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3,257,200

Heat-treatment

ALLOY STEEL FOR ELEVATED TEMPERATURE SERVICE

John M. Hodge, Pleasant Hills Borough, Pa., assignor to United States Steel Corporation, a corporation of Delaware

No Drawing. Filed Dec. 10, 1962, Ser. No. 243,581
3 Claims. (Cl. 148-36)

1800 F., 1 hour ----- Air-cool.
1300 F., 8 hour ----- Air cool.

5 Heat-treated as 3/4-inch square samples.

TABLE II.—TENSILE PROPERTIES

| Steel Designation | Test Temperature, F. | Yield Strength (0.2% Offset), p.s.i. | Tensile Strength, p.s.i. | Elongation, percent | Reduction of Area, percent |
|-------------------|----------------------|--------------------------------------|--------------------------|---------------------|----------------------------|
| 15 A----- | RT | 94,500 | 111,100 | 23.0 | 70.0 |
| | 550 | 76,800 | 93,300 | 18.0 | 71.5 |
| | 700 | 76,600 | 93,400 | 17.0 | 71.5 |
| | 850 | 69,900 | 84,900 | 21.0 | 71.0 |
| | 1,000 | 67,100 | 73,100 | 20.0 | 71.5 |
| | 1,100 | 63,800 | 68,500 | 17.0 | 75.5 |
| | 1,200 | 54,200 | 58,600 | 26.0 | 81.5 |
| | 1,300 | 44,500 | 48,000 | 30.0 | 83.0 |
| | RT | 94,600 | 110,600 | 22.0 | 75.4 |
| | 550 | 73,100 | 91,300 | 19.0 | 68.5 |
| 20 B----- | 700 | 74,500 | 89,800 | 19.0 | 71.0 |
| | 850 | 72,500 | 84,600 | 22.0 | 75.4 |
| | 1,000 | 67,300 | 74,500 | 22.0 | 79.6 |
| | 1,100 | 58,900 | 64,100 | 22.0 | 81.0 |
| | 1,200 | 54,500 | 56,000 | 20.0 | 73.9 |
| | 1,300 | 40,500 | 44,100 | 36.0 | 85.8 |

This application relates to alloy steels having improved elevated temperature properties and more particularly to steels of the 2 1/4% chromium-1% molybdenum type having increased elevated temperature strength.

Alloy steels of the 2 1/4% chromium-1% molybdenum type have been widely used for elevated temperature uses involving temperatures up to about 1050° F. For such service, these steels have a unique combination of properties of good stress rupture strength, excellent room and elevated temperature notch toughness and good weldability and fabricatability. It has heretofore been proposed to increase the elevated temperature strength and stress-rupture properties of such steels by the addition of strong carbide forming elements such as vanadium, titanium and columbium so that the steels can be used at higher temperatures. However, such attempts to improve the elevated temperature properties have resulted in a marked increase in notch sensitivity.

It is accordingly an object of this invention to provide an alloy steel of the 2 1/4% chromium-1% molybdenum type having good strength properties at temperatures of 1100° F. and higher along with good notch sensitivity.

The foregoing and further objects will be apparent from the following specification.

I have discovered that steel within the following composition levels has good elevated temperature properties and at the same time good notch sensitivity:

| | |
|------------------|----------|
| Carbon ----- | .20 max. |
| Manganese ----- | .30/.90 |
| Silicon ----- | .50 max. |
| Chromium ----- | 2.0/4.0 |
| Molybdenum ----- | .50/2.0 |
| Vanadium ----- | .50/1.0 |
| Columbium ----- | 0/.15 |

with the balance essentially iron and residual amounts of other elements.

In a preferred embodiment, the steel is made within the following range:

| | |
|------------------|----------|
| Carbon ----- | .10/.15 |
| Manganese ----- | .30/.60 |
| Silicon ----- | .20/.40 |
| Chromium ----- | 2.0/2.5 |
| Molybdenum ----- | .90/1.10 |
| Vanadium ----- | .50/.70 |
| Columbium ----- | .05/.15 |

with the balance essentially iron and residual amounts of other elements.

To illustrate the benefits of this invention, steels of the compositions given in the following Table I, heat treated as therein indicated, were tested to determine tensile, stress rupture and impact properties. The results of such tests are set forth in the following Tables II, III and IV.

TABLE I.—COMPOSITION

| Steel Designation | C | Mn | P | S | Si | Cr | Mo | V | Cb |
|-------------------|------|------|-------|-------|------|------|------|------|-------|
| A----- | 0.14 | 0.46 | 0.006 | 0.024 | 0.20 | 2.34 | 1.08 | 0.60 | ----- |
| B----- | 0.14 | 0.39 | 0.003 | 0.007 | 0.25 | 2.23 | 0.99 | 0.60 | 0.10 |

TABLE III.—STRESS RUPTURE PROPERTIES

| Steel Designation | Test Temperature, F. | 1,000-hr. Strength, p.s.i. | Elongation, percent | 10,000-hr. Strength, p.s.i. (Extrapolated) |
|-------------------|----------------------|----------------------------|---------------------|--|
| A----- | 1,100 | 32,000 | 20.0 | 24,000 |
| B----- | 1,100 | 28,500 | 26.0 | 21,000 |
| A----- | 1,200 | 18,000 | 29.0 | ----- |
| B----- | 1,200 | 19,800 | 31.0 | ----- |

TABLE IV.—V-NOTCH CHARPY IMPACT PROPERTIES

| Test Temperature, F. | A, ft.-lb. | B, ft.-lb. |
|----------------------|------------|------------|
| RT----- | 100 | >120 |
| 0----- | 24 | >120 |
| -50----- | 10 | 30 |
| -100----- | 8 | 6 |

I have further discovered that attainment of optimum notch toughness is dependent upon the use of suitable austenitizing temperatures during heat treatment. The temperature used must be high enough to dissolve a large proportion, but not all, of the vanadium carbides and, if columbium is present, to dissolve only a very small percentage of the columbium carbides. An austenitizing temperature of 1800° F. maintained for one hour produces such result. Since this is a time/temperature phenomenon, high temperatures at shorter times or lower temperatures at longer times may be used provided the foregoing objective is obtained, i.e. dissolving most but not all of the vanadium carbides while dissolving only a small amount of the columbium carbides.

From the foregoing data, it is evident that the steels of this invention possess high temperature strength, excellent stress rupture properties at temperatures as high as 1200° F. along with excellent notch toughness at 0° F. and with acceptable toughness as low as -100° F.

The results obtained are believed to result from the use of an excess of vanadium beyond the solubility limit for vanadium carbides at the austenitizing temperature used in practice. The undissolved carbides serve as grain growth inhibitors so that the steel when applied in service has a relatively fine grained microstructure and is favorable to notch toughness. The effect may be further augmented by small additions of columbium, which is of limited solubility at the austenitizing temperatures used in practice. The very small amount of columbium car-

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bide that is dissolved at the austenitizing temperature precipitates as very stable carbides that improve the elevated-temperature stability. The undissolved columbium carbides serve as grain-growth inhibitors and thereby augment the grain refinement.

While I have shown and described several specific embodiments of my invention, it will be understood that these embodiments are merely for the purpose of illustration and description and that various other forms may be devised within the scope of my invention, as defined in the appended claims.

I claim:

1. Alloy steel characterized by good notch sensitivity and together with good strength properties at temperatures above 1100° F., said steel containing essentially

| | |
|------------------|----------|
| Carbon | .10/.15 |
| Manganese | .30/.60 |
| Silicon | .20/.40 |
| Chromium | 2.0/2.5 |
| Molybdenum | .90/1.10 |
| Vanadium | .50/.70 |
| Columbium | .05/.15 |

balance essentially iron and residual amounts of other elements.

2. Alloy steel characterized by good notch sensitivity and together with good strength properties at temperatures above 1100° F., said steel containing essentially

| | |
|------------------|----------|
| Carbon | .10/.15 |
| Manganese | .30/.60 |
| Silicon | .20/.40 |
| Chromium | 2.0/2.5 |
| Molybdenum | .90/1.10 |
| Vanadium | .50/.70 |
| Columbium | .05/.15 |

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balance essentially iron and residual amounts of other elements, said steel having been heat treated to dissolve a substantial portion but not all of the vanadium carbides and only a small percentage of the columbium carbides.

5 3. Alloy steel characterized by good notch sensitivity and together with good strength properties at temperatures above 1100° F., said steel containing essentially

| | |
|--------------------|----------|
| Carbon | .10/.15 |
| 10 Manganese | .30/.60 |
| Silicon | .20/.40 |
| Chromium | 2.0/2.5 |
| Molybdenum | .90/1.10 |
| Vanadium | .50/.70 |
| 15 Columbium | .05/.15 |

20 balance essentially iron and residual amounts of other elements, said steel having been austenitized for about one hour at 1800° F. to dissolve a large proportion but not all of the vanadium carbides and a small percentage of the columbium carbides.

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DAVID L. RECK, *Primary Examiner.*

ROGER L. CAMPBELL, *Examiner.*

35 R. O. DEAN, P. WEINSTEIN, *Assistant Examiners.*