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ALLOY STEEL

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This invention relates to cutting steels and tools and has for its object certain improvements in the manufacture of steels and tools for cutting. The invention relates more particularly to improvements in high speed cutting steels and to improved high speed cutting tools as an article of manufacture.

High speed cutting tools are generally made now from steel of the 18-4-1 type, which is the commercial mode of referring to a steel containing approximately 18 percent of tungsten, 4 percent of chromium, and 1 percent of vanadium. This basic composition is modified in some instances, as by adding cobalt where a high degree of red hardness is required. The adoption of the 18-4-1 type steel has been so universal for the manufacture of high speed tools that it can be considered as standard for this purpose at the present time. Because of its high content of alloying elements, particularly tungsten, and the relative costliness of this element in comparison with possible substitutes, the 18-4-1 steel, however, is expensive, and it is known to possess certain disadvantages.

Accordingly, efforts have been made to provide other steels for the same purpose. In general, it has been attempted to substitute molybdenum for part or all of the tungsten in the 18-4-1 type of steel. In consequence there have appeared commercially other high speed steels of two general types. One of these is a tungsten-molybdenum steel containing a relatively large amount of molybdenum, for example, about 8.22 percent or more, together with tungsten, vanadium and chromium. The other is essentially a high molybdenum steel, containing about 9.5 percent of molybdenum together with vanadium, chromium, and carbon in about the amount present in 18-4-1 steel.

The molybdenum and the tungsten-molybdenum cutting steels have not found wide commercial acceptance for a number of reasons. In the first place, they have a marked tendency to develop a soft outer skin or bark both during the process of manufacture and in their subsequent hardening. They can be treated only within a relatively narrow range of hardening temperatures. These steels are subject to ready formation of coarse grains which results in an objectionable brittleness in the ultimate fully hardened cutting tool. These steels likewise exhibit a lack of strength and toughness in the hardened and tempered tool, and they are characterized by a lower cutting efficiency than is shown by the standard 18-4-1 type. These disadvantages have mili-

tated against the molybdenum and the tungsten-molybdenum cutting steels in favor of the more expensive 18-4-1 tungsten cutting steels.

It is among the objects of this invention to provide high speed tools formed from steels of relatively simple composition and relatively low content of alloying elements, which are less expensive than those commonly used for this purpose, which possess the hardness necessary for such purposes in combination with greatly improved toughness, are characterized by substantially better cutting efficiency than those available heretofore, possess the advantages of other high speed tools, and in which major disadvantages heretofore encountered are minimized.

I have discovered, and it is upon this that my invention is predicated, that cutting tools for high speed use possessing substantially improved characteristics, especially as regards performance in use, as compared with those heretofore available, are provided from steels of a balanced composition containing chromium, molybdenum and vanadium and without the use of tungsten as an essential element. In other words, I have found that tungsten is not necessary in such steels, and that in appropriately balanced compositions the molybdenum steels are particularly beneficial, contrary to prior beliefs in the art.

The balanced composition of my discovery may be stated as that in which the vanadium content of the steel is approximately $1\frac{1}{2}$ to $2\frac{1}{2}$ times and preferably about twice the carbon content, the combined content of vanadium, chromium, and carbon being approximately equal, to the content of molybdenum.

In the practice of the invention the tools are formed from steels containing about .6 to 1.25 percent of carbon, about 3.5 to 6.0 percent of chromium, about 5.0 to 11.0 percent of molybdenum, and about 1.00 to 3.0 percent of vanadium, the relative proportions of which are balanced in the manner above set forth.

While the foregoing range of composition is illustrative of the broader aspects of the invention, and is productive of tools embodying its stated objects, I have found that for many purposes the tools are advantageously made from steel containing about 0.7 to 1.0 percent of carbon, about 4.0 to 4.5 percent of chromium, about 6.5 to 7.3 percent of molybdenum, and about 1.4 to 1.9 percent of vanadium. Within this range of composition the alloying elements are balanced, according to my invention, in a manner which provides substantially improved characteristics, as will appear hereinafter.

The steels may contain the elements normally present as impurities in steels of this type, as well as other elements provided they are present in amounts which do not detrimentally affect the desirable properties which characterize the invention. Hence the remainder of the steels, apart from the essential constituents referred to, may be considered as being effectively iron.

Particular specimens of steels in accordance with the present invention have resulted in the following analyses:

TABLE I

Steel	Carbon	Chromium	Vanadium	Molybdenum
Specimen 1.....	.74	4.15	1.19	6.81
Specimen 2.....	.84	3.86	1.93	6.56
Specimen 3.....	.92	4.03	1.31	6.72
Specimen 4.....	.99	4.08	2.64	7.24
Specimen 5.....	1.03	4.10	2.14	6.67

Steels in accordance with the invention are made by any of the well known methods such as those practiced in producing alloy steels in electric furnaces or in crucibles.

The tools are made in the manner known in the art, most suitably by forging to roughly shape them, grinding to shape or machining to the desired form, and they are, as usual, heat treated to develop the necessary cutting properties. As is the general practice with high speed steels at present in use, the quenching temperature may vary within a certain prescribed temperature range, the tempering conditions being varied to suit the purpose for which the tool is intended.

By way of illustration, the steels of the invention may have an approximate hardening range of 2170° to 2250° F. and a tempering range 980 to 1100° F. The examples given hereinafter are indicative of how the properties may be varied by heat treatment.

Lack of sensitivity to variations in the hardening temperature over a comparatively wide range is a valuable property in high speed steel. Examination of the data supplied by mechanical tests clearly shows that the present vanadium-molybdenum type is no more, if in fact as, sensitive to such variations as the standard or 18-4-1 type. It is noticeably less sensitive than the tungsten-molybdenum type.

It is important that the steel from which the tool is formed shall not tend to coarsening of its grains, or to embrittlement, in bringing it to the fully hardened condition. Likewise, the steel should be easy to fabricate without showing any particular tendency to cracking. In high speed steels the carbides are the hard and brittle constituents. Thus, a high speed steel that has the property of dissolving a greater amount of these

carbides in the hardening operation will be stronger and tougher for a given degree of hardness than a steel which does not develop this property to the same extent. I have found, through microscopic examination of suitable polished specimens of my steel that the ability to dissolve carbides is noticeably greater than is the case generally with high speed steels containing tungsten.

One of the major properties requisite in a high speed tool is that of toughness. The reason for this is that the useful life of a tool is dependent in large part upon its toughness, because it is this property which permits the cutting edge to resist destruction. Toughness as it affects the life of a cutting tool may be considered of two types, viz. (a) ability to resist rupture, and (b) ability to resist crumbling or tearing away of small particles from the cutting edge. Experience has shown that a high ability to resist crumbling does not necessarily accompany a high ability to resist rupture.

At the present time there is no generally accepted method of test, whether static or dynamic, for measuring the toughness of high speed steel under actual working conditions wherein the metal is subject to severe stress either in the form of rapid impact or sudden reversal of stress. In order, therefore, to demonstrate the superiority of steel in accordance with the present invention over known types of high speed steel, a form of maximum fiber test supplemented by service tests were employed. The maximum fiber test serves also as a useful guide in selecting the best heat treating range for steel of any particular analysis.

In the maximum fiber test a specimen consisting of a round bar spanning spaced supporting rollers has transversely applied thereto midway of the supports, a load the magnitude of which is increased rather rapidly from a low initial value to that producing failure of the specimen. Specimen bars were in this way tested to destruction, the toughness factor being taken for purposes of comparison as the product of the maximum fiber strength, calculated from the standard formula, by the ultimate deflection at rupture, obtained from the stress-strain curve automatically traced on the drum of an Amsler hydraulic tensile testing machine.

Tests of this character were conducted on similarly dimension specimens of equal hardness comprising bars of the standard 18-4-1 steel, bars of the recently available tungsten-molybdenum steel above referred to, and bars composed of steel in accordance with the present invention. The results for different hardness values were as follows:

TABLE II

Hardness 65.5 to 66.6 Rockwell C

Steel	C	Cr	Mo	V	W	Hardened °F.	Tempered °F.	Comparative toughness
Standard.....	0.74	4	-----	1	18	2370	1050	70600
Mo-W.....	0.76	4	7	1	2	2245	1030	71400
This invention.....	0.92	4	7	1.25	-----	2190	1050	96300
This invention.....	1.03	4	7	2	-----	2200	1050	94985

TABLE III

Hardness 64.5 to 65.4 Rockwell C

Steel	C	Cr	Mo	V	W	Hardened °F.	Tempered °F.	Comparative toughness
Standard.....	0.72	4	-----	1	18	2350	1050	108100
Mo-W.....	0.76	4	7	1	2	2245	1080	50200
This invention.....	0.76	4	7	1.25	-----	2190	1080	170800

¹ Average values.

TABLE IV

Hardness 64 to 64.4 Rockwell C

Steel	C	Cr	Mo	V	W	Hardened °F.	Tempered °F.	Comparative toughness
Standard.....	0.71	4	-----	1	18	2340	1050	103500
Mo-W.....	0.76	4	7	1	2	2180	1030	164300
This invention.....	0.76	4	7	1.25	-----	2190	1050	183700

TABLE V

Hardness 63.5 to 64.0 Rockwell C

Steel	C	Cr	Mo	V	W	Hardened °F.	Tempered °F.	Comparative toughness
Standard.....	0.63	4	-----	1	18	2350	930	107100
Mo-W.....	0.76	4	7	1	2	2245 to 2180	1080	54900 to 145000
This invention.....	0.76	4	7	1.25	-----	2160 to 2190	1050	157500 to 168000

TABLE VI

Hardness 61.7 to 62.9 Rockwell C

Steel	C	Cr	Mo	V	W	Hardened °F.	Tempered °F.	Comparative toughness
Standard.....	0.63	4	-----	1	18	2350	930	143000
Mo-W.....	0.76	4	7	1	2	2180	1060	132000
This invention.....	0.76	4	7	1.25	-----	2190	1050	162000

The test results show substantially higher toughness coefficients for steels in accordance with this invention than for the best known types of high speed steels. Moreover, this increased toughness is not secured at a sacrifice of hardness, the comparisons being made on steels of substantially the same hardness.

The maximum fiber test is essentially demonstrative of ability to resist rupture. Resistance against crumbling or tearing away of small particles of material is best determined by suitably selected service tests. The power hack-saw blade with very acute angles for its cutting edges and the repeated shocks to which it is rapidly subjected in service, constitutes an excellent means of comparing specimens with respect to toughness against crumbling as well as cutting hardness.

Accordingly in the tests now to be reported, hacksaws made from steels provided by this invention were compared with saws of other high speed steels in terms of "work value", a factor dependent upon the total amount of metal cut before failure and the time required. Inclusion of the time element as a factor in the "work value" is important as being indicative of the rate of penetration of the saw through the metal and also as providing a fair index of the ability of the blade to hold a cutting edge.

In one such test there were compared blades provided by this invention with blades made from commercial 18-4-1 steel. The test comprised the operation for one month on a commercial basis of six machines sawing eighteen different kinds of steel. The work values expressed in terms of 18-4-1 steel as 100 were as follows:

TABLE VII

Steel	C	Cr	Mo	V	W	Work value
Standard.....	-----	4	-----	1	18	100
This invention.....	.81	4.04	7.52	1.86	-----	156.5

In another series of tests, blades in accordance with this invention were compared with blades of 18-4-1 steel and with hack-saws formed from the aforementioned commercial tungsten-molybdenum steel, which represents the only, and presumably the best, material of its type on the

market. Again expressing the work values in terms of the 18-4-1 steel as 100, the following results were obtained:

TABLE VIII

Steel	C	Cr	Mo	V	W	Work value
Standard.....	-----	4	7	1	18	100.0
Tungsten - molybdenum.....	0.78	3.76	8.22	1.09	2.16	46.7
This invention.....	.74 to .84	3.9 to 4.2	6.5 to 6.8	1.2 to 1.9	-----	123.5

It thus appears that saws made of steel in accordance with this invention are capable of substantially better performance than those of the 18-4-1 type and of the best molybdenum types of high speed steel commercially available.

Tests on high speed steels employed as lathe tools furnish comparative data as regards cutting hardness and red hardness. The value of the tool is measured by the elapsed time of cutting before failure under conditions where speed, depth of cut and rate of feed are maintained constant. In order to evaluate results for comparative purposes they may be expressed in terms of "work value" which is the product of the total elapsed cutting time by the feet cut per minute.

As showing the superiority of tools formed of steels in accordance with this invention with others of 18-4-1 steel, lathe tools of each type were used for cutting a heat treated chrome-nickel steel having a Brinell hardness of 220-240. Expressing the work values in terms of that for the 18-4-1 steel as 100, the following data was secured:

TABLE IX

Steel	C	Cr	Mo	V	W	Work value
Standard.....	-----	4	-----	1	18	100
This invention.....	.76	4.06	6.58	1.24	-----	157
This invention.....	.92	4.03	6.72	1.31	-----	164.5
This invention.....	.81	4.04	7.52	1.86	-----	194

The lathe tool performance of the novel steels described herein is thus shown to be from about 50 to 100 percent better than for the standard tungsten-molybdenum-vanadium steels.

In a similar test there were compared tools formed of the steel provided by this invention with tools formed of the more recent molybdenum type referred to. The results expressed in terms of the 18—4—1 steel as 100 percent are given in the following table, in which the work values represent the aggregate of results of a plurality of durability tests on tools of each material. In each individual test the cutting speed was held constant, but the speeds varied between the different tests, the material cut being a Cr-Ni steel heat treated to a Brinell hardness of 270 to 300. Thus this test is a measure of the relative value of the steels over a range of cutting speeds, so that it represents the ability of the tools to meet commercial requirements.

TABLE X

Steel	C	Cr	Mo	V	W	Work value
Standard.....		4		1	18	100.0
Molybdenum type.....	.68	3.5	9.5	1.1		86.1
This invention.....	.79	3.77	6.42	1.83		121.5

It follows that the molybdenum type steel possesses substantially less efficiency than the standard 18—4—1, while that provided by this invention is substantially better.

The tests considered individually as well as collectively, thus conclusively demonstrate the all-around superiority of steels in accordance with the balanced compositions of the present invention as compared to the best high speed tool steels at present commercially available. Greater toughness and resistance against rupture are evidenced by the maximum fiber tests. Superiority as regards toughness against crumbling, red hardness, and cutting hardness, is shown by the hack-saw and lathe tool service tests. Other factors of superiority are the comparative cheapness, and the observed ease of heat treatment affording the desired hardness, and freedom from cracking in fabrication and heat treatment. These and other features combine to effect a substantial advancement in the art for cutting steels employing the balanced compositions of this invention.

I claim:

1. An improved cutting steel containing about 0.6 to 1.25 percent carbon, about 1.0 to 3.0 percent vanadium, about 3.5 to 6.0 percent chromium, about 5.0 to 11.0 percent molybdenum, the combined content of carbon, vanadium and chromium being approximately equal to that of the molybdenum, and the balance substantially all iron.

2. An improved cutting steel containing about 0.6 to 1.25 percent carbon, about 1.0 to 3.0 percent vanadium, the vanadium content being approximately $1\frac{1}{2}$ to $2\frac{1}{2}$ times the carbon content, about 3.5 to 6.0 percent chromium, about 5.0 to 11.0 percent molybdenum, the combined content of carbon, vanadium, and chromium being ap-

proximately equal to that of the molybdenum, and the balance substantially all iron.

3. An improved cutting steel containing about 0.6 to 1.25 percent carbon, about 1.0 to 3.0 percent vanadium, the vanadium content being approximately twice the carbon content, about 3.5 to 6.0 percent chromium, about 5.0 to 11.0 percent molybdenum, the combined content of carbon, vanadium and chromium being approximately equal to that of the molybdenum, and the balance substantially all iron.

4. An improved cutting steel containing about .7 to 1.0 percent carbon, about 1.4 to 1.9 percent vanadium, the vanadium content being approximately twice the carbon content, about 4.0 to 4.5 percent chromium, about 6.5 to 7.3 percent molybdenum, the combined content of carbon, vanadium and chromium being approximately equal to that of molybdenum, and the balance substantially all iron.

5. As an article of manufacture, an improved cutting tool made from a heat treated steel containing about 0.6 to 1.25 percent carbon, about 1.0 to 3.0 percent vanadium, about 3.5 to 6.0 percent chromium, about 5.0 to 11.0 percent molybdenum, the combined content of carbon, vanadium and chromium being approximately equal to that of the molybdenum, and the balance substantially all iron.

6. As an article of manufacture, an improved cutting tool made from a heat treated steel containing about 0.6 to 1.25 percent carbon, about 1.0 to 3.0 percent vanadium, the vanadium content being approximately $1\frac{1}{2}$ to $2\frac{1}{2}$ times the carbon content, about 3.5 to 6.0 percent chromium, about 5.0 to 11.0 percent molybdenum, the combined content of carbon, vanadium and chromium being approximately equal to that of the molybdenum, and the balance substantially all iron.

7. As an article of manufacture, an improved cutting tool made from a heat treated steel containing about 0.6 to 1.25 percent carbon, about 1.0 to 3.0 percent vanadium, the vanadium content being approximately twice the carbon content, about 3.5 to 6.0 percent chromium, about 5.0 to 11.0 percent molybdenum, the combined content of carbon, vanadium and chromium being approximately equal to that of the molybdenum, and the balance substantially all iron.

8. As an article of manufacture, an improved cutting tool made from a heat treated steel containing about .7 to 1.0 percent carbon, about 1.4 to 1.9 percent vanadium, the vanadium content being approximately twice the carbon content, about 4.0 to 4.5 percent chromium, about 6.5 to 7.3 percent molybdenum, the combined content of carbon, vanadium and chromium being approximately equal to that of molybdenum, and the balance substantially all iron.

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