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## (54) HIGH STRENGTH, HIGH IMPACT TOUGHNESS STEEL ALLOY, AN ARTICLE OF MANUFACTURE MADE THEREFROM, AND A METHOD FOR MAKING THE SAME

(57) A steel alloy is disclosed. The alloy contains in weight percent:

C
about 0.21-about 0.27
Mn
about 0.1 max.
Si
about 0.1 max.
P
about 0.005 max.
S
about 0.002 max.
Cr
about 1.2-about 1.8
Mo
about 1.1-about 1.9
V
about 0.2-about 0.4
Ni
about 3.0-about 3.8
Nb
about 0.005-about 0.03
Cu
about 0.10 max.
Al
about 0.02 max.

The balance of the alloy is iron, impurities, and incidental amounts of residual elements that do not adversely affect the basic and novel properties provided by the alloy. An article of manufacture and method of making same are also disclosed.

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## Description

BACKGROUND OF THE INVENTION:

Field of the Invention:

**[0001]** This invention relates generally to a steel alloy that provides a novel combination of strength and toughness. More particularly, the invention relates to a useful article such as a gun barrel made from the steel and to a process for making such an article.

Description of the Related Art:

**[0002]** The known alloys that are used for making advanced gun barrels are designed to provide high strength and hardness in combination with good toughness. Currently it is desired that such alloys provide a room temperature yield strength of at least 150 ksi in combination with good toughness. However, advanced gun barrels now require increased fire power in long range rifles because of advances in armor. The increased fire power is typically realized by using larger ammunition rounds which result in greater stress on the gun barrel during discharge. Therefore, a need has arisen for the gun-barrel alloys to provide significantly higher strength while maintaining good impact toughness and process-ability, e.g., forgeability.

**[0003]** Advanced gun barrels experience a wide range of temperatures during use in combat service. Sustained firing will heat up the gun barrel which could over temper (soften) the steel alloy from which it is made. Operating conditions can range from elevated temperatures in desert environments to sub-zero temperatures in arctic environments. Because of such temperature extremes it is usually required that the alloy be tempered above a certain temperature to prevent over-tempering during sustained firing.

**[0004]** In view of the foregoing developments, it would be desirable to have a steel alloy that provides a minimum yield strength significantly higher than 150 ksi. and impact toughness of 100 ft-lbs at -40°F. Due to a service temperature of 850°F (454°C), it is also important that the alloy have a tempering temperature of at least 1000°F (538°C) so that it does not become overtempered during use in combat conditions. Moreover, a hardness of 38-39 HRC is desired by the gun barrel manufacturers to provide good forgeability.

SUMMARY OF THE INVENTION:

**[0005]** The foregoing requirements are realized to a large degree by the alloy according a first aspect of this invention. The alloy has the following composition in weight percent.

| | Main | Preferred |
|---|---|---|
| C | 0.21-0.27 | 0.22-0.25 |
| Mn | 0.1 max. | 0.1 max. |
| Si | 0.1 max. | 0.1 max. |
| P | 0.005 max. | 0.005 max. |
| S | 0.002 max. | 0.001 max. |
| Cr | 1.2-1.8 | 1.3-1.7 |
| Mo | 1.1-1.9 | 1.3-1.8 |
| V | 0.2-0.4 | 0.2-0.4 |
| Ni | 3.0-3.8 | 3.2-3.7 |
| Nb | 0.005-0.03 | 0.01-0.03 |
| Cu | 0.10 max. | 0.10 max. |
| Al | 0.02 max. | 0.015 max. |

**[0006]** The balance of the alloy is iron, impurities, and incidental amounts of residual elements that do not adversely affect the basic and novel properties provided by the alloy. Thus, the alloy may comprise, consist essentially of, or consist of the constituent elements as described herein.

**[0007]** In accordance with a second aspect of the present invention there is provided an article of manufacture made from the steel alloy described above. The article is characterized by having a room temperature yield strength of at least 150 ksi and preferably at least 170 ksi in the hardened and tempered condition. The article is further characterized by having a Charpy V-notch (CVN) impact toughness of at least 40 ft-lbs, when tested at a temperature of -40°F. The alloy

is capable of providing CVN impact toughness of about 60-100 ft-lbs at similar strength levels for best performance in the primary application for the alloy. The article according to this invention may be embodied as a gun barrel or a rifle barrel.

**[0008]** In accordance with a further aspect of this invention there is provided a method of making an article of manufacture from the alloy described above. The method according to this aspect of the invention includes the steps of hot rolling the article from a temperature of about 1950°F down to a temperature of about 1700°F. The hot-rolled alloy article is annealed at a temperature of about 1600-1700°F for about 1-4 hours, and then cooled to 70°F at a cooling rate equivalent to at least a fan cool. The annealed article is then tempered to final hardness and strength by heating at a temperature of 1110-1180°F for 2-8 hours and then cooled to 70°F. The article is characterized by having a grain size not greater than about 31.8μm in major dimension (i.e., not coarser than ASTM Grain Size No. 7) in the annealed and tempered condition.

**[0009]** The foregoing tabulation is provided as a convenient summary and is not intended thereby to restrict the lower and upper values of the ranges of the individual elements of the alloy of this invention for use in combination with each other, or to restrict the ranges of the elements for use solely in combination with each other. Thus, one or more of the element ranges of the main composition can be used with one or more of the ranges for the remaining elements in the preferred composition. In addition, a minimum or maximum for an element of the preferred composition can be used with the maximum or minimum for that element from the main embodiment.

**[0010]** Here and throughout this application, unless otherwise indicated, the following definitions apply. The term "percent" or the symbol "%" means percent by weight or mass. The term "basic and novel properties" means the combination of properties provided by the alloy as described above. The term "residual elements" means elements that are not intentionally added, but which may be present after melting and casting because of their presence in charge materials used to produce the alloy.

DETAILED DESCRIPTION:

**[0011]** This alloy contains at least about 0.21% carbon and preferably at least about 0.22% carbon because carbon plays a role in the formation of austenite at heat treating temperatures. Carbon also benefits the ability of the alloy to attain high hardness levels in the heat-treated condition. Further, carbon is important because it combines with other elements in the alloy to form carbides that contribute to the strength, temper resistance, and wear resistance provided by the alloy. Too much carbon can adversely affect the toughness and ductility provided by the alloy, especially the low temperature toughness. Therefore, the alloy contains not more than about 0.27% and preferably, not more than about 0.25% carbon.

**[0012]** Chromium is a good carbide former and also benefits the strength and wear resistance provided by the alloy. Therefore, the alloy contains at least about 1.2% chromium and preferably, at least about 1.3% chromium. However, chromium forms the $M_{23}C_6$ carbide. The presence of too many of such carbides although advantageously providing high hardness can adversely affect the impact toughness provided by the alloy. Chromium also promotes retained austenite and ferrite in the alloy which can adversely affect the strength provided by the alloy. Therefore, chromium is restricted to not more than about 1.8% and preferably to not more than about 1.7% in this alloy.

**[0013]** Molybdenum raises the Ac1 temperature of the alloy which benefits the heat resistance and temper resistance provided by the alloy. Molybdenum is a good solid solution strengthener and so, it contributes to the good hardenability, toughness, and strength provided by this alloy. For those reasons, the alloy contains at least about 1.1% molybdenum and preferably at least about 1.3% molybdenum. The alloy contains not more than about 1.9% molybdenum and preferably not more than about 1.8% molybdenum. That quantity of molybdenum is sufficient to achieve the desired properties without increasing the cost of the alloy unnecessarily.

**[0014]** Vanadium combines with carbon to form vanadium carbides that benefit the wear resistance and hot hardness provided by the alloy of this invention. The vanadium carbides also contribute to a fine grain structure that is necessary to attain the good combination of strength and toughness because they resist plastic deformation and enhance high temperature properties. In order to ensure the attainment of those properties the alloy contains at least about 0.2% vanadium. Too much vanadium results in the formation of relatively large vanadium carbides that adversely affect the wear resistance provided by this alloy. Accordingly, vanadium is limited to not more than about 0.4% in this alloy.

**[0015]** At least about 3.0% nickel is present in the alloy to stabilize austenite which coincidently limits the formation of undesired ferrite. Nickel also benefits the fracture toughness provided by the alloy and contributes to the good low temperature impact toughness provided by the alloy without adversely affecting the good strength of the alloy. Preferably, the alloy contains at least about 3.2% nickel. This amount is satisfactory to produce the desired properties. Additional nickel unnecessarily increases the cost of the alloy and increases the thermal sensitivity of the alloy during processing. The presence of too much nickel slows the martensite transformation which will cause stresses in the alloy during cooling and thereby increase the potential for the alloy to crack during production. Therefore, nickel is restricted to not more than about 3.8% and preferably to not more than about 3.7% in this alloy.

**[0016]** At least about 0.005% and preferably at least about 0.01% niobium is present in this alloy. Niobium, like

vanadium, combines with carbon to form finely dispersed carbides that benefit the strength and wear resistance provided by the alloy. Such carbides also function to pin grain boundaries which in turn helps to limit grain size and thereby, further benefit the good impact toughness provided by the alloy. However, niobium is preferably limited to not more than about 0.03% in this alloy to avoid the formation of relatively large carbides that can adversely affect the wear resistance property.

**[0017]** Manganese and silicon may be present as residual elements. The amounts of manganese and silicon in the alloy are preferably kept as low as practicable because too much of either or both of those elements adversely affects the good impact toughness provided by the alloy. Silicon is a strong ferrite former and therefore, it is also limited to inhibit the formation of ferrite in the alloy. For those reasons, the alloy contains not more than about 0.1% each of manganese and silicon.

**[0018]** The balance of the alloy is iron and the usual impurities. Such impurities include not more than about 0.005% phosphorus and not more than about 0.002% sulfur. Preferably, the alloy contains not more than about 0.001% sulfur. In addition, copper is preferably limited to not more than about 0.10% and aluminum is preferably limited to not more than about 0.02% in this alloy. The amounts of the impurity elements are preferably limited as set forth above because those elements adversely affect the good impact toughness provided by the alloy.

**[0019]** No special technique is necessary to produce this alloy. The alloy is preferably air melted and decarburized by argon oxygen decarburization (AOD). The alloy is further refined by vacuum arc remelting (VAR). The VAR ingot is stress relieved, homogenized, hot worked, and then heat treated to provide a suitable intermediate product such as bars.

**[0020]** To achieve a high impact toughness at low temperatures, i.e., -40°F, it is important for the alloy to have a relatively small grain size. Preferably, the alloy has a grain size that is not coarser than ASTM Grain Size No. 7 in the annealed-and-tempered condition. In order to obtain the desired grain size, the alloy is hot rolled from a starting temperature of about 1950 °F down to about 1700°F. A finished part made from the alloy, such as a gun barrel, is heat treated by annealing the article at 1600-1700°F for 1-3 hours, and then tempering at 1110-1180°F for 2-8 hours. Preferably, the alloy is tempered at 1150-1170°F for about 3-5 hours.

WORKING EXAMPLES

Example 1:

**[0021]** A laboratory-scale heat having the weight percent composition shown in Table 1 below was melted in a vacuum induction furnace and cast as a 35-lb. ingot.

TABLE 1

| C | Si | Mn | S | P | Cr | V | Ni | Mo | AL | Cu | Nb |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.24 | 0.01 | 0.01 | <0.001 | 0.005 | 1.51 | 0.30 | 3.49 | 1.58 | <0.01 | 0.02 | 0.02 |

**[0022]** The balance of the composition was iron.

**[0023]** The as-cast ingot was hot worked to make a 0.75" square bar. Standard size specimens for tensile and Charpy V-notch (CVN) impact testing were cut from the longitudinal orientation from the 0.75" bar. The specimens were heat treated by austenitizing at 1650°F for one hour and oil quenched to room temperature. The specimens were then tempered by heating at 1142°F for 4 hours followed by an air cool to room temperature.

**[0024]** The results of room temperature tensile testing including the ultimate tensile strength (UTS) and the 0.2% offset yield strength (YS), in ksi, the percent elongation (%El.) and the percent reduction in area (%R.A.) are shown in Table 2 below. Also shown in Table 2 are the results of CVN impact testing conducted at -40°F in ft-lbs. The values presented in Table 2 are the average of 3 tests.

TABLE 2

| UTS (ksi) | YS (ksi) | %El | %RA | CVN @ -40F (ft-lbs) |
|---|---|---|---|---|
| 184 | 170 | 21 | 70 | 100.2 |

Example 2:

**[0025]** A production-scale heat (30 tons) having the weight percent composition shown in Table 3 below was arc melted and decarburized by AOD.

TABLE 3

| C | Si | Mn | S | P | Cr | V | Ni | Mo | AL | Cu | Nb |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.23 | 0.05 | 0.02 | <0.001 | 0.003 | 1.50 | 0.31 | 3.49 | 1.51 | 0.004 | 0.07 | 0.02 |

**[0026]** The balance was iron.

**[0027]** The heat was then refined by VAR and cast into three (3) separate VAR ingots. Two of the VAR ingots were forged to billet. One of the billets was rotary forged to make six 5-in. square billets. A second VAR ingot was forged to a 10×12-in billet then hot rolled to 1.5 in diameter bar.

**[0028]** Standard size specimens for tensile and Charpy V-notch (CVN) impact testing were cut from both the 5-in. billets and the 10×12 in. billet from the longitudinal direction. The specimens were heat treated by austenitizing at 1650°F for one hour and oil quenched to room temperature. The specimens were then tempered at 1155°F and cooled to room temperature.

**[0029]** The results of room temperature tensile testing including the ultimate tensile strength (UTS) and the 0.2% offset yield strength (YS), in ksi, the percent elongation (%El.) and the percent reduction in area (%R.A.) are shown in Table 4 below. Also shown in Table 4 are the results of CVN impact testing conducted at -40°F in ft-lbs. The values presented in Table 4 are the average of 10 tensile tests and 15 impact tests.

TABLE 4

| Temper | UTS | YS | %El | %RA | CVN @ -40F |
|---|---|---|---|---|---|
| (4 hrs) | (ksi) | (ksi) | | | (ft-lbs) |
| 1155°F | 181 | 167 | 20 | 70 | 85 |

**[0030]** Standard size specimens for tensile and CVN impact testing were cut from the 1.5" bar that was heat treated at 1650°F for one hour. One bar lot was oil quenched and a second bar lot was air cooled. The bar lots were then tempered at different temperatures to determine the effect on the mechanical properties. A first lot of bars was tempered by heating at 1150°F for 4 hours. A second lot was tempered by heating at 1160°F for 4 hours and a third lot was tempered by heating at 1170°F for 4 hours. All bars were air cooled to room temperature after tempering. Samples were cut from the heat treated bar lot for testing The resulting grain sizes for the hot rolled bar lots were ASTM Grain Size No 11-12.

**[0031]** The results of room temperature tensile testing including the ultimate tensile strength (UTS) and the 0.2% offset yield strength (YS), in ksi, the percent elongation (%El.) and the percent reduction in area (%R.A.) are shown in Table 5 below. Also shown in Table 5 are the results of CVN impact testing conducted at -40°F in ft-lbs. The values presented in Table 5 are the average of 10 tensile tests and 6 impact tests for the bar lots tempered at 1150°F and 1160°F and the average of 5 tensile tests and 3 impact tests for the bar lot tempered at 1170°F.

TABLE 5

| Temper | UTS | YS | %El | %RA | CVN @ -40F |
|---|---|---|---|---|---|
| (4 hrs) | (ksi) | (ksi) | | | (ft-lbs) |
| 1150°F | 175 | 168 | 22 | 69 | 57 |
| 1160°F | 169 | 157 | 21 | 70 | 100 |
| 1170°F | 161 | 150 | 22 | 72 | 123 |

**[0032]** The terms and expressions which are employed in this specification are used as terms of description and not of limitation. There is no intention in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof. It is recognized that various modifications are possible within the invention described and claimed herein.

## Claims

**1.** A steel alloy consisting essentially of, in weight percent:

| | |
|---|---|
| C | about 0.21-about 0.27 |
| Mn | about 0.1 max. |
| Si | about 0.1 max. |
| P | about 0.005 max. |
| S | about 0.002 max. |
| Cr | about 1.2-about 1.8 |
| Mo | about 1.1-about 1.9 |
| V | about 0.2-about 0.4 |
| Ni | about 3.0-about 3.8 |
| Nb | about 0.005-about 0.03 |
| Cu | about 0.10 max. |
| Al | about 0.02 max. |

the balance being iron, impurities, and incidental amounts of residual elements that do not adversely affect the basic and novel properties provided by the alloy.

**2.** The steel alloy claimed in Claim 1 which contains at least about 0.22% carbon.

**3.** The steel alloy claimed in Claim 2 which contains not more than about 0.25% carbon.

**4.** The steel alloy claimed in Claim 1 which contains at least about 1.3% chromium.

**5.** The steel alloy claimed in Claim 4 which contains not more than about 1.7% chromium.

**6.** The steel alloy claimed in Claim 1 which contains at least about 1.3% molybdenum.

**7.** The steel alloy claimed in Claim 6 which contains not more than about 1.8% molybdenum.

**8.** The steel alloy claimed in Claim 1 which contains at least about 3.2% nickel.

**9.** The steel alloy claimed in Claim 8 which contains not more than about 3.7% nickel.

**10.** The steel alloy claimed in Claim 1 which contains at least about 0.01% niobium.

**11.** A steel alloy consisting essentially of, in weight percent:

| | |
|---|---|
| C | about 0.22-about 0.25 |
| Mn | about 0.1 max. |
| Si | about 0.1 max. |
| P | about 0.005 max. |
| S | about 0.001 max. |
| Cr | about 1.3-about 1.7 |
| Mo | about 1.3-about 1.8 |
| V | about 0.2-about 0.4 |
| Ni | about 3.2-about 3.7 |
| Nb | about 0.01-about 0.03 |
| Cu | about 0.10 max. |
| Al | about 0.02 max. |

the balance being iron, impurities, and incidental amounts of residual elements that do not adversely affect the basic and novel properties provided by the alloy.

**12.** An article of manufacture made from a steel alloy consisting essentially of, in weight percent:

| | |
|---|---|
| C | about 0.21-about 0.27 |
| Mn | about 0.1 max. |
| Si | about 0.1 max. |
| P | about 0.005 max. |
| S | about 0.002 max. |
| Cr | about 1.2-about 1.8 |
| Mo | about 1.1-about 1.9 |
| V | about 0.2-about 0.4 |
| Ni | about 3.0-about 3.8 |
| Nb | about 0.005-about 0.03 |
| Cu | about 0.10 max. |
| Al | about 0.02 max. |

the balance being iron, impurities, and incidental amounts of residual elements that do not adversely affect the basic and novel properties provided by the alloy, wherein the article is **characterized by** having a room temperature yield strength of at least 150 ksi in the hardened and tempered condition, and wherein the article is further **characterized by** having a Charpy V-notch impact toughness of at least at least 100 ft-lbs, when tested at a temperature of -40°C.

**13.** The article as claimed in Claim 12 wherein the alloy has a grain size that is not coarser than ASTM Grain Size No. 7 in the hardened-and-tempered condition

**14.** The article of manufacture as claimed in Claim 12 wherein the article is a gun barrel.

**15.** A method of making an article of manufacture from a steel alloy consisting essentially of, in weight percent:

| | |
|---|---|
| C | about 0.21-about 0.27 |
| Mn | about 0.1 max. |
| Si | about 0.1 max. |
| P | about 0.005 max. |
| S | about 0.002 max. |
| Cr | about 1.2-about 1.8 |
| Mo | about 1.1-about 1.9 |
| V | about 0.2-about 0.4 |
| Ni | about 3.0-about 3.8 |
| Nb | about 0.005-about 0.03 |
| Cu | about 0.10 max. |
| Al | about 0.02 max. |

the balance being iron, impurities, and incidental amounts of residual elements that do not adversely affect the basic and novel properties provided by the alloy, said method comprising the steps of

providing an intermediate form of said alloy;
hot rolling the intermediate form from a temperature of about 1950°F down to a temperature of about 1700°F to provide said article of manufacture;
annealing the article of manufacture at a temperature of about 1600°F to about 1700°F for about 1 to about 4 hours, followed by
cooling the annealed article of manufacture to about 70°F; followed by
tempering the article of manufacture to final hardness and strength by heating at a temperature of 1110-1180°F for about 2 to about 8 hours; and then
cooling the article of manufacture to about 70°F.

**16.** The method as claimed in Claim 15 wherein the tempering step is carried out by heating the article at a temperature of about 1160°F to about 1175°F for about 3 hours to about 5 hours.

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# EUROPEAN SEARCH REPORT

Application Number
EP 21 21 1845

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The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| The Hague | 18 April 2022 | Vlassi, Eleni |

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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# ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 21 21 1845

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82