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# WEAR-RESISTANT FERROUS ALLOYS

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This invention relates to ferrous alloys and in particular to ferrous alloys having high wear resistance. The invention is based on the discovery that the incorporation of titanium in an alloy steel provides a wear-resistant alloy, and this alloy is especially advantageous.

Heretofore, it was known that wear or abrasion-resistant alloys resulted from the incorporation of vanadium into alloy steels. Thus, wear-resistant higher carbon alloys, having in excess of about 1.25% carbon, resulted from the incorporation of vanadium in a weight ratio to carbon of about 2–4:1, as disclosed in U. S. Patent No. 2,174,281. Similar results are disclosed in U. S. Patent No. 2,575,219.

Vanadium was incorporated with special advantage in tool steels, especially high speed steels, including both of the tungsten and molybdenum types. The high speed steels include both higher carbon alloys and lower carbon alloys, the latter having about 0.6–1.25% carbon. In the lower carbon alloys, lower vanadium to carbon proportions are permissible, as low as 1:1, and proportions up to 4:1 may also be employed.

It has now been discovered in accordance with the invention that improved wear-resistance is imparted to alloy steels, especially high speed steels, by the incorporation or provision of titanium in the alloys. Titanium alone may be added to supply wear-resistance, or titanium and vanadium may be employed together.

Titanium furnishes improved results as compared to vanadium alone, and titanium is in many cases much more effective on a weight basis, 1% of titanium being equivalent to about 1–3%, for the most part, about 2.2%, of vanadium. Titanium increases the wear resistance to a greater extent than vanadium for equivalent proportions. Titanium refines the grain size of the steels to a greater extent than vanadium, thereby improving toughness. It also provides a marked improvement in the cutting performance of high speed steels.

Titanium alone is provided in an alloy in a proportion of about 0.3–6% by weight. Vanadium may also be provided, optionally, in a proportion up to about 6%, the proportion of titanium decreasing with increasing proportion of vanadium, and vice versa.

With the accompanying use of vanadium, a minimum of about 0.5%, the titanium content may be as low as 0.2% while providing improved results. The titanium range is thus about 0.2–6% by weight. It is generally preferred to employ at least 0.4% of titanium, and it is further preferred to provide at least 0.5%. Also, the total maximum amount of titanium and vanadium is about 6%.

In the higher carbon high speed steels, containing carbon in excess of about 1.25%, with a maximum of about 1.5%, the titanium to carbon weight ratio is about 0.7–4:1. In the lower carbon alloys, containing about 0.6–1.25% carbon, preferably 0.7–1.25%, the titanium to carbon ratio is about 0.3–4:1. The titanium to carbon ratio in the alloys is thus about 0.3–4:1. Boron may in certain instances be added and serves to replace carbon, and it is to be understood that this equivalent is embraced when reference is made to carbon. Also, titanium will form nitrides, so that it is not available to that extent to combine carbon. It will be understood, therefore, that the titanium-carbon ratio is exclusive of the titanium which combines with nitrogen.



When vanadium is also included, the above-described ratios of vanadium to carbon are effective, that is, the ratio is 2–4:1 for higher carbon alloys and 1–4:1 for lower carbon alloys, the overall ratio being 1–4:1. The proportions of titanium, vanadium and carbon are then selected within the above given limits to provide 1 part by weight of carbon for each 0.7–4 parts of titanium plus 1 part of carbon for each 2–4 parts of vanadium, in higher carbon alloys, and the overall proportions are 1 part of carbon to 0.3–4 parts of titanium plus 1 part of carbon to 1–4 parts of vanadium.

Tungsten or molybdenum is provided in the high speed steel alloys. Tungsten may be employed alone, in a tungsten high speed steel, in a proportion by weight of 13% to 19%. With the additional incorporation of 2–20% cobalt, 13–22% tugnsten may be provided. Preferably, at least 14% of tungsten is employed. Molybdenum may be employed alone or together with tungsten, in a molybdenum high speed steel, in a proportion of 4% to 9%. With the incorporation of tungsten, the proportion may be 3% to 9%, with the proviso that the sum $2Mo+W=$ 12.75% to 19%, preferably 14–19%. It is generally preferred that at least 4.25% of molybdenum be employed. About this amount of molybdenum without tungsten furnishes a relatively low alloy high speed steel of more limited application, and the preferred molybdenum proportion in the absence of tungsten is 8–9%.

Chromium is incorporated in a maximum proportion of about 5%. Preferably, about 3.5–5% of chromium is added. Cobalt is very often advantageous and is optionally employed in an amount less than about 20%, preferably less than about 12.5%. When added, the proportion of cobalt is preferably at least about 2%.

The alloys also contain silicon and manganese, in maximum amounts by weight of about 1% of silicon, preferably 0.2–1%, and about 2% of manganese, preferably 0.1–2%. Columbium may be added, in an amount less than about 1.5%. In most steels the sulfur content will be low, say, 0.03% maximum, but it can be added to improve machinability of the steel in amounts up to about 0.5%. The phrases "less than" and "up to" mean that the presence of the element is optional and its proportion does not exceed that given. The balance of the alloy will be substantially all iron with residual impurities, such as phosphorus, arsenic and metallic elements, present in ordinary amounts.

The new alloys can be hardened to a Rockwell hardness in excess of C60, and some, as high as or higher than C67. At the same time, they can be annealed to a hardness of under 275 Brinell, at which hardness they are commercially machinable.

In general, the new wear-resistant high speed steel alloys have the following composition:

| | |
|---|---|
| Carbon | 0.6–1.5%. |
| Titanium | 0.2–6%. |
| Vanadium | Up to 6%. |
| Silicon | 1% max. |

| | |
|---|---|
| Manganese | 2% max. |
| Tungsten | 13% to 19%. |
| Tungsten with 2–20% cobalt | 13% to 22%. |
| Molybdenum | 4% to 9%. |
| Molybdenum with tungsten | 3% to 9%. |
| Where 2Mo+$W$ equals | 12.75% to 19%. |
| Chromium | 5% max. |
| Cobalt | Less than 20%. |
| Columbium | Less than 1.5%. |
| Sulfur | Less than 0.5%. |
| Titanium+vanadium | 6% total max. |

The carbon content equals 1 part for each 0.3–4 parts of titanium plus 1 part for each 1–4 parts of vanadium. The balance is substantially iron with residual impurities in ordinary amounts.

The new tungsten high speed steels have the following composition:

| | |
|---|---|
| Carbon | 0.6–1.5%. |
| Titanium | 0.2–6%. |
| Vanadium | Up to 6%. |
| Silicon | 1% max. |
| Manganese | 2% max. |
| Tungsten | 13% to 19%. |
| Tungsten with 2–20% cobalt | 13% to 22%. |
| Chromium | 5% max. |
| Cobalt | Less than 20%. |
| Columbium | Less than 1.5%. |
| Sulfur | Less than 0.5%. |
| Titanium + vanadium | 6% total max. |

The new molybdenum high speed steels have the following composition:

| | |
|---|---|
| Carbon | 0.6–1.5%. |
| Titanium | 0.2–6%. |
| Vanadium | Up to 6%. |
| Silicon | 1% max. |
| Manganese | 2% max. |
| Molybdenum | 4% to 9%. |
| Molybdenum with tungsten | 3% to 9%. |
| where 2Mo+W equals | 12.75% to 19%. |
| Chromium | 5% max. |
| Cobalt | Less than 20%. |
| Columbium | Less than 1.5%. |
| Sulfur | Less than 0.5%. |
| Titanium + vanadium | 6% total max. |

Titanium may be completely or partly substituted for vanadium in the common tungsten and molybdenum high speed steels listed on page V of "Classification and Symbols for Identification of High Speed Steels," 7th ed., 1952 (Gorham Tool Co., Detroit, Mich.). Substitution on an equal weight basis provides better wear resistance, refines the grain size to a greater extent, and provides a marked improvement in cutting performance. For the most part a lesser amount of titanium replaces a given amount of vanadium in the high speed steels, preferably in a titanium-vanadium ratio of about 1:2.2, and as low as 1:3. With a high level of substitution, approaching maximum replacement of vanadium, the ratio approaches 1:1, especially in the higher vanadium alloys. Thus, instead of the normal percentages of vanadium in the standard high speed steel compositions, the vanadium proportion can be furnished by titanium alone or both titanium and vanadium according to the formula

$$(1\text{–}3)\mathrm{Ti}+\mathrm{V}=\mathrm{V_s}$$

wherein $V_s$ is the vanadium content, in percent, of the standard steel, with the proviso that Ti is a minimum of 0.2%.

Representative examples of high speed steels tested and found to give these superior results are the following, wherein the symbols are the standard identification symbols of the corresponding vanadium alloys, having the same amounts of vanadium instead of the titanium:



*Tungsten high speed steels*

| W | Cr | Ti | Co | C | Symbol |
|---|---|---|---|---|---|
| *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | |
| 18 | 4 | 1 | | 0.7 | T-1 |
| 18 | 4 | 2 | | 0.8 | T-2 |
| 18 | 4 | 2 | 8 | 0.8 | T-5 |
| 22 | 4.5 | 1.5 | 12 | 0.8 | T-6 |
| 18 | 4 | 4 | | 1.2 | T-9 |
| 13 | 4.25 | 5 | 5 | 1.5 | T-15 |

*Molybdenum high speed steels*

| Mo | Cr | Ti | W | Co | Cb | C | Symbol |
|---|---|---|---|---|---|---|---|
| *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | |
| 8.5 | 4 | 1 | 1.5 | | | 0.8 | M-1 |
| 5 | 4 | 2 | 6 | | | 0.8 | M-2 |
| 6 | 4 | 2.4–3 | 6 | | | 1 | M-3 |
| 4.5 | 4.5 | 4 | 5.5 | | | 1.3 | M-4 |
| 8 | 4 | 2 | 1.5 | | | 0.85 | M-7 |
| 4.5 | 4.25 | 1.5 | 5.5 | | 1.25 | 0.8 | M-8 |
| 8 | 4 | 2 | | | | 0.85 | M-10 |
| 3 | 4.75 | 5 | 6.75 | 5 | | 1.5 | M-15 |

The high speed steels also contain silicon and manganese, and the normal impurities, and boron is added to several of the molybdenum steels.

When titanium was added to the high speed steels, in partial and complete substitution for vanadium, it was observed that the steels responded to heat treatment in a manner similar to the other high speed steels, with slightly higher hardening temperatures required to develop full secondary hardness. The higher hardening temperatures can be tolerated, since a marked tendency exists to retain a fine grain size and to retain numerous excess carbide particles. The titanium steels are superior in wear resistance to those containing only vanadium. This is apparently due partly to the presence of a large quantity of hard, wear-resistant titanium carbide, titanium nitride and/or titanium carbonitride particles.

Improved results are obtained when 0.2%, preferably 0.4%, or more of titanium is substituted for the same amount of vanadium in the high speed steels. Equivalent or superior results are obtained when about 1–3%, preferably about 2.2%, of vanadium is replaced by 1% of titanium. Stated in another way, titanium is substituted for vanadium on the basis of ⅓% to 1% of titanium, preferably about

$$0.5\%\left(\frac{1}{2.2}\right)$$

for each 1% of vanadium, with a minimum of 0.2% titanium.

Further exemplary alloys of titanium and of both titanium and vanadium used in the manufacture of high speed tools are the following:

| W | Mo | Cr | Ti | V | Co | C | Symbol |
|---|---|---|---|---|---|---|---|
| *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | |
| 18 | ------ | 4 | 0.4—0.55 | ------ | ------ | 0.7 | Based on T-1. |
| 18 | ------ | 4 | 0.2—0.3 | 0.5 | ------ | 0.7 | Do. |
| 18 | ------ | 4 | 0.4—0.5 | 1 | 8 | 0.8 | Based on T-5. |
| 14 | ------ | 4 | 0.5 | 1 | 5 | 0.75 | Based on T-8. |
| 13 | ------ | 4.25 | 3 | 1 | 5 | 1.50 | Based on T-15 |
| 5.5 | 4.5 | 4.5 | 0.7—1.4 | 2 | ------ | 1.3 | Based on M-4. |
| 1.5 | 8.5 | 4 | 0.3 | 0.5 | ------ | 0.8 | Based on M-1. |

A very advantageous high speed steel similar to M–10 but new in other respects has the following complete composition:

| W | Mo | Cr | Ti | V | Co | Mn | Si | C |
|---|---|---|---|---|---|---|---|---|
| *Percent* 0.8–1.2 | *Percent* 7.75–8.25 | *Percent* 3.8–4.2 | *Percent* 0.6–0.9 | *Percent* 1.3–1.7 | *Percent* 2.8–3.2 | *Percent* 0.2–0.3 | *Percent* 0.2–0.3 | *Percent* 1.1–1.16 |

the balance being substantially iron with residual impurities in ordinary amounts.

The invention thus provides new and improved highly wear-resistant high speed steel alloys having wide application, wherein titanium is used as one of the principal alloying elements. The alloys can be hardened to a Rockwell hardness in excess of C60, and some, as high as or higher than C67. The alloys have a fine grain size and improved toughness. The cutting performance of tools is markedly improved. The invention constitutes a significant advance in the development of high speed steels for industrial applications.

I claim:

1. A wear-resistant high speed tool steel comprising, in proportions by weight, about 0.6 to 1.5% of carbon, about 0.2 to 6% of titanium, up to about 6% of vanadium, about 1% maximum of silicon, about 2% maximum of manganese, about 13–19% of tungsten, about 5% maximum of chromium, less than about 20% of cobalt, less than about 1.5% of columbium, less than about 0.5% of sulfur, the total maximum of titanium and vanadium being about 6%, the proportions of titanium, vanadium and carbon being selected within the given limits to provide 1 part of carbon for each 0.3–4 parts of titanium plus 1 part of carbon for each 1–4 parts of vanadium, and the balance substantially iron with residual impurities in ordinary amounts.

2. A wear-resistant high speed tool steel comprising, in proportions by weight, about 0.6 to 1.5% of carbon, about 0.2 to 6% of titanium, up to about 6% of vanadium, about 1% maximum of silicon, about 2% maximum of manganese, about 4–9% of molybdenum, about 5% maximum of chromium, less than about 20% of cobalt, less than about 1.5% of columbium, less than about 0.5% of sulfur, the total maximum of titanium and vanadium being about 6%, the proportions of titanium, vanadium and carbon being selected within the given limits to provide 1 part of carbon for each 0.3–4 parts of titanium plus 1 part of carbon for each 1–4 parts of vanadium, and the balance substantially iron with residual impurities in ordinary amounts.

3. A wear-resistant high speed tool steel comprising, in proportions by weight, about 0.6 to 1.5% of carbon, about 0.2 to 6% of titanium, up to about 6% of vanadium, about 1% maximum of silicon, about 2% maximum of manganese, about 13–22% of tungsten, about 5% maximum of chromium, about 2–20% of cobalt, less than about 1.5% of columbium, less than about 0.5% of sulfur, the total maximum of titanium and vanadium being about 6%, the proportions of titanium, vanadium and carbon being selected within the given limits to provide 1 part of carbon for each 0.3–4 parts of titanium plus 1 part of carbon for each 1–4 parts of vanadium, and the balance substantially iron with residual impurities in ordinary amounts.

4. A wear-resistant high speed tool steel comprising, in proportions by weight, about 0.6 to 1.5% of carbon, about 0.2 to 6% of titanium, up to about 6% of vanadium, about 1% maximum of silicon, about 2% maximum of manganese, about 3–9% of molybdenum, tungsten, the sum 2Mo+W equalling about 12.75% to 19%, about 5% maximum of chromium, less than about 20% of cobalt, less than about 1.5% of columbium, less than about 0.5% of sulfur, the total maximum of titanium and vanadium being about 6%, the proportions of titanium, vanadium and carbon being selected within the given limits to provide 1 part of carbon for each 0.3–4 parts of titanium plus 1 part of carbon for each 1–4 parts of vanadium, and the balance substantially iron with residual impurities in ordinary amounts.

5. A wear-resistant high speed tool steel comprising, in proportions by weight, about 0.6 to 1.5% of carbon, about 0.2 to 6% of titanium, up to about 6% of vanadium, about 0.2–1% of silicon, about 0.1–2% of manganese, about 13–19% of tungsten, about 3.5–5% of chromium, less than about 12.5% of cobalt, less than about 1.5% of columbium, less than about 0.5% of sulfur, the total maximum of titanium and vanadium being about 6%, the proportions of titanium, vanadium and carbon being selected within the given limits to provide 1 part of carbon for each 0.3–4 parts of titanium plus 1 part of carbon for each 1–4 parts of vanadium, and the balance substantially iron with residual impurities in ordinary amounts.

6. A wear-resistant high speed tool steel comprising, in proportions by weight, about 0.6 to 1.5% of carbon, about 0.2 to 6% of titanium, up to about 6% of vanadium, about 0.2–1% of silicon, about 0.1–2% of manganese, about 4–9% of molybdenum, about 3.5–5% of chromium, less than about 12.5% of cobalt, less than about 1.5% of columbium, less than about 0.5% of sulfur, the total maximum of titanium and vanadium being about 6%, the proportions of titanium, vanadium and carbon being selected within the given limits to provide 1 part of carbon for each 0.3–4 parts of titanium plus 1 part of carbon for each 1–4 parts of vanadium, and the balance substantially iron with residual impurities in ordinary amounts.

7. A wear-resistant high speed tool steel comprising, in proportions by weight, about 0.6 to 1.5% of carbon, about 0.2 to 6% of titanium, up to about 6% of vanadium, about 0.2–1% of silicon, about 0.1–2% of manganese, about 8–9% of molybdenum, about 3.5–5% of chromium, less than about 12.5% of cobalt, less than about 1.5% of columbium, less than about 0.5% of sulfur, the total maximum of titanium and vanadium being about 6%, the proportions of titanium, vanadium and carbon being selected within the given limits to provide 1 part of carbon for each 0.3–4 parts of titanium plus 1 part of carbon for each 1–4 parts of vanadium, and the balance substantially iron with residual impurities in ordinary amounts.

8. A wear-resistant high speed tool steel comprising, in proportions by weight, about 0.6 to 1.5% of carbon, about 0.2 to 6% of titanium, up to about 6% of vanadium, about 0.2–1% of silicon, about 0.1–2% of manganese, about 13–22% of tungsten, about 3.5–5% of chromium, about 2–12.5% of cobalt, less than about 1.5% of columbium, less than about 0.5% of sulfur, the total maximum of titanium and vanadium being about 6%, the proportions of titanium, vanadium and carbon being selected within the given limits to provide 1 part of carbon for each 0.3–4 parts of titanium plus 1 part of carbon for each 1–4 parts of vanadium, and the balance substantially iron with residual impurities in ordinary amounts.

9. A wear-resistant high speed tool steel comprising, in proportions by weight, about 0.6 to 1.5% of carbon, about 0.2 to 6% of titanium, up to about 6% of vana-

dium, about 0.2–1% of silicon, about 0.1–2% of manganese, about 3–9% of molybdenum, tungsten, the sum 2Mo+W equalling about 12.75% to 19%, about 3.5–5% of chromium, less than about 12.5% of cobalt, less than about 1.5% of columbium, less than about 0.5% of sulfur, the total maximum of titanium and vanadium being about 6%, the proportions of titanium, vanadium and carbon being selected within the given limits to provide 1 part of carbon for each 0.3–4 parts of titanium plus 1 part of carbon for each 1–4 parts of vanadium, and the balance substantially iron with residual impurities in ordinary amounts.

10. A wear-resistant high speed tool steel comprising,



in proportions by weight, about 1.1–1.16% of carbon, about 0.6–0.9% of titanium, about 1.3–1.7% of vanadium, about 0.2–0.3% of silicon, about 0.2–0.3% of manganese, about 7.75–8.25% of molybdenum, about 0.8–1.2% of tungsten, about 3.8–4.2% of chromium, about 2.8–3.2% of cobalt, and the balance substantially iron with residual impurities in ordinary amounts.

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