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STEEL ALLOY

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This invention relates to molybdenum high-speed steels. As that term is used herein, it means molybdenum alloy steels characterized by their ability to develop a condition of hardness after suitable heat treatment which permits tools, such as forming tools, lathe tools, drills, reamers, dies, etc., made from such steel, to operate efficiently even when the working edges or surfaces of such tools become relatively hot.

Particularly, this invention relates to high-speed steels which derive their outstanding characteristics from the use of molybdenum therein in combination with other elements. Examples of the constituents of commercial molybdenum high-speed steels are as follows:

No. 1

C	Mn	Si	Cr	Mo	W	V
Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
.70	.15	.15	4.00	4.00	5.25	1.25
.90	.45	.45	4.50	4.75	6.00	1.75

No. 2

C	Mn	Si	Cr	Mo	W	V
Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
.70	.15	.15	3.75	8.00	1.25	.90
.90	.45	.45	4.25	9.00	1.75	1.20

No. 3

C	Mn	Si	Cr	Mo	W	V
Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
.70	.15	.15	3.75	8.50	Nil	1.80
.90	.45	.45	4.25	9.50	-----	2.20

The above analyses are given by way of example only and not by way of limitation, because it is possible to vary the proportions of the constituents of these steels to a considerable extent. For instance, steels having a composition within the following ranges are practical molybdenum high-speed steels:

C	Mn	Si	Cr	Mo	W	V
Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
.30	.15	.15	3.00	3.00	Nil	.50
1.00	.45	.45	5.00	10.00	8.00	2.50

As compared with the older high-speed steels, that is those containing tungsten only, these steels have been found to have certain disadvantages. The most outstanding of these are, first, a narrow hardening range and, second, a strong tendency to decarburize in the hardening operation.

These molybdenum type high-speed steels have a very narrow useful hardening temperature range of about 2175–2225° F. Such a narrow range necessitates very accurate control of furnace temperatures which makes necessary expensive and delicate equipment. If the hardening temperature is not accurately and carefully controlled in treating the molybdenum steels, excessive grain growth may result. If the temperature is not sufficiently high, such steel will show a proper hardness after the hardening operation, but will not show the necessary hardness after tempering in the range of 900–1100° F. Lack of hardness after such a tempering operation results in a tool which does not have maximum secondary hardness and consequently will not produce satisfactory results when operating conditions tend to heat up the tool.

If, on the other hand, the temperature is higher than the desired range, the resulting tool will be very coarse-grained, which means a very brittle tool. Since tools of this character are used under heavy loads, this brittleness contributes to early failure.

All of these molybdenum high-speed steels will readily decarburize during heating for hardening, resulting in a very soft surface and often requiring the grinding or scraping of the tool, a costly and time-consuming operation. To prevent such decarburization during hardening, very special heating equipment such as salt baths and special controlled atmosphere furnaces is necessary. For many reasons, the average machine shop does not possess the special equipment necessary to heat-treat these molybdenum steels. Such equipment is costly, and it requires considerable skill and experience in the operation thereof to produce satisfactory results.

We have discovered that the disadvantages and the shortcomings of these steels can be overcome and that the molybdenum high-speed steels can be advantageously used in the ordinary small tool shop which has only the usual commercial heat treating equipment by adding to this type of steel, columbium, in amounts from about .15–3.00%.

Tests were made as described below to discover the effect of different amounts of columbium on the three types of molybdenum steel noted above.

Hot working

To each of the numbered molybdenum steels referred to above, varying amounts of columbium were added and ingots cast. For comparison purposes, one ingot of each type of steel was made with no columbium added. With steel No. 1, eight ingots were made with columbium varying from nil to 2.02%. With steel No. 2, the columbium was varied from nil to 2.63% in the eight ingots made. With steel No 3, the columbium was varied from nil to 1.89% in the eight ingots made. When cast, the ingots were cooled in lime to room temperature, followed by annealing from a temperature of 1550° F. The ingots were surface-ground and heated for hot working to a temperature of 1900–1950° F. During such hot working, no difficulties because of the presence of columbium were encountered and the resulting bars were free from scabs and slivers and showed a good hot-worked surface.

Annealing

The addition of columbium does not interfere with or change the annealing properties of these types of steel. Equally soft material can be obtained with or without columbium.

The test specimens were given a standard high-speed mill anneal, which consists of packing them in cast iron borings and heating to a temperature of 1550–1560° F. It required 18 hours for the charge to reach furnace temperature. This was followed by soaking at least 22 hours and cooling slowly for a total time of 20 hours to approximately 1200° F. After this operation, each specimen was examined for hardness in accordance with the Brinell test.

For the No. 1 type of steel, it was found that, between the columbium range of nil to 1.18%, the Brinell hardness test showed reading between 217 and 229. Within the columbium range of 1.18 to 2.02%, the Brinell readings ranged up to 241.

With steel No. 2, the Brinell test showed readings of 235 to 241 in the columbium range from nil to .36%. With columbium from .36 to 1.50%, the Brinell test showed about 230. Increased amounts of columbium showed a slight decrease in hardness.

Tests of No. 3 steel indicated that, for a columbium range of nil to 1.89%, the Brinell readings ranged between 207 and 229, most of them in the neighborhood of 217.

These tests indicate that the addition of columbium to any of the above-mentioned standard molybdenum high-speed steels does not change the annealing characteristic of the steel.

Hardening

An outstanding advantage derived from the addition of columbium is the retention of fine grain structure during hardening operations and consequently the extension of the useful hardening range. Molybdenum high-speed steels without columbium show an excessively coarse fracture when treated from 2300° F., while steels containing approximately 1.00 to 1.50% columbium show a very fine grain structure at this higher temperature and substantially equal to that obtained at the lower temperatures. This characteristic is useful with any high-speed steel, because it enables that steel to be heat-treated over a wide range of temperatures without materially affecting the structure characteristics, thereby resulting in tougher, stronger tools.

The addition of columbium raises the initial hardening temperature and this is an advantage, because the higher the initial hardening temperature, the greater the amount of secondary hardness which can be obtained and consequently the higher the operating efficiency of the tool.

After the annealing operation described above, the specimens were turned from 1⅛" square cross section to 1⅛" round. Sections approximately 1⅛" round by 3" long were treated from superheating temperatures of 2200° F., 2250° F., and 2300° F. This temperature range was employed to allow for the overheating of the steels containing little or no columbium and permitted the evaluation of the various columbium additions.

Regardless of the subsequent superheating temperature, all samples were preheated to 1500° F. for a total time of 30 minutes in an atmosphere analyzing CO_2—11.00%; O_2—nil, CO—2.40%. Samples from both the No. 2 and No. 3 steel were superheated in an atmosphere analyzing CO_2—5.90%, O_2—nil, CO—12.10%. Samples from the No. 1 type of steel were superheated in an atmosphere analyzing CO_2—10.30%, O_2—nil, CO—4.60%. These atmospheres were selected as representing average practice in the hardening of high speed steel, and can be obtained in ordinary furnaces. For the three superheating temperatures employed, the samples were allowed to remain in the high temperature for a total time of ten minutes, followed by oil quenchnig to approximately room temperature. The specimens were then classified by the so-called "Shepherd fracture comparison test." In making such comparison, the grain structure of the specimens were compared by three different observers with the standard Shepherd grain structures which are numbered 1 to 10, No. 1 being extremely coarse, while No. 10 is very fine.

These tests indicate that, in regard to the No. 1 steel treated at 2200° F., within the columbium range of .09 to 1.18%, the Shepherd classification number was between 9¼ and 9½. With the same type of steel heated to 2250° F. and within the same columbium range, the grain structure was substantially the same toward the higher portion of this columbium range and about ¼ of a point lower toward the lower portion thereof. When this No. 1 steel was heated to 2300° F., the grain structure was fine, as indicated by the numeral 9 for the higher columbium content, such as 1.18% and graded down to a Shepherd index of about 7 for a negligible columbium content.

With the No. 2 type of steel heated to 2200° F., the Shepherd index was substantially 9½ for all columbium ranges from nil to 1.50%. When the same steels were heated to 2250° F., they maintained their fine grain structure with the higher columbium content, that is, about 1.50%, but dropped off to about 8¾ when only traces of columbium were present. When the steels were heated to 2300° F., the fine grain structure was maintained with an index of 9¼ to 9½ with the 1.50% columbium content, but as the columbium was decreased, the index dropped so that it was only 6½ with no columbium.

With the third type of steel heated to 2200° F., the Shepherd index was in excess of 9 for the range from nil to 1.27% columbium. When the steels were heated to 2250° F., the same index was maintained for about the upper half of the columbium range, but in the lowest part thereof dropped to about 8½. When this type of steel was heated to 2300° F., the Shepherd index with

1.27% columbium was about 8 and dropped from there to about 6 or 6¼ with no columbium.

The specimens of each type of steel with the different amounts of columbium treated at 2200°, 2250°, and 2300° F. were also examined for grain size by the intercept grain count method. In this method of determining grain size, the microspecimen is examined at 1000 magnification on a 5" line spanned across the image. The number of grains cut or intercepted by this line is counted and this is known as the grain count. Naturally, the higher the grain count, the finer the grain and vice versa.

An examination of specimens of the No. 1 type steel heated to 2200° F. indicated that, with columbium contents from nil to .81%, the grain count varied from 12.40 to 14.20. With specimens from the same steel heated to 2250° F. a grain count for .09% to 1.18% columbium ranged between 11 and 12 with a slight increase in grain size as the columbium content dropped toward zero. When specimens of the same steel containing varying amounts of columbium were heated to 2300° F., the finest grain was shown with a columbium content of .81–2.02% with a definite increase in grain size as the columbium content dropped toward zero.

With specimens of the No. 2 type of molybdenum steel treated at a temperature of 2200° F., the grain count within the columbium range of .06 to .36% was in excess of 12, with a very slight increase in grain size below this columbium range, and a slight decrease above. With a treating temperature of 2250°, these same type of specimens had a grain count of 11.9, with a columbium content of .36%. The grain size increased slightly as the columbium was lowered below this amount, with a grain count of about 12 for all the higher columbium contents. With a treating temperature of 2300°, the finest grain was found with a columbium content of 1.50%. The grain count measured 10.6. As the columbium content was lowered, the grain size increased.

With the No. 3 type of commercial molybdenum steel and a treating temperature of 2200° F., the finest grain was found with a columbium content of .26 to .74%. As this content was raised to .87%, fine grain was substantially maintained. As it was lowered to a mere trace of columbium, the grain coarsened. With specimens heated to 2250° F., the finest grain was obtained with a columbium content from .74 to 1.89%. The grain count was about 12. The grain size increased slightly when the columbium content dropped below this range. When the specimens of this No. 3 steel were heated to 2300° F., the finest grain was obtained after reaching a columbium content of .87%. This grain count measured 8.6. With a decrease in columbium, the grain size increased sharply.

Hardness tests of hardened specimens of each of the commercial molybdenum steels with varying amounts of columbium from 0 to slightly in excess of 2% as indicated, showed a Rockwell hardness of substantially C 64/65 for oil treating temperatures of 2200° F.–2300° F.

Surface carbon

From the standpoint of the tool manufacturer, a very important consideration is the ability of tool steel to resist decarburization during the hardening operation. Any steel which has a tendency to decarburize excessively during this operation has definite undesirable features in connection with the manufacture of tools. Decarburization of the surface of the steel often results in warping, distortion, or cracking of the tool. It also results in a very soft surface and to remove this, expensive grinding must be resorted to. Moreover, on certain types of tools made from these steels, such as intricate form cutters, the design of the tool does not permit any grinding after heat treating. For all these reasons, it is very desirable to have a steel which does not decarburize on the surface when treated with the usual heat treating methods employed to produce a high-speed tool.

Specimens of the three types of molybdenum steel with different amounts of columbium were heat treated as described under "Hardening." Following this treatment, the specimens were annealed in lead from a temperature of 1400° F. so as not to affect the surface carbon content, cooled in lime to room temperature, and cleaned with hydrochloric acid. Four steps or cuts, each .005" on the diameter, were then machined off and carbon determinations made on the layers as removed. Prior to any hardening, surface carbons were obtained on the machined diameter, representing .005" on the diameter.

On No. 1 type of steel, the carbon content on the surface of all specimens before hardening was determined and found to be .80%. On the specimens oil treated at 2200° F., the carbon content on the first .0025" thick layer ranged from .77% on the steel containing 1.18% Cb down to .64% on the steel containing no columbium. On the second layer, which went to a depth of .005", the carbon ranged from .77% for the high columbium down to .69% for the columbium free steel. On the third layer which went to a depth of .0075", the carbon ranged from .77% down to .72%, and on the fourth layer which went to a depth of .010", the carbon ranged from .77% to .75%. With treating temperatures of 2250° F. and 2300° F., the carbon results observed were substantially the same as the 2200° F. figures. Since the slight difference between .80% (original carbon content) and .77% is considered to be within the limit of experimental error in chemically determining carbon, the results indicate virtually perfect maintenance of surface carbon content on the high columbium steels at all three treating temperatures.

On the No. 2 steel, the carbon content on the surface of all specimens before hardening was ascertained to be .79%. On the specimens oil treated at 2200° F., the carbon content of the first .0025" thick layer ranged from .66% on the steel containing 1.27% columbium down to .49% on the steel containing no columbium. On the second step or layer, the carbon content ranged from .72% on the high columbium steel down to .54% on the columbium-free steel, on the third step .75% down to .64%, and on the fourth step .77% down to .70%. With higher treating temperatures the carbon results on the various steps were uniformly higher, the columbium-containing analyses steel showing a marked advantage. At a treating temperature of 2300° F. for example, on the first layer, which was taken off to a depth of .0025", the carbon ranged from .79% for the high columbium steel down to .68% for the columbium-free steel, and on the second layer taken at a depth of .005" the carbon ranged from .79% to .72%. These results indicate that for temperatures approaching 2300° F., virtually no decarburization occurs

on the steel containing the higher columbium percentages.

On the No. 3 steel, the carbon content on the surface of all specimens before hardening was determined as .81%. Specimens were treated at 2200° F., 2250° F., and 2300° F., and carbon determinations were made at various depths as in the case of steels #1 and #2. In each case it was found that the higher columbium contents results in either a marked decrease in, or entire elimination of, decarburization. As an example, on the steel containing 1.27% columbium, the carbon contents of the first layer of .0025" on the specimens treated at 2200° F. and 2300° F. were .73% and .81% respectively.

In light of the results disclosed, the presence of columbium is seen to decrease to an unharmful amount, or to eliminate entirely, the occurrence of decarburization through the range of desirable hardening temperatures on all three of the commercial molybdenum high speed types.

Tantalum can be used with or in place of columbium to provide the advantages set forth herein. Titanium, zirconium, cerium, and uranium may be also used individually, or with columbium, or tantalum, or each other, to effect the purpose of this invention, as the advantages of the invention, at least to a certain extent, are inherent also in the use of these elements.

While we have shown the invention as embodied in a specific form, it is to be understood that various changes in details may be made without departing from the scope of the invention as defined by the appended claims.

We claim:

1. A molybdenum steel alloy containing from about 0.30 to about 1.00 percent carbon, from about 3.00 to about 5.00 percent chromium, from about 3 to about 10 percent molybdenum, less than 8 percent tungsten, from about 0.50 to about 2.50 percent vanadium, from about 0.15 to about 3.00 percent of an element selected from the group consisting of columbium, tantalum, titanium, zirconium, cerium and uranium and the balance substantially all iron.

2. A molybdenum steel alloy containing from about 0.30 to about 1.00 percent carbon, from about 3.00 to about 5.00 percent chromium, from about 3 to about 10 percent molybdenum, less than 8 percent tungsten, from about 0.50 to about 2.50 percent vanadium and about 0.15 to about 3.00 percent columbium and the balance substantially all iron.

3. A molybdenum steel alloy containing from about 0.30 to about 1.00 percent carbon, from about 3.00 to about 5.00 percent chromium, from about 3 to about 10 percent molybdenum, less than 8 percent tungsten, from about 0.50 to about 2.50 percent vanadium and about 0.50 to about 2.50 percent columbium and the balance substantially all iron.

4. A steel alloy containing from about 0.7 to about 0.9 percent carbon, from about 3.00 to about 5.00 percent chromium, from about 3 to about 10 percent molybdenum, less than 8 percent tungsten, from about 0.50 to about 2.50 percent vanadium, from about 0.15 to about 3.00 percent columbium and the balance substantially all iron.

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