Patented Nov. 16, 1937 2,099,509

UNITED STATES PATENT OFFICE

2,099,509

STEEL ALLOY

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No Drawing. Application November 23, 1935, Serial No. 51,224

13 Claims. (Cl. 75—126)

The present invention relates to molybdenum steels of the type adapted for dies such as hot or cold forging dies, wire drawing dies and casting dies, and for cutting tools, especially red hard cutting tools, such as turning tools, milling cutters, punches and the like.

The invention has for an object to provide an improved steel of this type and one which can be economically manufactured.

Another object is to provide a steel of this type having a low hardening temperature.

It has been discovered in accordance with the invention that if molybdenum and chromium are combined in the steel in relatively high proportions and in proportions such that the proportion of chromium and that of molybdenum are not too widely different then a desired toughness and hardness, together with the property of hardening at a relatively low hardening temperature is given to the steel. It has also been discovered that in such steels the tendency to decarburize and/or demolybdenize at high temperatures is entirely eliminated or very much reduced. The chromium appears to serve as a carrier for the molybdenum and possibly causes a thin film of chromium or mixed oxide on the surface which inhibits decarburization and demolybdenization. For a die steel the proportion of chromium should preferably be substantially equal to or greater than but not more than about 25% or perhaps 50% greater than the proportion of molybdenum and for a tool steel the proportion of molybdenum should preferably be substantially equal to the proportion of chromium or between the proportions 3:2 and 2:3 and probably between the proportions 5:4 and 4:5.

Certain other alloying ingredients commonly used in die steels and in high speed steels may also be added for their usual effects without impairing the effect of the molybdenum and chromium or losing the advantages thereof. It is particularly desirable to add a small proportion of vanadium, for example 0.1 to 3% or possibly 4% to increase the toughness. It is also advantageous in this steel for some uses to add cobalt in proportions heretofore used in high speed steels such as up to about 15%. Tungsten may be added as a substitute for part of the molybdenum but this increases the cost.

Molybdenum has been used heretofore in steels as an alloying ingredient and has even been combined with chromium with varying success. However, the steels produced have been of other types than that of the present invention or the proportions and quantities of molybdenum and chromium necessary to obtain the results of the present invention have not been maintained. In fact experiments heretofore made have indicated that a steel of the type produced by the present invention must not contain so large a proportion of chromium or of molybdenum as has now been found highly effective. It has now been discovered that chromium in proper percentages has a pronounced effect in bringing out the hardening and heat resisting properties induced by molybdenum in these alloys and that when large percentages of chromium, as 7 or better 8 to 17% are combined with large percentages of molybdenum, as 7 or better 8 to 20% the full effect of these elements and particularly of the molybdenum is brought out and intensified and the full cutting and heat resisting, that is scale resisting and/or red hardness, properties are given to the steel. It is believed that the addition of chromium with the molybdenum and especially with the addition of chromium in a proportion not greatly different from that of the molybdenum has the effect of increasing the solubility of the molybdenum in iron and for this reason improves the quality of the alloy. The solubility of the molybdenum carbide, mixed carbides, and iron carbide is believed also to be improved and in any event it is found that the steel can be properly hardened at lower temperatures, (below 2100° F.) as for example at temperatures between 1950 and 2050° F. or if the steel contains a small proportion of cobalt around 2150 or 2200° F.

The improved steel may contain, for example,

	Percent by weight
Molybdenum	7 –20
Chromium	7 –17
Vanadium	0 – 3
Carbon	0.20– 1.50
Silicon	0 – 1.50
Manganese	0 – 1.50
Cobalt	0 –15 or more
Iron	Remainder

The steel of the present invention is particularly suitable for dies and for high speed hot-

hard tools. If the steel is to be used for dies a composition such as the following may be used:

	Effective composition	Preferred composition
	Percent	*Percent*
Molybdenum	7 –12	8 –11
Chromium	7 –15	8 –12.50
Vanadium	0.10–2.50 or none	0.50–2
Carbon	0.20–0.80	0.30–0.65
Silicon	0.15–1.50	0.75–1.25
Manganese	0.15–1.50	0.30–0.60
Cobalt	0.50–7 or none	0.50–5 or none
Iron	Remainder	Remainder

If the steel is to be used for high speed hot-hard cutting tools a composition such as the following may be used:

	Effective composition	Preferred composition
	Percent	*Percent*
Molybdenum	8 –20	9 –12
Chromium	8 –17	9 –12
Vanadium	0.50– 3	0.50– 3
Carbon	0.50– 1.25	0.60– 1.15
Silicon	0 – 1.00	0 – 1.00
Manganese	0 – 1.00	0 – 1.00
Cobalt	2 –14 or none	7 –12 or none
Iron	Remainder	Remainder

The steel alloyed in accordance with the invention which proved effective for dies was found upon analysis to contain:

	Percent
Molybdenum	6.18
Chromium	8.18
Vanadium	0.75
Carbon	0.33
Silicon	0.98
Cobalt	0.52
Iron	Remainder

Dies made of this steel and dies made of a more expensive steel containing 9% tungsten, 3.25% chromium, 0.40% vanadium and 0.30% carbon, a well known tungsten hot-work die steel without molybdenum were subjected to comparative tests and it was found that the dies made of this steel were markedly more durable in use than dies of the tungsten hot-work die steel which steel is known as a particularly satisfactory steel for use in dies and the like.

Another steel which also gave highly satisfactory results as a die steel and also proved superior to the standard 18—4—1 steel as a high speed cutting tool analyzed as follows—

	Percent
Molybdenum	8.42
Chromium	8.69
Vanadium	1.67
Carbon	.66
Silicon	.29
Manganese	.31
Cobalt	3.96
Iron	Remainder

Still better die steels may contain:

	Percent.	Percent.	Percent.	Percent.
Molybdenum	8	9	10	10
Chromium	10.50	11.0	10	12.50
Vanadium	.50 to 1.25	.75	.90	.90
Carbon	.30 to .60	.60	.60	.65
Silicon	1.00	1.00	1.00	1.00
Manganese	0.20 to 1.00	0.65	0.65	0.65
Cobalt	None	.50	1.00	1.00
Iron	Remainder	Remainder	Remainder	Remainder

A tool steel alloyed in accordance with the invention which in service tests was found superior to standard 18—4—1 steel was found upon analysis to contain:

	Percent
Molybdenum	10.51
Chromium	10.54
Vanadium	1.81
Carbon	.85
Silicon	.29
Manganese	28
Iron	Remainder

Still better tool steels may contain for example:

	Percent.	Percent.	Percent
Molybdenum	10.50	11.50	12
Chromium	10	10	10.50
Vanadium	2	1.50	1.25
Carbon	.85	.85	.95
Silicon	.75	.75	.75
Manganese	.60	.60	.60
Cobalt	4 or more	4 or more	4 or more
Iron	Remainder	Remainder	Remainder

The cobalt may also advantageously be made about 7 or 12% instead of 4% in these steels to provide greater toughness.

Where good forgeability is required the maximum carbon should not be used with the maximum limits in chromium and molybdenum shown for my alloy.

It has been found that with 8% or more of molybdenum as the chromium is increased above 8% the steel becomes progressively softer after heat treatment for a given molybdenum content and that therefore the carbon must be increased to bring out the full hardening power of the increased chromium in relation to fixed quantities of molybdenum. For instance, with 8.50% chromium and 8.50% molybdenum, .65 to .75% carbon gives a satisfactory hardness for high speed cutting tools, but with 10.50% chromium and 10.50% molybdenum, .85 to .95% or more carbon must be used to obtain the proper hardness when heat treated for cutting tools. With the latter composition it is possible to get a Rockwell hardness of C 64 to C 67 or a range equal to or better than that obtained from the standard 18—4—1 steel.

The addition of cobalt toughens the steels above described while at the same time it raises the hardening temperature. Cobalt up to about 4% in a steel containing about 8.50 chromium and about 8.50 molybdenum toughens the steel to improve its shock resistance together with some improvement in the quality of its cutting edge. About 7 or 7½ to about 12% cobalt substantially improves the cutting quality and generally in proportion to the amount added.

Because of the low hardening range (1950 to 2050° F.) of these steels containing 8% and more of both chromium and molybdenum it is possible to hold and soak these steels at this range of temperatures for a long period of time to cause the solution of the carbides without the risk of burning and severe scaling as would be the case when long heating and soaking at temperature of 2150 to 2500° F. are used as for other types of high speed tool and die steels. Even if the steel contains cobalt and therefore has a higher hardening temperature it can still be soaked at or near the hardening temperature partly because of the protective effect of the cobalt.

All of the steels herein described are readily forgeable and may be hardened for example by heating to about 1950 to 2150° F. or higher if containing a higher percentage of cobalt, and quenching in oil or air as is usual practice and

they may be tempered by reheating to about 900 to 1100° F.

The various known high melting point metals may be added to the above described alloy without sacrificing the advantageous features of the invention except as, in some cases, they increase the cost of the steel, when desired to give to the steel the qualities which these high melting alloys are known to give. Vanadium already mentioned has the effect of raising the drawing temperature and toughening the steel. Uranium up to 3% has an effect substantially similar to the effect of vanadium. Tungsten raises both the hardening and drawing temperatures and tends to make the steel hot short. Tantalum up to 10% increases the initial hardness of the steel when quenched and raises the tempering temperature. Columbium up to 10% toughens the steel. Titanium or zirconium up to 3% increases the hardness obtained upon quenching and increases the hardening and drawing temperatures while it also tends to make the steel brittle. Cobalt can be added up to 15 and possibly 20% as in other high speed steels. It raises the hardening and drawing temperature considerably and toughens the steel but has a tendency to cause hot shortness when added in large amounts. Nickel up to 5% reduces the hardening temperature and reduces the initial hardness but it does not affect the drawing temperature. It tends to make the alloy tougher but increases the hot shortness. The preferred steels made to embody the principles of the invention do not contain more than about 5% of the above high melting point metals except those steels which contain cobalt.

The steels described have the decided advantage that they can be produced at much less cost than tungsten steel having more or less similar properties and yet when containing the preferred proportions of the alloying metals they are for many purposes as good as or decidedly superior to more expensive steels heretofore produced.

It seems from examination of tools after use that the high chromium and high molybdenum high speed steel herein described has a particularly low galling property under the chip as shown by the smooth condition of the edge of the tool after cutting. This may account in part for the greater cutting efficiency of the high chromium high molybdenum steel as compared with 18–4–1 high speed steel.

The low chromium molybdenum steels (containing 4% chromium) must be hardened or heat treated in special atmosphere furnaces to overcome the marked tendency to decarburize and demolybdenize.

This feature of preventing decarburization and demolybdenization, is also especially valuable in greatly simplifying the manufacturing process since the low chromium molybdenum steels have also a marked tendency to lose a considerable proportion of their carbon and molybdenum at the surface when being rolled and forged. The decarburization and demolybdenization frequently extends to a depth of $\frac{1}{32}$'' and more, depending on the time at heat. The high chromium with high molybdenum almost, if not quite, entirely prevents this. Chromium, when used in substantially equal proportions with molybdenum, particularly when these two elements are in excess of 8% each, has the extremely valuable effect of preventing decarburization and demolybdenization. Naturally, the absence of demolybdenization as well as the greatly reduced tendency of such steels to decarburize at the surface of tools made from it greatly increases the surface hardness and therefore, the effective cutting qualities of these tools as compared with tools of molybdenum steels containing 8.50% of molybdenum or more with only 3–5% (usually 4%) of chromium.

The higher chromium, 8% and over, especially in combination with the molybdenum of 8% and more, greatly increases the scale resistance of such steels. This condition, unlike the case of the low chromium molybdenum steels, permits the high chromium (8% or more) molybdenum steels to be hardened in the ordinary standard type of heat treating furnace used for tungsten high speed steels and other non-molybdenum die steels.

It should be emphasized that a valuable effect of the high chromium (8% and more) and particularly 10%, with 8% and more of molybdenum, is found in the lowering of the effective hardening temperature necessary to obtain full hardness of the steel. For example, a steel containing .80% carbon, 8.5% molybdenum and 3.5% chromium requires a temperature of 2150–2250° F. for full hardening whereas a steel containing .85% carbon, with 10.50% chromium and 10.50% molybdenum requires only 2000° F. for complete hardening. This also compares with 2350° F. required for full hardening of the standard 18–4–1 high speed steel. The value of this lower hardening temperature in hardening tools, especially tools having fine edges, will prove to be very great to the manufacturers of such tools because of the elimination of the hazard of breakage and burning or wasting of the fine edges. The expressions "full hardening" and "complete hardening" are used herein to define the ordinary hardening that is satisfactory in use in dies, cutting tools and the like and is obtained by quenching from what are commonly referred to as "hardening temperatures" but the use of this language is not intended to mean that the same steel may not be hardened to a slightly greater hardness by special heat treatment nor that other heat treatments may not be found which will produce a slightly greater degree of hardness.

In service tests the steel containing 10.50% molybdenum and 10.50% chromium with 1.80% vanadium hardened at 2000° F. and a steel containing 8.50% molybdenum, 8.50% chromium with 1.70% vanadium and 4% cobalt gave much longer service than a standard 18–4–1 steel.

If it is preferred to include a small amount of tungsten in the steel this may be done, noting that the equivalency of molybdenum to tungsten is such that 1% of tungsten may replace ½ to ¾% of molybdenum to produce substantially the same effect. The steel may therefore contain for example, up to 3% tungsten with a reduction of the molybdenum. The cost is, however, increased and usually without a corresponding improvement in the steel.

Such a composition may be as follows—

	Percent
Molybdenum	10 –12
Chromium	9 –12
Tungsten	0. 50– 3
Vanadium	0. 50– 3
Carbon	0. 20– 1. 50
Silicon	0. 20– 1. 50
Cobalt	0 –12
Iron	Remainder

It is one of the objects and principal advantages of the invention that it provides a high quality steel which because it can be made tung-

sten free can be manufactured at a low cost as compared with other more or less equivalent high speed steels now on the market. While even a small percentage of tungsten is entirely unnecessary to the production of a high quality die or tool steel it is not harmful and scrap steel containing small quantities of tungsten may, therefore, be used in producing the steel of the invention. Too high a percentage of tungsten with high chromium and high molybdenum should be avoided because it causes hot shortness.

It is contemplated that variations from the illustrative compositions will be made in accordance with well understood metallurgical principles without departing from the spirit of the invention or sacrificing the advantages thereof. The term "tool" as used in the claims is used in its broad significance to include dies as well as other tools. The term "hot working" is used to include both rolling and forging.

The expression "the remainder substantially all iron" as used in the claims is intended to include, in addition to iron, minor impurities and small proportions of alloying elements not sufficient to change the general character of the steel or destroy the advantages of the combination of molybdenum and chromium in the proportions used.

I claim:

1. A forgeable tungsten-free steel characterized by being stable against demolybdenization and decarburization at its hot working and hardening temperatures and capable of complete hardening when quenched from a temperature between 1950 and 2050° F. and comprising as its principal alloying ingredients approximately 8.50% molybdenum, 8.50% chromium, 0.75 to 1.50% vanadium, an effective amount up to 5% cobalt, and 0.30 to 0.65% carbon with the remainder substantially all iron.

2. A forgeable tungsten free steel characterized by being stable against demolybdenization and decarburization at its hot working and hardening temperatures and capable of complete hardening when quenched from a temperature between 1900 and 2100° F. and comprising as its principal alloying ingredients approximately 8 to 11% molybdenum, 8 to 12.50% chromium, 0.10 to 3% vanadium, 0.50 to 5% cobalt, and 0.30 to 0.80% carbon with the remainder substantially all iron.

3. A forgeable steel comprising as its principal alloying ingredients approximately 10 to 12% molybdenum, chromium sufficient in amount to practically prevent demolybdenization and decarburization of the steel at its hot working and hardening temperatures, said chromium being more than 10% and not substantially more than 12%, 3 to 12.50% cobalt, 0.50 to 2% vanadium and 0.60 to 1.15% carbon with the remainder substantially all iron.

4. A forgeable steel comprising as its principal alloying ingredients approximately 10 to 12% molybdenum, chromium sufficient in amount to practically prevent demolybdenization and decarburization of the steel at its hot working and hardening temperatures, said chromium being more than 10% and not substantially more than 12%, 0.50 to 2% vanadium and 0.60 to 1.15% carbon, the major portion of the remainder being iron.

5. A forgeable steel characterized by being stable against demolybdenization and decarburization at its hot working temperature and by being capable of complete hardening when quenched from a temperature of 1950 to 2050° F. comprising as its principal alloying ingredients approximately 8–13% molybdenum, more than 10 but not more than 17% chromium, 0.50 to 1.25% carbon and an effective amount up to 5% of metal selected from the group consisting of vanadium, tantalum and columbium, the major portion of the remainder being iron.

6. A forgeable steel comprising as its principal alloying ingredients approximately 10.50% molybdenum, 10.50% chromium, 1 to 2% vanadium, 4 to 12% cobalt and 0.85 to 1.15% carbon, with the remainder substantially all iron.

7. A forgeable steel characterized by being stable against demolybdenization and decarburization at its hot working and hardening temperatures and capable of complete hardening when quenched from a temperature between 1900 and 2100° F. and comprising as its principal alloying ingredients approximately 10.50% molybdenum, 10.50% chromium, 1 to 2% vanadium and 0.85 to 1.15% carbon, the major portion of the remainder being iron.

8. A forgeable tungsten free steel characterized by being capable of complete hardening when quenched from a hardening temperature of about 1950 to 2050° F. and having the property of effectively resisting demolybdenization and decarburization at its hot working and hardening temperatures, comprising as its principal alloying ingredients 8 to 13% molybdenum, 8 to 15% chromium, .10 to 3% vanadium and 0.20 to 1.50% carbon, the major portion of the remainder being iron.

9. A forgeable tungsten free steel chracterized by being capable of complete hardening when quenched from a hardening temperature of about 1950 to 2050° F. and having the property of effectively resisting demolybdenization and decarburization at its hot working temperatures, comprising as its principal alloying ingredients 8 to 13% molybdenum, 8 to 15% chromium, .10 to 3% vanadium, 0.50 to 15% cobalt, and 0.20 to 1.50% carbon, with the remainder substantially all iron.

10. A forged edge tool for cutting metals made of a tungsten free steel characterized by being stable against demolybdenization and decarburization at its hot working and hardening temperatures and capable of complete hardening when quenched from a temperature between 1900 and 2100° F. having as its principal alloying ingredients 8 to 13% molybdenum, 8 to 15% chromium and 0.20 to 1.50% carbon, the major portion of the remainder being iron.

11. A forged tool made of a tungsten free steel characterized by being stable against demolybdenization and decarburization at its hot working and hardening temperatures and capable of complete hardening when quenched from a temperature between 1900 and 2100° F. having as its principal alloying ingredients 8 to 13% molybdeum, 8 to 15% chromium, an effective amount up to 4% vanadium, and 0.20 to 1.50% carbon, the major portion of the remainder being iron.

12. A forged tool made of a tungsten free steel characterized by being stable against demolybdenization and decarburization at its hot working and hardening temperatures and capable of complete hardening when quenched from a temperature between 1900 and 2100° F. comprising as its principal alloying ingredients approximately 8 to 13% molybdenum, 8 to 15% chromium, an effective amount up to 3% vanadium, and 0.20 to 1.50% carbon, the proportion of molybdenum to chromium lying within the range 5 to 4 and 4 to 5, the major portion of the remainder being iron.

13. A forged tool made of a tungsten free steel characterized by being stable against demolybdenization and decarburization at its hot working and hardening temperatures and capable of complete hardening when quenched from a temperature between 1900 and 2100° F. having as its principal alloying ingredients 8 to 13% molybdenum, 8 to 15% chromium, an effective amount up to 3% vanadium, an effective amount up to 15% cobalt and 0.20 to 1.50% carbon, the major portion of the remainder being iron.

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