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LOW ALLOY STEEL CONTAINING BORON AND TITANIUM FOR HIGH-TEMPERATURE USE

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This invention relates to steels that combine desirable properties at normal temperatures with excellent high temperature properties.

Certain parts of jet engine and gas turbines, such as their rotors, parts of aircraft superchargers, and related devices operate at high stress and elevated temperatures. Various steels have been developed for such purposes, for instance the well-known steel alloy disclosed in United States Patent No. 2,398,702. In general, the steels used for such purposes up to the present time have been highly alloyed, and it is characteristic of them that they are very difficult to fabricate, they require special heat treatments of long duration and, in some instances, are rather complicated, or because being highly alloyed they are a drain on strategic metals.

The present shortage of certain critical metals has created the need for steels of low alloy content that are adapted to replace the highly alloyed steels used up to the present time for the foregoing and related purposes. In particular, there is a demand for steels containing a maximum of 5 per cent of alloying elements, which possess a 1000-hour rupture strength at 1100° F. of at least 40,000 pounds per square inch (p. s. i.), and which also possess good ductility to fracture at 1100° F. Steels meeting this combination of requirements have not been available heretofore.

It is among the objects of the invention to provide low alloy steel articles for high temperature use having a satisfactory combination of high temperature properties, and particularly a rupture strength at 1000 hours and 1100° F. of 40,000, or more, pounds per square inch, coupled with desirable ductility to fracture under those conditions.

A further object is to provide steel articles in accordance with the foregoing object that likewise possess desirable mechanical properties at normal temperatures.

Still another object is to provide steel articles embodying the foregoing objects and whose properties are developed by a simple and short heat treatment.

Yet another object is to provide steel articles in accordance with the foregoing objects containing not over about 5 per cent of alloy content.

The invention is predicated upon my discovery that its stated objects are attained with steels containing from about 0.15 to 0.5 per cent of carbon, from 0.0005 to 0.004 per cent of boron, from about 0.75 to 2.5 per cent of chromium, from about 0.2 to 2.0 per cent of manganese, from about 0.25 to 1.0 per cent of molybdenum, from about 0.1 to 1.5 per cent of silicon, from about 0.2 to 1.0 per cent of vanadium, and titanium from about

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1 to 6 times the amount of carbon. The remainder of the steels consist of iron together with impurities and elements in amounts that do not adversely affect the properties that characterize the steels of this invention. For full development of those properties the steels should contain not over about 0.04 per cent each of phosphorus and sulfur.

Within the foregoing limits I now prefer that the steels contain from about 0.20 to 0.35 per cent of carbon, from 0.001 to 0.003 per cent of boron, from about 1 to 2 per cent of chromium, from about 0.5 to 1.0 per cent of manganese, from about 0.4 to 0.6 per cent of molybdenum, from about 0.5 to 1.0 per cent of silicon, from about 0.7 to 0.9 per cent of vanadium, and titanium from 1 to 4 times the amount of carbon.

Steels of the foregoing composition are readily fabricated by all hot forming operations such, for example, as forging, sheet rolling, and piercing into seamless tubes. Likewise, they can be welded readily.

The best combination of strength and ductility at both room temperature and at 1100° F. is developed by air cooling, or normalizing, followed by tempering to about 302/365 Brinell. This heat treatment produces a martensitic structure. For maximum ductility in the rupture test at 1100° F. sections up to 2 inches the steels are normalized at 1800° F. and tempered at 1200° F. This gives a 1000-hour rupture strength of the order of 40,000 p. s. i. If a 1000-hour rupture strength in excess of 45,000 p. s. i. is desired, with possibly some sacrifice of ductility, the normalizing temperature should be increased to 1950° F., followed by tempering at 1200° F. For larger section sizes the normalizing temperature can be increased, or an oil quench from 1800° F. or 1900° F. followed by tempering, without impairing the room temperature or 1100° F. properties.

The excellent properties of these steels at elevated temperatures are characteristically exemplified by the properties of a steel in accordance with the invention and containing 0.22 per cent of carbon, 0.002 per cent of boron, 1.60 per cent of chromium, 0.57 per cent of manganese, 0.48 per cent of molybdenum, 0.77 per cent of silicon, 0.78 per cent of vanadium, and 0.35 per cent of of titanium. This steel when normalized from 1800° F. and tempered 6 hours at 1200° F. had the following room temperature properties:

Tensile strength	p. s. i.	150,000
0.2% Yield strength	p. s. i.	139,250
Elongation in 2"	per cent	15.5
Reduction of area	do	57.1
Brinell hardness		311/321

Furthermore, considering their low alloy content the steels of this invention possess unusually high rupture strength and ductility to fracture at failure. Thus the foregoing steel when heat treated as described had a rupture strength of 440,000 p. s. i. in 1000 hours at 1100° F., while the ductility at fracture was 21.0 per cent. Surprisingly enough, the ductility is four times that of a steel of essentially the same composition but containing no boron or titanium, the 1000 hour rupture strength at 1100° F. of which was 35,000 p. s. i., and the elongation at rupture 5.0 per cent, when normalized at 1800° F. and tempered at 1200° F.

The same steel when normalized from 1950° F. and tempered 6 hours at 1250° F. gave the following room temperature properties:

Tensile strength	p. s. i.	152,500
0.2% Yield strength	do	137,000
Elongation in 2''	per cent	15
Reduction of area	do	55
Brinell hardness		302/311

while the 1000-hour rupture strength at 1100° F. was 48,000 p. s. i. and the elongation at rupture was 5%.

Thus the rupture strength after 1000 hours at 1100° F. is greater than that had by the milder heat treatment while the ductility is equal to that of a comparable steel without boron and titanium.

Thus the steels of this invention containing exceedingly small amounts of boron and small amounts of titanium are much more useful for work at 1100° F. than similar steels without boron and titanium. And the range of boron stated is critical for when the boron content exceeds 0.005 per cent the high temperature (1100° F.) strength is impaired, and the hot working properties are likewise affected adversely, so much so that at 0.01 per cent of boron the hot working temperature must be held below 2000° F. Moreover, when heat treated as described the products possess high tensile strength at room temperature, stress-rupture strength in 1000 hours at 1100° F. of at least 40,000 p. s. i. and elongation at rupture of at least 5 percent and as great as 20 per cent.

The high temperature properties of these steels adapt them to the making of parts that are subjected to high stress at such high temperatures as 1100° F., and obviously they represent a major saving of critical alloying elements in comparison with the presently used alloy steels containing several times as much as alloy content as is present in these steels. The properties of these steels adapt them excellently for other purposes also, such as for aircraft brake discs.

According to the provisions of the patent statutes, I have explained the principle and mode of practicing my invention and have described what I now consider to represent its best embodiment. However, I desire to have it understood that, within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

I claim:

1. Steel adapted for operation at elevated temperatures up to at least 1100° F. which as normalized from about 1800° F. and tempered at 1200° F. to 311 to 321 Brinell has room temperature tensile strength of about 150,000 pounds per square inch, and has a rupture strength in 1000 hours at 1100° F. of at least about 40,000 pounds per square inch and elongation at rupture of about 21 per cent, and having substantially the following composition: carbon 0.15 to 0.5 per cent, boron 0.0005 to 0.004 per cent, chromium 0.75 to 2.5 per cent, manganese 0.2 to 2 per cent, molybdenum 0.25 to 1 per cent, silicon 0.1 to 1.5 per cent, vanadium 0.2 to 1 per cent, and titanium from 1 to 6 times the amount of carbon, and the remainder iron together with impurities and elements in a total amount that does not impair the stated properties.

2. Steel adapted for operation at elevated temperatures up to at least 1100° F. which as normalized from about 1800° F. and tempered at 1200° F. to 311 to 321 Brinell has room temperature tensile strength of about 150,000 pounds per square inch, and has a rupture strength in 1000 hours at 1100° F. of at least about 40,000 pounds per square inch and elongation at rupture of about 21 per cent, and having substantially the following composition: carbon 0.2 to 0.35 per cent, boron 0.001 to 0.003 per cent, chromium 1.0 to 2.0 per cent, manganese 0.5 to 1 per cent, molybdenum 0.4 to 0.6 per cent, silicon 0.5 to 1.0 per cent, vanadium 0.7 to 0.9 per cent, and titanium from 1 to 4 times the amount of carbon, and the remainder iron together with impurities and elements in a total amount that does not impair the stated properties.

3. A hot worked and heat treated steel article for operation at elevated temperatures up to at least 1100° F., the article having been normalized from about 1800° F. and tempered at about 1200° F. to 311 to 321 Brinell and having room temperature tensile strength of about 150,000 pounds per square inch, a rupture strength in 1000 hours at 1100° F. of at least about 40,000 pounds per square inch and elongation at rupture of about 21 per cent, and having substantially the following composition: carbon 0.15 to 0.5 per cent, boron 0.0005 to 0.004 per cent, chromium 0.75 to 2.5 per cent, manganese 0.2 to 2 per cent, molybdenum 0.25 to 1 per cent, silicon 0.1 to 1.5 per cent, vanadium 0.2 to 1 per cent, and titanium from 1 to 6 times the amount of carbon, and the remainder iron together with impurities and elements in a total amount that does not impair the stated properties.

4. A hot worked and heat treated steel article for operation at elevated temperatures up to at least 1100° F. the article having been normalized from about 1800° F. and tempered at about 1200° F. to 311 to 321 Brinell, and having room temperature tensile strength of about 150,000 pounds per square inch and a rupture strength in 1000 hours at 1100° F. of at least about 40,000 pounds per square inch and elongation at rupture in excess of about 9 per cent, and having substantially the following composition: carbon 0.2 to 0.35 per cent, boron 0.001 to 0.003 per cent, chromium 1.0 to 2.0 per cent, manganese 0.5 to 1 per cent, molybdenum 0.4 to 0.6 per cent, silicon 0.5 to 1.0 per cent, vanadium 0.7 to 0.9 per cent, and titanium from 1 to 4 times the amount of carbon, and the remainder iron together with impurities and elements in a total amount that does not impair the stated properties.

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