# United States Patent [19]

**Waid et al.**

[11] **3,899,368**

[45] **Aug. 12, 1975**


[54] **LOW ALLOY, HIGH STRENGTH, AGE HARDENABLE STEEL**


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[22] Filed: **Dec. 13, 1973**

[21] Appl. No.: **424,552**

[52] **U.S. Cl.** ..... **148/36**; 75/125; 75/128 G; 148/12 F

[51] **Int. Cl.** ..... **C22c 39/26**

[58] **Field of Search** ..... 75/128 G, 125, 128 A, 75/128 W, 128 T, 128 F; 148/12 F, 36



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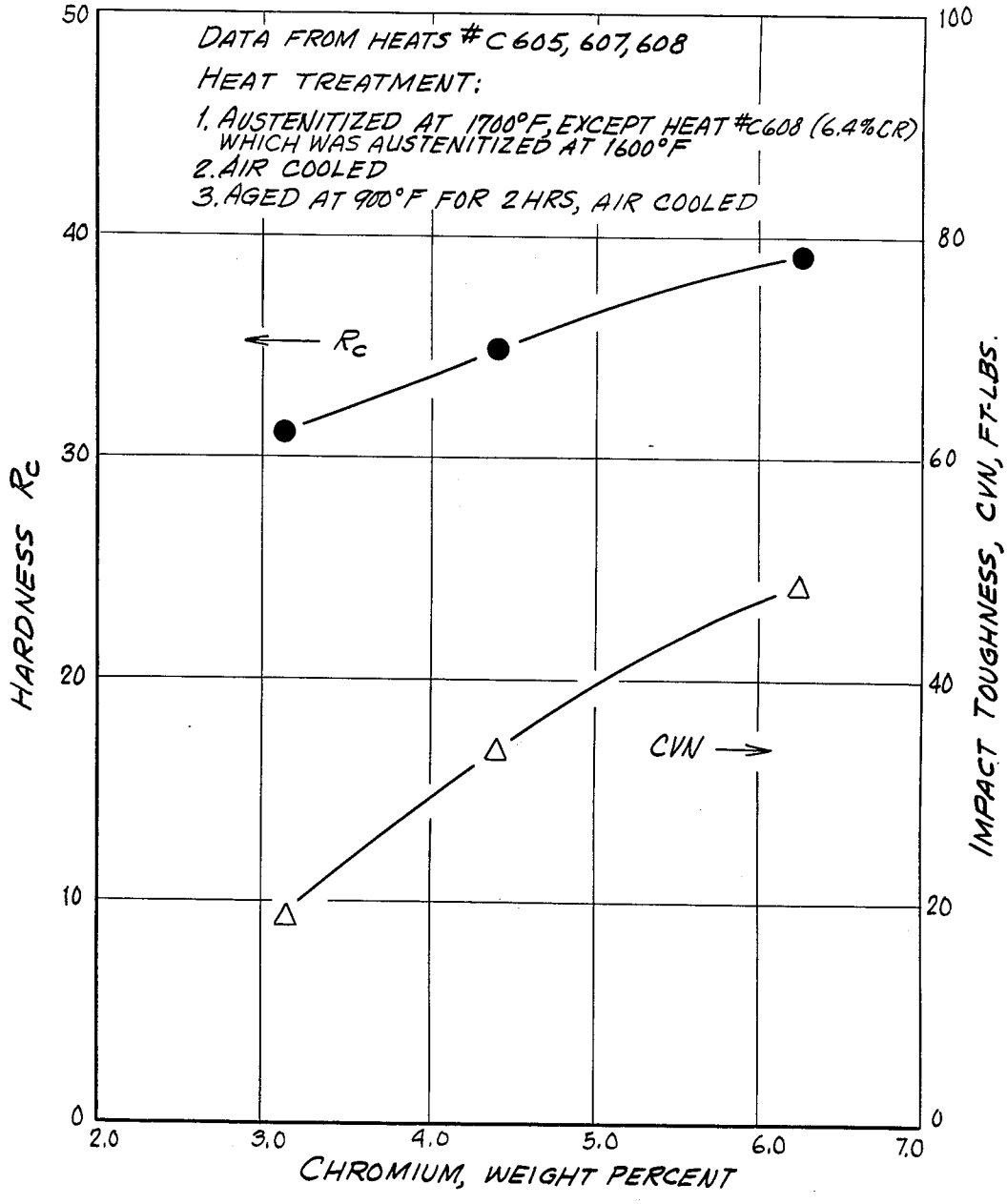
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[57] **ABSTRACT**

Low alloy, high strength, age hardenable steel, especially adapted for bar product applications, consisting essentially in percentage by weight of about: up to 0.06% maximum of carbon, from more than 1% up to 8% chromium, 0.25 to 3.5% nickel, 1 to 4% copper, 0.01 to 0.5% niobium, 0.2 to 2% manganese, 0.01 to 1% silicon, up to 1.5% molybdenum, up to 1.2% aluminum, up to 0.5% titanium, up to 0.1% boron, up to 0.035% phosphorous, up to 0.040% sulphur, balance iron except for impurities within commercial tolerances, characterized as hot rolled and air cooled or as thereafter solution treated at about 1,600°–2,200°F and thence air or more rapidly cooled, by room temperature hardness of about 30 Rockwell "C" and under, suitable for forming and machining, and as thereafter aged at about 700°–1,100°F, by room temperature properties as follows: tensile strengths of about 160–180 ksi, yield strengths of about 135–145 ksi, tensile elongations of about 17–20%, Rockwell "C" hardnesses of about 35–40, and Charpy impact energies of about 15–30 ft-lbs. and higher depending on the heat treatment.


**5 Claims, 1 Drawing Figure**




HARDNESS AND TOUGHNESS PROPERTIES AS A FUNCTION OF CHROMIUM CONTENT

# LOW ALLOY, HIGH STRENGTH, AGE HARDENABLE STEEL

This invention pertains to a low carbon, low alloy, age hardenable steel, especially adapted for bar product applications, of high strength, ductility and toughness in the age hardened condition, but of relatively low hardness as solution treated for ease of forming into articles and machining.

The principal required alloying elements of the steel ar nickel, chromium and copper together with small amounts of niobium. Silicon and maganense are also included in amounts which occur in the melting of normal fine grained aluminum killed steels. The steels may also contain small amounts of one or more of Mo, Ti, Al and B as optional additions.

The invention provides a low alloy (low alloying content with respect to such steels as maraging or stainless), high strength steel which is age hardenable, which can be machined or fabricated to close tolerances easily while in a relatively soft condition, after hot working and air cooling (or more rapid quench), or after hot working, air cooling, solution treating and either air cooling or oil or water quenching, then strengthened by an aging treatment to obtain a desired strength level with little distortion and no need for a subsequent finish machining operations. The steel of the invention involves both a specific chemistry range and a specific processing sequence. The addition of copper provides the principal precipitating phase which is present in the aged steel as $\epsilon$-copper. This precipitate accounts for most of the strengthening that occurs during the aging treatment. The processing sequence consists of hot working the steel into bar product forms, then air cooling.

Preferably, the material should be in a soft condition after air cooling and ready for machining or fabrication; however, if this is not the case, an intermediate heat treatment can be employed. This heat treatment consists of heating the steel in the temperature range of about 1,600° to 2,200°F, thence air cooling or quenching in either oil or water. This treatment imparts to the steel a soft, machinable structure. After the machining process is complete, merely heating the steel in the temperature range of about 700° to 1,100°F for various lengths of time (usually 1 to 6 hours), depending on the aging temperature used, will yield a hardened workpiece with ultimate tensile strengths exceeding 160 ksi.

The broad, preferred and optimum alloy ranges for the steel of the invention are:

| Element | Broad | Weight Percent Preferred | Optimum |
|---|---|---|---|
| C | 0.06 max. | 0.05 max. | 0.04 max. |
| Mn | 0.2–2.0 | 0.3–0.8 | 0.4–0.8 |
| Si | 0.01–1.0 | 0.2–0.5 | 0.2–0.35 |
| Ni | 0.25–3.5 | 0.5–1.5 | 0.5–1.5 |
| Cr | >1.0–8.0 | 1.5–5.0 | 1.5–4.5 |
| Cu | 1.0–4.0 | 1.5–3.5 | 1.5–3.5 |
| Nb | 0.01–0.5 | 0.02–0.45 | 0.02–0.3 |
| Mo | 0–1.5 | 0–0.25 | 0–0.12 |
| Al | 0–1.2 | 0–0.25 | 0–0.15 |
| Ti | 0–0.5 | 0–0.25 | 0–0.25 |
| B | 0–0.1 | 0–0.005 | 0–0.005 |
| P | 0.035 max. | 0.025 max. | 0.020 max. |
| S | 0.040 max. | 0.030 max. | 0.020 max. |
| Bal. | Fe | Fe | Fe |



Typical room temperature mechanical properties of the steel as hot rolled into 1¼ inch round bars, austenitized at about 1,700°F, air cooled and aged at about 900°F for about 2 hours, are:

| UTS Ksi | YS Ksi | RA % | El % | Charpy Ft-lbs. | Hardness Rc |
|---|---|---|---|---|---|
| 175 | 140 | 60 | 18 | 25 min. | 35–40 |

Hardness as solution treated and quenched is typically about 25–30 Rc.

The alloy element contents are designed to develop a steel which can be easily machined or fabricated to close tolerances while in a relatively soft condition, after hot working and air cooling (or more rapid quench), or after hot working, air cooling, solution treating and either air cooling or water or oil quenching. Subsequently, an aging treatment is used to obtain the desired strength level. Specifically, the major alloying elements are added for the following reasons:

1. Copper is the principal strengthening element in this alloy system. During the aging process it precipitates as $\epsilon$-copper particles causing a substantial increase in strength.

2. Nickel is added for two purposes. The first is to prevent hot shortness in this copper containing steel and the second is to improve the impact toughness properties.

3. Carbon is restricted to a maximum of 0.06 weight percent because of its deleterious effects on impact toughness. Carbon also raises the base hardness of this alloy system causing machining of articles made from the proposed alloy steel to be more difficult.

4. Columbium (niobium) is added both for its grain refining effects during hot rolling, thus increasing both strength and impact toughness properties, and the precipitation of niobium carbides andd nitrides during the aging treatment which causes an increase in strength properties.

5. Chromium is added to achieve sufficient air-cooled hardenability in bars up to 2 inch round. It has been found that chromium improves impact toughness properties of this alloy, up to approximately four (4.0) weight percent thereof.

6. Molybdenum is essentially a residual element, however, higher amounts of this element, up to 1.5 weight percent may be added to reduce the susceptibility of this alloy steel to temper embrittlement.

7. The additions of manganese and silicon are at levels which occur in the melting of normal fine grained steels.

8. Additions of aluminum, if any is added, is either for the purpose of reducing grain size during hot rolling, thus complementing the niobium and/or columbium additions, or for deoxidation purposes if the steel of this invention is to be aluminum killed.

The following Tables I–III inc., give room temperature Rockwell "C" (Rc) hardness and Charpy impact (CVN) energy in ft-lbs. for test results on steels of the tabulated compositions in the various heat treated conditions shown therein.

TABLE I

| Heat | Composition C | Mn | Si | Cr | Mo | Ni | Cu | Al | Cb | Heat Treatment W.Q. $R_C$ | W.Q. CVN | W.Q. & Aged $R_C$ | W.Q. & Aged CVN | A.C. $R_C$ | A.C. CVN | A.C. & Aged $R_C$ | A.C. & Aged CVN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *C585 | .027 | .59 | .23 | .54 | .15 | 1.02 | 2.0 | .02 | .065 | 23.7 | 112.7 | 32 | 69 | 22 | 41 | 28.5 | 14.5 |
| *C586 | .026 | 1.10 | .23 | .52 | .15 | 1.00 | 1.95 | .012 | .061 | 25 | 105 | 34 | 9 | 22.5 | 17.7 | 30 | 4 |
| *C587 | .029 | 1.53 | .23 | .52 | .15 | 1.00 | 2.0 | .01 | .061 | 27 | 85 | 34.5 | 6.7 | 23 | 6.1 | 31 | 5 |
| **C585 | Same Chemistry as Above | | | | | | | | | 18 | 173 | 29 | 88.5 | 12.5 | 217.5 | 17 | 158 |
| **C586 | Same Chemistry as Above | | | | | | | | | 22 | 157 | 29 | 93 | 17 | 173 | 23 | 139 |
| **C587 | Same Chemistry as Above | | | | | | | | | 25.5 | 141 | 31.5 | 76.5 | 24 | 109 | 26 | 60 |
| *C605 | .028 | .50 | .17 | 3.1 | .18 | 1.00 | 2.0 | <.01 | .084 | 27.5 | 22.5 | 35 | 2.1 | 26 | 5.6 | 34 | 2.2 |
| *C606 | .030 | .47 | .17 | 4.9 | 1.0 | 1.00 | 2.0 | <.01 | .082 | 28 | 10.8 | 36.5 | 2.2 | 30 | 5.7 | 38 | 2.3 |
| *C607 | .027 | .46 | .15 | 4.4 | .18 | 1.00 | 2.0 | <.01 | .085 | 27.5 | 35.4 | 36 | 2.6 | 28.5 | 56 | 37 | 3.1 |
| *C608 | .027 | .44 | .17 | 6.3 | .18 | 1.00 | 2.0 | <.01 | .080 | 28 | 47.5 | 36 | 4.8 | 30 | 24 | 37.5 | 2.5 |
| **C605 | Same Chemistry as Above | | | | | | | | | 27 | 94 | 34 | 11.5 | 24 5 | 95 | 31 | 9.5 |
| **C606 | Same Chemistry as Above | | | | | | | | | 27 | 62 | 35 | 19 | 30.5 | 92 | 37 | 4.5 |
| **C607 | Same Chemistry as Above | | | | | | | | | 27 | 90 | 34.5 | 39.2 | 28 | 101 | 34.5 | 34 |
| **C608 | Same Chemistry as Above | | | | | | | | | 27.5 | 87 | 35.5 | 19 | 30 | 89 | 36.5 | 48 |

Aged at 900 F for two hours.
* Austenitizing temperature was 2100 F.
** Austenitizing temperature was 1700 F, except for Heat #C608, where the temperature was 1600 F.
CVN = Charpy V-notch impact specimens tested at +70 F.

TABLE II

| Heat | Composition C | Mn | Si | Cr | Mo | Ni | Cu | Cb | Processing and Heat Treatment: As-Rolled $R_C$ | As-Rolled CVN | As-Rolled and Aged $R_C$ | As-Rolled and Aged CVN | W.Q. $R_C$ | W.Q. & Aged $R_C$ | W.Q. & Aged CVN | A.C. $R_C$ | A.C. and Aged $R_C$ | A.C. and Aged CVN | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 674 | .036 | .67 | .19 | 4.0 | .065 | 1.0 | 2.0 | - | 32.5 | 71.2 | 38.4 | 13.7 | 28.5 | 36.5 | 2.2 | 28.2 | 38.3 | 4.5 | 2100 F Aust. Temp |
| | | | | | | | | | | | | | 30.5 | 36.5 | 12.0 | 30.8 | 38 | 19 | 1700 F Aust. Temp |
| **C674 | Same Chemistry as Above | | | | | | | | 31.5 | 65 | 38.4 | 5.7 | 28.5 | 36.1 | 2.7 | 28.1 | 37 | 3.7 | 2100 F Aust. Temp |
| | | | | | | | | | | | | | 31 | 38 | 5.7 | 33 | 39 | 7.2 | 1700 F Aust. Temp |
| *C675 | .042 | .61 | .17 | 4.0 | .065 | 1.0 | 2.0 | .032 | 33.7 | 60.2 | 38.6 | 34.2 | 28.7 | 37 | 2.5 | 27.6 | 38.6 | 5.0 | 2100 F Aust. Temp |
| | | | | | | | | | | | | | 30.2 | 37 | 18.5 | 31.2 | 38 | 33.5 | 1700 F Aust. Temp |
| **C675 | Same Chemistry as Above | | | | | | | | 32.6 | 60.2 | 38.9 | 13.0 | 29.7 | 37.3 | 2.2 | 28.2 | 38 | 6.5 | 2100 F Aust Temp |
| | | | | | | | | | | | | | 31 | 38 | 18.2 | 31 | 38.5 | 27.5 | 1700 F Aust. Temp |
| *C676 | .041 | .86 | .21 | 4.0 | .066 | 1.0 | 2.0 | .07 | 34.2 | 71.2 | 39 | 26 | 27.3 | 39 | 2.7 | 29.1 | 38.5 | 4.5 | 2100 F Aust. Temp |
| | | | | | | | | | | | | | 33.3 | 38 | 22.7 | 33 | 38.4 | 32.2 | 1700 F Aust. Temp |
| **C676 | Same Chemistry as Above | | | | | | | | 33.1 | 44.2 | 40 | 12.5 | 29.5 | 36.3 | 2 | 29.5 | 39.5 | 10 | 2100 F Aust. Temp |
| | | | | | | | | | | | | | 33.1 | 37 | 9.5 | 31 | 38.5 | 19.7 | 1700 F Aust. |
| *C677 | .039 | .78 | .18 | 4.0 | .066 | 1.0 | 2.0 | .091 | 33.7 | 67 | 38.6 | 51.5 | 29.5 | 39 | 4.2 | 29.3 | 38.5 | 4.5 | 2100 F Aust. Temp |
| | | | | | | | | | | | | | 32.3 | 37 | 25.2 | 32.6 | 38 | 41 | 1700 F Aust. Temp |
| **C677 | Same Chemistry as Above | | | | | | | | 33.1 | 45.7 | 39.5 | 7.7 | 29 | 38.5 | 3.5 | 29 | 39.2 | 5.2 | 2100 F Aust Temp |
| | | | | | | | | | | | | | 32.5 | 37.5 | - | 31.5 | 38.5 | 30.2 | 1700 F Aust. Temp |

Aged at 900 F for two hours.
* 1850 F soaking temperature.
** 2250 F soaking temperature.

TABLE III

| Heat | Composition C | Mn | Si | Cr | Mo | Ni | Cu | Cb | Processing and Heat Treatment: As-Rolled $R_C$ | As-Rolled CVN | As-Rolled and Aged $R_C$ | As-Rolled and Aged CVN | W.Q. $R_C$ | W.Q. & Aged $R_C$ | W.Q. & Aged CVN | A.C. $R_C$ | A.C. and Aged $R_C$ | A.C. and Aged CVN | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 725 | .016 | .52 | .25 | 1.95 | .06 | 1.0 | 2.2 | .08 | 20.5 | 180 | 14.5 | 171 | 22.5 | 32.0 | 9.5 | 22.7 | 30 | 6.7 | 2100 F Aust. Temp |
| | | | | | | | | | | | | | 19.2 | 30.5 | 70 | 9.5 | 13.5 | 178 | 1700 F Aust Temp |
| **C725 | Same Chemistry as Above | | | | | | | | 24 | 98 | 29 | 41.5 | 25 | 34.5 | 12.2 | 22.5 | 29.5 | 5.7 | 2100 F Aust. Temp |
| | | | | | | | | | | | | | 23 | 30 | 59 | 11.5 | 14 | 184 | 1700 F Aust. Temp |
| *C726 | .019 | 1.04 | .26 | 2.0 | .07 | 1.0 | 2.2 | .08 | 24 | 133 | 26 | 132 | 26.5 | 34.5 | 2.0 | 23 | 31.5 | 5.0 | 2100 F Aust. Temp |
| | | | | | | | | | | | | | 23 | 32 | 61.0 | 22.5 | 23 | 127 | 1700 F Aust. Temp |
| **C726 | Same Chemistry as Above | | | | | | | | 26 | 52 | 32 | 10.7 | 26 | 34 | 3.2 | 23.5 | 31.5 | 6.0 | 2100 F Aust. Temp |
| | | | | | | | | | | | | | 23 | 33 | 49 | 18 | 22 | 138 | 1700 F Aust. Temp |
| *C727 | .015 | 1.50 | .26 | 2.0 | .065 | .98 | 2.2 | .079 | 25.5 | 107.5 | 29.5 | 97 | 24 | 34 | 2.5 | 22.5 | 32 | 4.0 | 2100 F Aust. Temp |
| | | | | | | | | | | | | | 23.5 | 30 | 52 | 23.5 | 27 | 85 | 1700 F Aust. Temp |
| **C727 | Same Chemistry as Above | | | | | | | | 24.5 | 50 | 31 | 8.5 | 24 | 34.5 | 3.5 | 23 | 31.5 | 6.0 | 2100 F Aust. Temp |
| | | | | | | | | | | | | | 25.5 | 31.5 | 42 | 21 | 27.5 | 87 | 1700 F Aust. |
| *C728 | .021 | 1.98 | .26 | 2.0 | .064 | .98 | 2.2 | .075 | 25.5 | 103 | 31 | 83 | 27.5 | 35 | 2.0 | 22 | 33 | 4.2 | 2100 F Aust. Temp |
| | | | | | | | | | | | | | 25.5 | 31.5 | 31 | 19.5 | 30 | 17 | 1700 F Aust. Temp |
| **C728 | Same Chemistry as Above | | | | | | | | 27 | 18 | 34 | 4.5 | 24.5 | 35 | 2.0 | 24.5 | 32.5 | 4.0 | 2100 F Aust. Temp |
| | | | | | | | | | | | | | 25.5 | 31 | 6.5 | 24 | 30 | 52.5 | 1700 F Aust. Temp |
| *C729 | .016 | .97 | .25 | 1.0 | .06 | 1.0 | 2.25 | .088 | 20 | 151 | 21 | 97 | 22 | 34.5 | 8.7 | 23 | 31.5 | 8.5 | 2100 F Aust. Temp |
| | | | | | | | | | | | | | 17.5 | 29.5 | 49 | 10.5 | 16 | 148 | 1700 F Aust. Temp |
| **C729 | Same Chemistry as Above | | | | | | | | 23 | 38 | 28 | 17.5 | 27 | 33 | 6 | 23 | 29 | 6.5 | 2100 F Aust. Temp |
| | | | | | | | | | | | | | 22 | 29.5 | 64 | 9 | 14 | 189 | 1700 F Aust. Temp |
| C730 | .017 | 1.00 | .26 | 1.5 | .063 | 1.0 | 2.2 | .08 | 20.5 | 153 | 24.5 | 143 | 26 | 34 | 6.2 | 24 | 31 | 6.5 | 2100 F Aust. Temp |
| | | | | | | | | | | | | | 24 | 31.5 | 66 | 13 | 18.6 | 151 | 1700 F Aust. Temp |
| **C730 | Same Chemistry as Above | | | | | | | | 24 | 53 | 30 | 13 | 21 | 32.5 | 7.5 | 23 | 30.5 | 5 | 2100 F Aust. Temp |
| | | | | | | | | | | | | | 25 | 30 | 70 | 13 | 15 | 181 | 1700 F Aust. Temp |
| *C731 | .019 | 1.03 | .27 | 2.1 | .064 | 1.0 | 2.2 | .08 | 24 | 127 | 26 | 112 | 24 | 34.5 | 4.2 | 24 | 31 | 7.2 | 2100 F Aust. Temp |
| | | | | | | | | | | | | | 25 | 32 | 56.5 | 19 | 24 | 122 | 1700 F Aust. Temp |
| **C731 | Same Chemistry as Above | | | | | | | | 25.5 | 64 | 32 | 11 | 27 | 34.5 | 4.7 | 24 | 31 | 5.5 | 2100 F Aust. Temp |
| | | | | | | | | | | | | | 23 | 32 | 40.5 | 16.5 | 22 | 126 | 1700 F Aust. Temp |

(TABLE III continued)

| Heat | Composition C | Mn | Si | Cr | Mo | Ni | Cu | Cb | Processing and Heat Treatment: As-Rolled: As-Rolled $R_C$ | As-Rolled: As-Rolled CVN | As-Rolled: As-Rolled and Aged $R_C$ | As-Rolled: As-Rolled and Aged CVN | W.Q. $R_C$ | W.Q. & Aged $R_C$ | W.Q. & Aged CVN | A.C. $R_C$ | A.C. and Aged $R_C$ | A.C. and Aged CVN | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *C732 | .033 | .99 | .28 | 2.6 | .063 | .98 | 2.2 | .079 | 25 | 105 | 29.5 | 78 | 26 | 34.5 | 6 | 24 | 32 | 7.2 | 2100 F Aust. Temp |
| | | | | | | | | | | | | | 22.5 | 30.5 | 57 | 21.5 | 25.5 | 117 | 1700 F Aust. Temp |
| **C732 | Same Chemistry as Above | | | | | | | | 26 | 43 | 32.5 | 11.5 | 25.5 | 34.5 | 4.5 | 25 | 32.5 | 7.5 | 2100 F Aust. Temp |
| | | | | | | | | | | | | | 26.5 | 33 | 48 | 22 | 26 | 92 | 1700 F Aust. Temp |

Aged at 900 F for two hours.
* 1850 F soaking temperature.
** 2250 F soaking temperature.
CVN = Charpy V-notch impact specimens tested at +70 F.

Referring to the data of these tables it will be seen that the steels containing less than applicant's lower limit of more than 1.0% chromium do not possess the combination of high hardness and impact strength of those falling within applicant's composition range as to chromium. This is further illustrated by the accompanying drawing comprising a graphical plot of chromium content versus hardness and Charpy impact energy, for steels C607, C608 and C609 of the above tables under the heated treated conditions shown in the drawing. The reason for this beneficial effect of chromium is not completely understood, but a reasonable explanation is that the increasing chromium content changes the microstructure of the steel from a mixture of proeutectoid ferrite and low carbon martensite at low chromium levels, to an all low carbon martensite structure at high chromium levels.

The following Table IV gives the results of tensile tests on representative steels according to the invention and of the compositions shown in the table.

TABLE IV

MECHANICAL PROPERTY DATA ON AGE HARDENABLE BAR PRODUCT ALLOY FROM 1¼" ROUND BARS ROLLED ON THE MASSILLON 12" BAR MILL

| Heat No. | Soaking Temp °F | Y.S. ksi | U.T.S. ksi | R.A. % | El.(2") % | CVN ft-lbs. | Hardness Rc | Condition |
|---|---|---|---|---|---|---|---|---|
| C860 | 2150 | 105 | 149 | 67 | 16 | 55 | 30–32 | As-Rolled |
| | | 138 | 175 | 56 | 18 | 12 | 38–39 | As-Rolled and Aged |
| | | 139 | 160 | 66 | 19 | 43 | 35–36 | Austenitized, Air Cooled and Aged |
| C861 | 2150 | 101 | 149 | 63 | 16 | 32 | 30–31 | As-Rolled |
| | | 135 | 175 | 47 | 17 | 6 | 37–38 | As-Rolled and Aged |
| | | 142 | 165 | 63 | 18 | 31 | 35–37 | Austenitized, Air Cooled and Aged |
| C933 | 1900 | 109 | 156 | 65 | 15 | 50 | 32–33 | As-Rolled |
| | | 146 | 177 | 60 | 18 | 26 | 38–40 | As-Rolled and Aged |
| | | 144 | 177 | 60 | 18 | 29 | 36–37 | Austenitized, Air Cooled and Aged |

Composition

| Heat No. | C | Mn | Si | P | S | Ni | Cr | Mo | Cu | Nb | Al |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C860 | .03 | .63 | .25 | <.008 | .009 | 1.0 | 3.97 | .07 | 1.95 | .10 | <.01 |
| C861 | .03 | .63 | .28 | .015 | .020 | 1.0 | 4.01 | .07 | 2.15 | .095 | <.01 |
| C933 | .03 | .70 | .21 | .012 | .015 | 1.0 | 4.00 | .06 | 2.15 | .10 | .02 |

Aged = 900 F, 2 hrs.
Austenitized 1700 F, 1 hr. A.C., aged 900 F, 2 hrs.

The steel of the invention may be produced by melting in the electric furnace. The alloy content provides the air cooled hardenability shown in Table I–III inc., in sizes up to about 2 inch rounds. The product is air cooled from the bar mill and then processed through bar finishing operations to develop commercial straightness and any required surface removal. Components may then be finished machined from the bar stock by the customer and simply aged to achieve strength properties. Alternatively, the customer may austenitize and air cool or oil or water quench before machining. The alloy does not suffer from either machinability or distortion problems upon heat treating as above.

An optimum specific weight percent composition is:

| C | Mn | Si | P | S | Ni | Cr | Cu | Nb | Al | Bal. |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.03 | 0.65 | 0.25 | 0.01 | 0.015 | 1.0 | 4.0 | 2.15 | 0.10 | 0.03 | Fe |

The invention provides in a preferred embodiment, low alloy, high strength, hot rolled bar stock from the mill-(hot rolled at about 2,250°–1,850°F), primarily intended for steel parts produced by machining a bar of the steel or forging to final part size and tolerance, and thence hardening by aging as above. Further heat treatment and machining to a final size and tolerance is not required.

Insofar as is known to the applicant, the prior art has not developed a steel of the above composition and properties. A unique property of the steel of this invention is that the above mentioned mechanical properties are achieved by a simple aging treatment of the finished machined part which requires no subsequent finish machining operations after hardening. In contrast with previously known steels, similar properties are achieved only be producing a roughly machined part from a carbon strenghtened steel, which is then austenitized, oil quenched and tempered to the desired hardness or strength level, which involves some degree of distortion, and when then requires a more difficult finish machining operation of the thus hardened part.

The steel of the invention finds utility, among others, for industrial gearing other than automotive, shafting for pumps, track shoes for off highway equipment, such as caterpiller tractors, power take-off units for farm implements, and heavy machinery.

What is claimed is:

**1.** Low alloy, high strength, age hardenable, alloy steel consisting essentially in percentage by weight of about: 0.05% C max., 0.3–0.8% Mn, 0.2–0.5% Si, 0.5–1.5% Ni, 1.5–5.0% Cr, 1.5–3.5% Cu, 0.02–0.45% Nb, 0–0.25% each of Mo, Al and Ti, 0–0.005% B, 0.015% P max., 0.02% S max., balance iron except for impurities within commercial tolerances, characterized as hot rolled at about 2,250°–1,850°F and air cooled, and also as thereafter solution treated at about 1,600°–2,200°F and cooled at least as rapidly as air cool, by a Rockwell "C" hardness of about 30 and under, suitable for forming and machining, and as thereafter aged at about 700°–1,100°F by room temperature tensile properties as follows, tensile and yield strengths of about 160–180 and 135 145 ksi, respectively, tensile elongations of about 17–20%,, Charpy impact energies of about 15–30 ft-lbs. and higher, and Rockwell "C" hardnesses of about 35–40.

**2.** Low, alloy, high strength, age hardenable, alloy steel consisting essentially in percentage by weight of about: 0.04% C max., 0.4–0.8% Mn, 0.2–0.35% Si, 0.5–1.5% Ni, 1.5–4.5% Cr, 1.5–3.5% Cu, 0.02–0.3% Nb, 0–0.12% Mo, 0–0.15% Al, 0–0.25% Ti, 0–0.005% B, 0.015% P max., 0.02% S max., balance iron except for impurities within commercial tolerances, characterized as hot rolled at about 2,250°–1,850°F and air cooled, and also as thereafter solution treated at about 1,600°–2,200°F and cooled at least as rapidly as air cool, by a Rockwell "C" hardness of about 30 and under, suitable for forming and machining, and as thereafter aged at about 700°–1,110°F by room temperature tensile properties as follows, tensile and yield strengths of about 160–180 and 135–145 ksi, respectively, tensile elongations of about 17–20%, Charpy impact energies of about 15–30 ft-lbs. and higher, and Rockwell "C" hardnesses of about 35–40.

**3.** A wrought article made of a steel according to claim **1** in the condition as hot rolled and air cooled and characterized by a hardness of about 30 Rockwell "C" and under, adapting the same for forming and machining, and therafter age hardening.

**4.** A wrought article made of a steel according to claim **1** in the condition as solution treated and characterized by a hardness of about 30 Rockwell "C" and under, adapting the same for forming and machinine, and thereafter age hardening.

**5.** A wrought article composed of an age hardened steel according to claim **1** having room temperature tensile properties as follows; tensile and yield strengths about 160–180 and 135–145 ksi, respectively, tensile elongation about 17–20%, Charpy impact energy about 15–30 ft.-lbs., and Rockwell "C" hardness about 35–40.

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