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ALLOY STEEL AND METHOD OF HEAT TREATMENT THEREFOR

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My invention relates to a new and improved low alloy steel, and particularly to a hot work steel having exceptional hardenability properties which makes it especially useful for hot work implements of large size.

There are two basic methods of preparing hot work implements used in metal shaping operations, such as forging. The first method is to machine the die steel in its annealed or softened condition, and then heat-treat the machined die. The second method is to reverse the foregoing steps, that is, first heat-treat the die steel, and then machine it.

In applications in which a very high hardness in the hot work implement is desired, the second method is not desirable because the heat treatment will raise the hardness to a level which makes the steel extremely difficult to machine. A typical application in which a high hardness is necessary is a forging die which is subjected to high-impact loads.

To prepare a forging die from a die block, it is therefore necessary to first machine the steel in its annealed condition and then heat-treat it due to the machining difficulties involved if the steel is first heat treated. In order to achieve the necessary hardness in the heat treatment, the steel is invariably quenched in oil or water. Such a quench is often undesirable because the steel is thereby subjected to distortion and warping, and there is danger of cracking. If the die should crack, all of the time and effort expended in machining the die block is completely lost, and the die is a total loss except for its scrap value.

By contrast, my die steel, after being machined and then heat treated, will come out of a heat treating furnace at almost maximum hardness after a slow furnace cool. Using such a slow cool minimizes distortion, warping and danger of cracking, and practically eliminates scrapping of the die due to the above-mentioned defects.

Typical applications for my new steel are dies and inserts for hot forging work, dies for extrusion work, and plastic molds and die casting dies.

The composition of my new alloy steel is substantially as follows, it being understood that the specified ranges are to be interpreted in the light of conventional check analyses tolerances.

	Percent by weight
Carbon	.35–.50
Manganese	.35–.60
Silicon	.40–1.00
Nickel	3.00–4.00
Chromium	1.00–3.50
Molybdenum	.50–1.00
Vanadium	.25–.40

Balance substantially all iron with the usual impurities.

Carbon, of course, is essential in order to provide the necessary strength and hardness for the hot working applications mentioned above. If the carbon content is much above .50, the steel becomes difficult to weld, and it is highly desirable that the steel be weldable so that cracks and repairs due to accidents or mishandling in the field can be easily made. If the carbon content is much below .35, it is difficult to get the required hardness. I therefore limit the carbon content of my steel to the range of from about .35 to about .50, and preferably to a range of from about .37 to about .45.

Manganese is necessary in order to reduce red shortness caused by sulphur. As is well known in the art, manganese readily combines with sulphur, and as a general rule, I find it desirable to add manganese in the ratio of 20 times the sulphur. I therefore desire from about .35 to about .60 percent manganese. Any substantial quantity of manganese above .60 promotes an above normal number of non-metallic inclusions (i.e., the steel becomes dirty). If much below .35 manganese is added, the desired control of hot shortness is not obtained with normal sulphur contents. I therefore limit my manganese to from about .35 to about .60 percent, and preferably from about .40 to about .60 percent.

Phosphorous and sulphur are tramp elements in my steel, and should be kept at as low a level as economically feasible. Preferably, neither of these elements should exceed .025 percent.

Silicon is necessary in order to increase the resistance to tempering of my steel. If much over 1 percent silicon is used, the steel tends to become brittle, whereas if much less than .40 percent is used, the silicon is ineffective to accomplish its desired result. I therefore limit silicon to the range of from about .40 to about 1.00 percent, and preferably to the range of from about .70 to about 1.00 percent.

Nickel and chromium are both necessary in order to increase hardenability. With respect to this particular steel, I use the word "hardenability" to indicate hardness penetration in pieces of large cross section, not ability to harden. I have discovered that when the nickel and chromium content fall within rather well defined ranges, exceptional hardenability characteristics result. At the same time, however, the nickel content cannot be too high or the steel will become austenitic. Likewise, the chromium content cannot be too high or the steel will become non-hardenable. I therefore limit the nickel content of my steel to the range of from about 3.00 to about 4.00 percent, and preferably from about 3.50 to about 4.00 percent, and chromium to the range of from about 1.00 to about 3.50 percent, and preferably to the range of from about 2.00 to about 2.50 percent. Hardness penetration through massive steel sections requires substantial amounts of nickel and chromium. Although they may be partially interchanged, amounts substantially below those indicated will not effect through hardening.

Molybdenum and vanadium both increase resistance to softening and tempering. These elements also increase the secondary hardening effect which is one of the best characteristics of my steel. If either the molybdenum or vanadium contents are too high, however, the steel will become unhardenable. If the contents are too low, the necessary effects will not be obtained. I therefore limit my broad ranges of molybdenum and vanadium to the ranges of from about .50 to 1.00 and to from about .25 to about .40, respectively, and preferably to the ranges of from about .80 to about 1.00 and from about .25 to about .35, respectively.

The unusual properties of my steel will become apparent from a study of the following tables. In the tables, steel A is a steel falling within the scope of my invention and having the following composition:

(A)

Carbon	.396
Manganese	.61
Silicon	.65
Nickel	3.97
Chromium	2.90
Molybdenum	1.04
Vanadium	.33

And the balance iron with the usual impurities.

Steel B is a steel widely used in hot work applications, such as hammer forging dies, whose nominal ranges are as follows:

(B)

Carbon	.50–.60
Manganese	.65–.90
Silicon	.20–.35
Nickel	.80–1.00
Chromium	.80–1.10
Molybdenum	.25–.35

And the balance iron with the usual impurities.

The unusual hardenability of my steel is indicated in the following table. A review of the data shows that the optimum annealing temperature is around 1100° F. to 1125° F. Even at these temperatures the transformation is incomplete after 100 hours.

TABLE I

Isothermal Annealing

STEEL A

Austenitized 1 hour at 1,600° F. and transformed at—	Brinell diameter—oil quenched			
	16 hours	48 hours	88 hours	113 hours
1,250° F	2.70	----------	----------	----------
1,200° F	2.70	2.80/2.85	----------	----------
1,150° F	2.70	2.95/3.10	3.20/3.30	----------
1,125° F	----------	3.20/3.30	----------	3.50/3.70
1,100° F	2.65/2.70	3.00/3.10	3.60/3.75	----------
1,050° F	2.55/2.60	----------	----------	----------
1,000° F	2.55/2.60	----------	----------	----------

A comparison of my new steel to the standard steel with respect to resistance to tempering is set out below:

TABLE II

Temper., ° F.	Steel B		Steel A	
	70°	900°	70°	900°
1,000	[1] 3.10	3.45	[1] 2.70	3.40
1,050	----------	----------	2.80	3.40
1,100	3.20	3.55	3.00	3.70

[1] Brinell diameter.

A comparison of the Brinell diameter values in the above table will disclose that up to and including a tempering temperature of 1100 degrees, my new steel has a markedly higher resistance to tempering than the conventional steel. This shows that my new steel is more suitable than the standard steel for such applications as forging hammers in which the steel is subjected to high-impact loads and alternate heating and cooling.

In order to achieve the good hardenability characteristics, I preferably austenitize my steel in the range of from about 1600° F. to about 1650° F., air harden the steel to at least a temperature at which it can be held in the hand (or, in other words, approximately room temperature) and then double temper the steel. The first temper should be at a temperature sufficient to condition the retained austenite. This temperature may vary somewhat from analysis to analysis within my broad range, but a temperature on the order of about 1000° F. will usually be quite satisfactory. The second tempering temperature should be sufficient to achieve the desired hardness. Again, this temperature may vary somewhat from analysis to analysis within my broad range, but a temperature in the range of from about 1000° F. to 1100° F. will usually be quite satisfactory.

It should also be noted that my new steel will have extremely high resistance to abrasion. There is a substantial quantity of vanadium and molybdenum present, both of which are good carbide formers, and therefore it will resist washing very well. This, of course, is important in repetitive applications, such as forging work.

Although I have illustrated and described preferred and specific embodiments of my invention, it will be understood that it is not so limited, and that slight modifications may be made by one skilled in the art without departing from the spirit of the invention. Accordingly, the scope of my invention should only be limited by the scope of the hereinafter appended claims.

I claim:

1. A method of developing substantially uniform hardness in a piece of steel of large cross section by heat treatment, the composition of said steel being substantially as follows in percent by weight:

Carbon	From about .35 to about .50
Manganese	From about .35 to about .60
Silicon	From about .40 to about 1.00
Nickel	From about 3.00 to about 4.00
Chromium	From about 1.00 to about 3.50
Molybdenum	From about .50 to about 1.00
Vanadium	From about .25 to about .40

and the balance substantially all iron, said steel having exceptional hardenability and good resistance to softening, said method including the steps of sustenitizing the steel in the range of from about 1600° F., to about 1650° F., air hardening the steel to approximately room temperature, and then double tempering the steel, the first tempering temperature being sufficient to condition the retained sustenite, and the second tempering temperature being sufficient to achieve a desired, substantially uniform hardness throughout pieces of large cross section.

2. An alloy steel consisting essentially of, in percent by weight, about .35 to about .60 carbon, .35 to about .50 manganese, .40 to about 1.00 silicon, 3.00 to about 4.00 nickel, 1.00 to about 3.50 chromium, .50 to about 1.00 molybdenum, and .25 to about .40 vanadium, balance essentially iron, said steel being characterized by having good resistance to abrasion and softening after prolonged exposure at elevated temperatures, and by excellent through hardness in large, mechanically worked cross sections when austenitized in the range of from about 1600° F. to about 1650° F., air hardened to approximately room temperature and then double tempered.

3. An alloy steel consisting essentially of, in percent by weight, about .37 to about .45 carbon, .40 to about .60 manganese, .70 to about 1.00 silicon, 3.50 to about 4.00 nickel, 2.00 to about 2.50 chromium, .80 to about 1.00 molybdenum, .25 to about .35 vanadium, balance essentially iron, said steel being characterized by having good resistance to abrasion and softening after prolonged exposure at elevated temperature, and by excellent through hardness in large mechanically worked cross sections when austenitized in the range of from about 1600° F. to about 1650° F., air hardened to approximately room temperature and then double tempered.

4. A forgeable alloy steel hardenable by austenitizing in the range of from about 1600° F. to about 1650° F., air hardening to room temperature, and double tempering, and capable of retaining a through hardness of 3.50 to 3.75 Brinell diameter after prolonged exposure at elevated temperature comprising, in percent by weight, car-

bon .35 to about .60, manganese .35 to about .50, silicon .40 to about 1.00, nickel 3.00 to about 4.00, chromium 1.00 to about 3.50, molybdenum .50 to about 1.00, and vanadium .25 to about .40, balance essentially iron.

5. A mechanically worked, hot work implement of large cross section especially adapted for subjection to high impact loads of a repetitive nature under elevated temperature conditions and being characterized by having a substantially uniform through hardness of 3.50 to 3.75 Brinell diameter upon austenitizing, air hardening, and double tempering at a final temperature in the range of about 1000° F. to 1100° F., and comprising, in percent by weight, carbon .35 to about .60, manganese .35 to about .50, silicon .40 to about 1.00, nickel 3.00 to about 4.00, chromium 1.00 to about 3.50, molybdenum .50 to about 1.00, and vanadium .25 to about .40, balance essentially iron.

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