior properties can be obtained in a composition containing, by weight, about 0.30 to 0.40 percent of carbon, 0.20 to 1 percent of manganese, 0.50 to 1.50 percent of silicon, 3 to 4 percent of chromium, 2.5 to 3.5 percent of molybdenum, 0.50 to 1 percent of vanadium, 1.50 to 2.50 percent of cobalt and the remainder iron. Here again sulfur and phosphorus can be present either in trace amounts or in amounts sufficient to provide for free machining, that is up to 0.50 percent. Lead and selenium may also be added if desirable for free machining characteristics in amounts up to 0.25 percent.

The preferred range of compositions within the foregoing broad ranges contains, by weight, about 0.32 to 0.37 percent of carbon, 0.20 to 0.40 percent of manganese, 0.80 to 1.20 percent of silicon, 3 to 3.5 percent of chromium, 2.60 to 2.90 percent of molybdenum, 0.65 to 0.85 percent of vanadium, 1.50 to 2 percent of cobalt and the remainder iron and incidental impurities and alloying constituents which do not deleteriously detract from the superior characteristics of the resulting compositions. Within this preferred range exceptionally outstanding

properties of hardness and ultimate tensile strength at high temperature are found.

The alloy steels of compositions within the invention are prepared in accordance with standard mill practices. The material can be melted in any of the air electric arc melting furnaces, induction furnaces or by other means. Under certain circumstances the material can be melted under vacuum or in inert gas atmospheres. After melting, the molten metal is teemed into ingots. To obtain material from which dies may be made, the ingots are hot worked by forging, pressing or rolling by initially heating to a temperature of about 2000° F. The ingots are worked at this temperature until the desired reduction is obtained after which they are cooled. The product may be in the form of square billets, round bars, die blocks, or some other form as may be required by the final die shape.

The die is then machined or prepared from the proper form of structure; thereafter it is heat treated by heating to temperatures of about 1800° to 2000° F., held for the proper length of time depending on size and shape and then is quenched in air, oil, salt or other medium. This treatment is further followed by a tempering treatment at temperatures up to about 1300° F. which involves heating to the tempering temperature, holding at that temperature for the proper period of time consistent with size and shape and then air cooling. Under certain conditions single tempering treatments may be used, although the most satisfactory results for normal usage are obtained by using either a double or triple tempering treatment, that is the tempering cycle is repeated a number of times. It is possible also to precede the tempering treatment by a deep freezing treatment to temperatures as low as −320° F.

The invention will be further described by means of a specific example in which the details are given by way of illustration and not by way of limitation.

An ingot was prepared by melting the various components in the usual manner. Analysis of the ingot showed the following chemistry, in weight percent:

C	0.34
Mn	0.29
Si	0.97
Cr	3.18
Mo	2.70
V	0.80
Co	1.73
Fe	Bal.

The mechanical properties of the steel in the heat treated condition were determined. The data in all of the following tables were obtained on specimens with the foregoing analysis. The steel specimens were air quenched from 1900° F. and then tempered at various temperatures in two cycles of three hours each. Hardness tests were made before and after tempering. The hardness data obtained are:

Table I

Tempering temperature:	Rockwell C hardness
As quenched	55.0
800° F	56.0
900° F	58.6
950° F	58.0
1000° F	57.5
1050° F	55.0
1100° F	52.9
1150° F	50.6
1200° F	40.7
1300° F	28.5

From these data it is evident that the alloy of this in-

vention evidences high tempered hardness that stays surprisingly uniform and high through the temperature range of 800 to 1300° F. The alloy of the invention finds use at hardnesses of about 30 Rockwell C although it will be noted from the data in Table I that hardnesses of 40 Rockwell C are readily obtained and that a minimum of 50 Rockwell C is obtained at a tempering temperature of 1100° F. This response to tempering is of primary importance in providing resistance to heat checking since it indicates a high tensile strength after exposure at elevated temperatures. It also shows that dies made therefrom will resist softening when used for extended periods of time at the indicated temperatures.

Thereafter, the room temperature tensile properties were determined on specimens air quenched from 1900° F. and then tempered in two 3 hour cycles at the tempering temperature indicated in the following tabulation:

Table II

Tempering Temperature, ° F.	Ult. Tensile Strength, p.s.i.	0.2% Yield Strength, p.s.i.	Elongation [1] (Percent)	Reduction of Area (Percent)
950	296,400	246,900	8.9	16.2
1,050	287,700	262,800	10.7	40.6
1,100	270,900	250,400	9.6	37.8
1,150	237,700	223,200	10.6	34.8
1,200	181,000	158,900	13.6	42.8

[1] Using a 1¼" gauge length and 0.250" diameter.

The foregoing data demonstrate the high strengths that can be achieved in compositions within the scope of this invention. It may be noted that adequate ductility remained notwithstanding the high strength. Accordingly, it is evident that stock of the composition can be readily formed to structural shapes for use in aircraft and similar applications as well as be used as dies.

The elevated temperature tensile properties as well as the rupture properties of the steel were determined on specimens that were tempered using a double cycle for 3 hours each at 1100° F. after air quenching from 1900° F. The tensile data are:

Table III

Test Temperature, ° F.	Ult. Tensile Strength, p.s.i.	0.2% Yield Strength, p.s.i.	Elongation [1] (Percent)	Reduction of Area (Percent)
600	238,600	224,500	10.5	42.3
800	213,500	209,200	13.6	52.5
900	207,500	198,600	14.4	56.1
1,000	189,600	178,900	15.6	45.4
1,100	172,500	159,900	16.3	59.6

[1] Using a 1¼" gauge length and 0.250" diameter.

As predicted from the tempered hardness data (Table I), these data show that the composition has high tensile strength at high temperatures. Accordingly, heat checking in dies made therefrom will be largely suppressed. Moreover, these and similar data show that our compositions can consistently be prepared with an ultimate tensile strength of at least 165,000 p.s.i. and a yield strength of at least 150,000 p.s.i. at temperatures to 1100° F.

The rupture data obtained are:

Table IV

Test Temperature	Type Specimen	Stress, p.s.i.	Life, Hours	Elongation [1] (Percent)	Reduction of Area (Percent)
1,000° F	Smooth	170,000	7.6	12.0	55.9
1,000° F	do	150,000	66.1	9.8	46.9
1,000° F	do	125,000	334.0	6.0	22.3
1,000° F	Notch	170,000	96.1		
1,000° F	do	150,000	140.0		
1,100° F	Smooth	100,000	35.2	5.3	10.3
1,100° F	do	80,000	63.6	9.2	30.6
1,100° F	do	70,000	84.4	14.3	43.7

[1] Using a 1" gauge length and 0.160" diameter.

From the foregoing discussion and data, it is evident that the present invention provides compositions of outstanding usefulness where high strength at elevated temperatures are desired. Moreover, the uniformly high hardness over a high temperature range indicates the resistance to heat checking that, in addition to the characteristics of good toughness, good machinability and very good wear resistance, make these materials of primary importance in the aluminum die casting industry and for use in hot work forging die applications.

According to the provisions of the patent statutes, we have explained the principle of our invention and have described what we now consider to represent its best embodiment. However, we desire to have it understood that, within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

We claim:

1. A low alloy content, high hardness, temper resistant steel having a composition consisting essentially, by weight, of 0.30 to 0.40 percent of carbon, 0.20 to 1 percent of manganese, 0.50 to 1.50 percent of silicon, 3 to 4 percent of chromium, 2.5 to 3.5 percent of molydenum, 0.50 to 1 percent of vanadium, 1.50 to 2.50 percent of cobalt and the remainder iron and incidental impurities that do not deleteriously affect the product.

2. A low alloy content, high hardness, temper resistant steel having a composition consisting essentially, by weight, of about 0.32 to 0.37 percent of carbon, 0.20 to 0.40 percent of manganese, 0.80 to 1.20 percent of silicon, 3 to 3.5 percent of chromium, 2.60 to 2.90 percent of molybdenum, 0.65 to 0.85 percent of vanadium, 1.50 to 2 percent of cobalt and the remainder iron.

3. An allow in accordance with claim 2 containing at least one element selected from the group consisting of sulfur, phosphorus, lead and selenium in an amount sufficient to enhance the machining characteristics thereof.

4. A steel in accordance with claim 1 characterized by a tempered Rockwell C hardness of at least 50, with an ultimate tensile strength of at least 165,000 p.s.i. and a yield strength of at least 150,000 p.s.i., at temperatures up to at least 1100° F.

5. A die block composed of a steel in accordance with claim 4.

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