FORGING STEEL FOR ELEVATED TEMPERATURE SERVICE

Samuel J. Manganello, Penn Hills Township, Allegheny County, Pa., assignor to United States Steel Corporation, a corporation of Delaware

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I claim:

1. A forging steel for elevated temperature service having the following compositional ranges, by weight:

- Carbon: 0.25 to 0.35%
- Nickel: 5.5 to 6.0%
- Chromium: 0.85 to 1.45%
- Vanadium: 0.20 to 0.65%
- Manganese: 0.30 to 1.10%
- Molybdenum: 0.90 to 2.25%
- Silicon: 0.15 to 0.40%
- Aluminum (acid soluble): 0.05 to 0.20%

Forged longitudinal specimen blanks of the foregoing steels were austenitized for four hours at 1775° C., cooled to 600° F., and tested for both yield strength and elongation at room temperature and elevated temperature stress-rupture properties. The compositional ranges of my improved steel are:

- Yield strength, p.s.i.: A 105,000 to 107,000, B 109,000 to 110,000, C 105,000 to 107,000
- Elongation, %: A 15.5, B 16.0, C 16.0
- Reduction of area, %: A 55.2, B 58.4, C 60.3
- Energy absorbed at 75° F., ft-lb.: A 17.5, B 20.6, C 24.0
- Charpy V-notch 50% shear fracture transition temp., ° F.: A 185, B 160, C 110

Forged longitudinal specimen blanks of the foregoing steels were austenitized for four hours at 1775° C., cooled to 600° F., and tested for both yield strength and elongation at room temperature and elevated temperature stress-rupture properties. The compositional ranges of my improved steel are:

- Carbon: 0.35 to 0.36%
- Nickel: 5.0 to 6.0%
- Chromium: 0.50 to 0.65%
- Vanadium: 0.75 to 0.95%
- Manganese: 1.15 to 1.35%
- Molybdenum: 1.45 to 1.95%
- Silicon: 0.15 to 0.40%
- Aluminum: 0.05 to 0.20%

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The stress-rupture test results (obtained with combination smooth-notched creep rupture specimens) on two of the steels are listed in the following Table III:

<table>
<thead>
<tr>
<th>Steel</th>
<th>1,000 F., 60,000 p.s.i.</th>
<th>1,000 F., 50,000 p.s.i.</th>
<th>1,100 F., 40,000 p.s.i.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100.4</td>
<td>16.2</td>
<td>71.5</td>
</tr>
<tr>
<td>B</td>
<td>42.5</td>
<td>13.5</td>
<td>72.4</td>
</tr>
</tbody>
</table>

1 Time to rupture in hours.
2 Elongation in 3 inch.
3 Reduction of area.
4 Specimens blanks were austenitized for 4 hours at 1,800° F. and furnace cooled to room temperature immediately.

The normalized steels had a uniform microstructure consisting of an intimate mixture of ferrite plus bainite. The steel may be single or double-normalized (homogenized then normalized) and still exhibit the good combination of microstructure and properties. Thus the steel has sufficient hardenability to permit heavy forgings to cool during normalizing without forming proeutectoid ferrite and pearlite which have an undesirable effect on strength and impact properties.

I have found that even with the specified nickel content, manganese and molybdenum must be critically balanced to achieve the desired improved mechanical properties. In evaluating the various test results, it was observed that when the manganese content dropped below a certain level, the steel was not satisfactory unless the molybdenum content was above a certain level. Further investigation revealed that the converse was also true. Thus, when the manganese is in the range 0.30 to 0.75 percent the molybdenum should be 1.6 to 2.25 percent, and when the manganese is in the range 0.75 to 1.10 percent the molybdenum should be less than 1.6 percent. The silicon content should not be much higher than 0.40 percent, because high amounts of silicon are deleterious to stress-rupture properties. Higher amounts of nickel and vanadium are beneficial to notch toughness (impact properties). In fact, increasing the nickel content appears to be also beneficial to the tensile and stress-rupture properties of this steel. Higher amounts of molybdenum (and to a certain extent, vanadium) are beneficial to the stress-rupture properties. The carbon content must be kept within a rather narrow range (0.25 to 0.35 percent) to maintain high yield strength and reasonably good notch toughness.

The heat treatment to which these chromium-molybdenum-vanadium steels are subjected is critical. The use of final austenitizing temperatures higher than about 1800° F. is detrimental to notch toughness; the impairment to notch toughness is caused chiefly by austenite grain coarsening. However, the time at austenitizing temperature will vary within the conventional range of 20 to 40 hours depending upon the cross-sectional area of the forging under treatment. The tempering temperature is maintained within the range of 1225 to 1280° F. for times of 20 to 40 hours at temperature. As is conventional, the steel is air cooled (in still or agitated air) after austenite-tempering, and furnace cooled to room temperature.

A review of the data indicates that the steel composition of this invention produces the desired properties for steam-turbine rotors and other heavy forgings for elevated temperature service. Thus the steel has a room temperature 0.2 percent offset yield strength in excess of 85,000 p.s.i., a fracture transition temperature less than 250°F., good resistance to temper embrittlement, very good stress-rupture properties at temperatures up to 1200°F., and is notch insensitive. As previously stated, the steel has a microstructure consisting of a mixture of ferrite and bainite.

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 claim.

I claim:

A heavy forging steel for elevated temperature service characterized by a minimum room temperature yield strength of 85,000 p.s.i., a maximum Charpy V-notch 50 percent shear fracture transition temperature of 250°F. and good stress-rupture properties in the range of 950 to 1200°F., said steel consisting essentially of:

<table>
<thead>
<tr>
<th>Element</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Carbon</td>
<td>0.25/0.35</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.70/1.25</td>
</tr>
<tr>
<td>Chromium</td>
<td>0.85/1.45</td>
</tr>
<tr>
<td>Vanadium</td>
<td>0.20/0.65</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.30/0.75</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>1.6/2.25</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>max</td>
</tr>
<tr>
<td>Silicon</td>
<td>max</td>
</tr>
<tr>
<td>Aluminum</td>
<td>max</td>
</tr>
<tr>
<td></td>
<td>.015</td>
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<tr>
<td></td>
<td>.40</td>
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with the balance iron and residual impurities.

References Cited by the Examiner

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<table>
<thead>
<tr>
<th>Patent Number</th>
<th>Date</th>
<th>Inventor</th>
<th>Classification</th>
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<tbody>
<tr>
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<td>2/1928</td>
<td>Herman</td>
<td>75—128 X</td>
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<td>2,798,805</td>
<td>7/1937</td>
<td>Hodge</td>
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<td>2,921,849</td>
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<td>Furgason</td>
<td>75—128</td>
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</table>

HYLAND BIZOT, Primary Examiner.

DAVID L. RECK, Examiner.

P. WEINSTEIN, Assistant Examiner.