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[54] **HOT HARD STAINLESS STEEL**

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 233,804, March 10, 1972, abandoned.

[52] **U.S. Cl.** ..... **148/37,** 75/126 B, 75/126 E, 75/126 F, 75/130.5, 148/135

[51] **Int. Cl.** **C22c 39/14**

[58] **Field of Search** ..... 148/37, 135; 75/126 B, 75/126 E, 126 F, 126 R, 130.5

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[57] **ABSTRACT**

A hot hard chromium stainless steel having good hot workability containing about 0.9–1.4% carbon, 13–19% chromium, 1.5–2.75% molybdenum, 0.3–2.5% vanadium, 0.10–0.55% columbium and the balance primarily iron.

7 Claims, No Drawings

HOT HARD STAINLESS STEEL

RELATED CASES

This application is a continuation-in-part of my co-pending application Ser. No. 233,804, and now abandoned, filed Mar. 10, 1972.

BACKGROUND OF THE INVENTION

This invention relates to stainless steel and, more particularly, to a stainless steel having good hot workability, which can be heat treated to high hardnesses, and which in its heat treated condition has good wear resistance and a high degree of hot hardness at elevated temperatures.

A.I.S.I. Type 440C stainless steel contains about 0.95–1.20% carbon, a maximum of 1.00% each of manganese and silicon, 16.00–18.00% chromium, a maximum of 0.75% molybdenum and the balance iron except for incidental impurities. Type 440C has long been used in the manufacture of such parts as stainless bearings for use at room temperature (e.g. 70°F). The steel has good forgeability, but because of its relatively low hot hardness cannot be used to make parts which in use must withstand loads at elevated temperatures. Some stainless steels having higher hot hardness than Type 440C which have been developed as modifications of that type are set forth in Table I.

TABLE I

	Alloy A	Alloy B	Alloy C	Alloy D
C	0.95–1.20	1.15	1.20	1.10–1.15
Mn	1.00 Max.	0.50	0.50	0.15 Max.
Si	1.00 Max.	0.30	0.30	0.15 Max.
Cr	13.00–16.00	14.5	14.5	14.0–16.0
Mo	3.75–4.25	4.00	4.00	3.75–4.25
V	0.15 Max.	1.10	2.0	2.5–3.0
W	—	—	—	2.0–2.5
Co	—	—	—	5–5.5

In each alloy, the balance is iron except for incidental impurities. Alloy A has a much higher hot hardness than Type 440 C and good corrosion resistance, but it is very difficult to hot work. Alloys B and C have been reported as having even higher hot hardness than Alloy A, and Alloy D was developed for making bearings intended for use at elevated temperatures. Unfortunately, the hot workability of Alloys A–D decreases with increasing alloy content so that Alloy D with the maximum alloy content has the poorest hot workability and the lowest ingot yield. The poorer hot workability and reduced yields attained in the manufacture of wrought products from Alloys A–D as compared to Type 440C results in parts fabricated of Alloys A–D being costlier than those made from 440C with the cost increasing disproportionately to the increase in alloying content.

SUMMARY OF THE INVENTION

It is therefore a principal object of this invention to provide a stainless steel having greatly improved wear resistance, hot hardness and temper resistance as compared to Type 440C alloy, but which is characterized by a hot workability equivalent to that of Type 440C and is free of the difficulties associated with other modifications of Type 440C.

A further object of this invention is to provide such a stainless steel having high hot hardness and good temper resistance combined with good hot workability so

that it is eminently well suited for use in making parts intended for use in corrosive environments both at room and elevated temperatures such as bearing parts, cams, shafts, gears, gage blocks, micrometer spindles and others.

Much of the foregoing objects as well as further advantages of this invention are attained by providing a stainless steel which consists essentially of the following broad analysis while all of the objects and advantages are provided by the stainless steel which consists essentially of the following preferred analysis, both in the approximate amounts indicated in weight percent in keeping with good metallurgical practice:

	Broad	Preferred
Carbon	0.9–1.4	0.95–1.15
Silicon	1 Max.	1.0 Max.
Manganese	1 Max.	1.0 Max.
Chromium	13–19	13.5–14.5
Molybdenum	1.5–2.75	1.75–2.5
Vanadium	0.3–2.5	0.75–1.25
Columbium	0.10–0.55	0.20–0.35

The remainder of the alloy is iron except for incidental impurities which may vary from a few hundredths of a percent or less as in the case of sulfur and phosphorus or up to 1 or 2 tenths of a percent as in the case of a deoxidizer such as aluminum or a few hundredths of a percent as in the case of calcium so long as the desired properties of the alloy are not impaired. It is to be noted that while the best all-round properties are provided by the preferred composition, it is not intended to restrict the ranges indicated by presenting them in tabular form for ready reference. It is contemplated that any one or more of the preferred ranges indicated can be used with any one or more of the broad ranges indicated for the remaining elements.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the alloy of this invention, a minimum of about 0.9% carbon is required to ensure the attainment of the minimum desired hardness of no less than about Rc 60. Carbon ranging from about 0.95–1.15% is preferred. As the carbon content approaches 1.4%, increasing difficulty is experienced in forging unless the carbide-forming elements, chromium, molybdenum, vanadium and columbium, are balanced toward the lower ends of their permitted ranges.

A minimum of about 13% chromium is required to provide the desired corrosion resistance particularly to the environment usually to be encountered in jet engines under operating conditions, including water vapor, chloride ions and other corrodents to be found in the atmosphere. Preferably chromium is present in an amount ranging from about 13.5–14.5% because above about 14.5% chromium, increasing difficulty is encountered in forging the alloy unless such elements as molybdenum, vanadium and carbon are reduced toward the lower end of their ranges.

Molybdenum in amounts of about 3% or more contributes to the difficulty hitherto encountered in such well-known modifications of Type 440C as Alloy A. Therefore, molybdenum is limited to a maximum of about 2.75% and preferably to no more than about 2.5%. Below about 1.5%, molybdenum is not present in a sufficient amount to contribute sufficiently to the sec-

ondary hardening reaction by which the alloy attains the desired as-heat-treated hardness.

Vanadium contributes to the forgeability, heat-treated hardness, and hot hardness of this alloy. Below about 0.3% vanadium is not present in a sufficient amount for this purpose. Preferably 0.75–1.25% vanadium is used to provide the best combination of both forgeability and hardness. For best as-heat-treated hardness, the larger amounts of vanadium are used, that is up to about 2.5%. However, substantially better forgeability is obtained with only a maximum of about 2% vanadium and with no significant reduction in hot hardness. With up to 2% vanadium, up to 1.2% carbon is preferably used, and, with vanadium in excess of 2%, carbon in excess of 1.2% is preferably used.

In the absence of vanadium, columbium has either a negligible effect on the heat-treated hardness or, when larger amounts of columbium are used, some slight reduction in the as-heat-treated hardness results. Apparently columbium does not contribute to the secondary hardening effect in this composition. However, a small addition of columbium, about 0.10–0.55%, preferably 0.20–0.35% makes possible the use of a higher austenitizing temperature to provide a better secondary hardness rather than the deleterious effect which would normally be expected from using austenitizing temperatures as high as about 2100°F. Above about 0.55% columbium some deleterious effect on required properties, such as fatigue life, is to be expected without any compensatory improvement in other properties.

This alloy is melted and cast into ingots in the usual way, and, because of its exceptional hot workability, it is readily worked into parts using conventional techniques. The alloy is preferably forged from a furnace temperature of about **2000°** to 2050°F. Annealing is preferably carried out at about 1550° to 1650°F. The preferred annealing treatment consists of thoroughly heating at 1600°F, then cooling at the rate of about 20°/hr. to about 1450°F where the part is held for about 2 to 4 hours, then cooling at the rate of about 20°/hr. to about 1350°F where it is again held for about 2 to 4 hours, then again cooling at the rate of 20°/hr. down to 1100°F or below, and then cooling in air. Austenitizing is carried out at about 2050° to 2150°F, preferably at about 2100°F, followed by oil quenching and refrigerating at −105°F or below. Before this refrigeration, the parts are preferably stress relieved by heating at about 300°–350°F to avoid warping and possible cracking. It is an advantageous characteristic of this allow that no more of a tempering treatment is required to develope its full room temperature and hot hardness than two successive 2 hour heat treatments at the desired temperature with intermediate cooling. Preferably, in addition to cooling to room temperature, the parts, following the first stage of the tempering treatment, are cooled to room temperature and then refrigerated at about −105°F or below to ensure maximum freedom from retained austenite, but this refrigeration is not required to develope full room temperature and hot hardness.

It is to be noted that the alloy of this invention is balanced so that in its heat treated condition it is substantially free of retained austenite, that is, hardened and tempered parts contain no more than about 3%, preferably no more than 1%, retained austenite.

EXAMPLE 1

As an example of the present invention, a 75-pound air induction heat was prepared having the following analysis:

	Weight percent
Carbon	1.07
Manganese	0.39
Silicon	0.25
Chromium	14.22
Molybdenum	2.19
Vanadium	0.99
Columbium	0.27

The balance was iron except for incidental impurities. The ingot was annealed by heating for about 4 hours at about 1560°F (850°C), then cooling at about 20°/hr. to about 1100°F and then cooling in air. Duplicate hot tensile impact specimens were prepared from the top portion of the ingot and tested at 1900°, 2000°, 2050°, 2100°, 2150°, 2200° and 2250°F with average impact strength in foot pounds, percent elongation (% El.) and percent reduction in area (% R.A.) as indicated in Table II.

TABLE II

Test Temp. °F	Impact Strength (Ft. lbs)	% El.	% R.A.
1900	48	12.6	15.9
2000	49	15.3	23.8
2050	55	17.8	22.6
2100	52	20.1	23.0
2150	44	20.6	22.6
2200	48	20.3	24.5
2250	43	17.6	18.2

These results, particularly the ductility as measured by the percent elongation, clearly demonstrate the improved forgeability of this alloy, particularly as compared to the aforementioned Alloys A–D. In fact, the forgeability of this alloy is not significantly different from that of Type 440C.

The remainder of the ingot was forged from 2200°F by pressing to a 2 inch round cornered square bar which was then hot cut into three substantially equal lengths. Two of these lengths were reheated, and one was then forged to a 1¾ inch octagonal bar and the other to a 1⅛ inch square bar. Forging was considered very easy and was carried out without any defects such as split ends or surface tears. The bars were again annealed, and the annealed hardness was found to be Rc 29.5. When the bars were annealed using the preferred annealing cycle with an initial temperature of 1560°F where they were held for 4 hours, the resulting hardness was Rb 100.

Specimens of the alloy which had been annealed using the last mentioned preferred cycle were then austenitized at 2050° and 2100°F, oil quenched, refrigerated at about -105°F and then tempered at 975°F, 1000°F and 1025°F. Each tempering treatment included heating at temperature for 2 hours, air cooling to room temperature, refrigerating at about −105°F until thoroughly cooled to that temperature then holding at the tempering temperature one more for 2 hours, and then air cooling. The results are shown in Table III.

TABLE III

Aust. Temp.	Hardness (Rc) As-quenched	Refrigd. (−105°F)	Tempering Temperature—°F 975°	1000°	1025°
2050°F	59.8	64.0	61.5	60.5	55.5
2100°F	54.0	63.0	62.5	60.0	57.0

Specimens tempered at 975° and 1025°F were examined for retained austenite but none could be detected.

The resistance of this alloy to tempering is even better demonstrated by the following results obtained when specimens of the alloy were austenitized at 2100°F for 10 minutes, oil quenched, refrigerated at −105°F, and then tempered for 1 hour at the temperatures indicated in Table IV. In the regrigerated condition, the specimens had a hardness of Rc 64.0. For comparison, typical specimens of Type 440C alloy which had been austenitized at 1950°F for 15 minutes, oil quenched and refrigerated at −105°F were also tempered for 1 hour at the temperatures indicated in Table IV with the results shown. The refrigerated hardness of Type 440C was Rc 60.5.

TABLE IV

Tempering Temperature (°F)	Hardness (Rc) Ex. 1	Type 440C
300	63.5	60.0
400	61.0	58.5
500	59.5	58.0
600	58.0	57.5
700	58.0	57.5
800	58.0	57.5
900	60.5	57.0
1000	62.0	52.0
1100	53.5	41.5

To demonstrate the hot hardness of the alloy, specimens were machined from the 1⅛ inch square bar and were preheated at 1500°F, austenitized at 2100°F, step quenched in a salt bath to 1000°F, air cooled, refrigerated at −105°F, and then tempered by heating at 975°F for 2 hours, refrigerated and once again heating at 975°F for 2 hours. Hardnesses were measured at room temperature, 500°F, 600°F, 700°F, 800°F, 900°F, 1000°F with the following results.

TABLE V

HARDNESS (Rc)						
Room	500	600	700	800	900	1000
61.5	58.5	57.3	—	55.4	54.8	52.9
61.5	—	57.8	56.7	55.5	54.5	52.5

The hot hardnesses in Table V are exemplary of this alloy which consistently provides a minimum hot hardness of Rc 50 at 1000°F following the two stage tempering with intermediate cooling at least to room temperature.

Because of its unique combination of heat-treated hardness, hot hardness, temper resistance, wear resistance and corrosion resistance, with good forgeability, the alloy of this invention is well suited for use in making parts which are required to withstand loading at temperatures ranging from about 350° to 1000°F.

The terms and expressions which have been employed are used as terms of description and not of limitation, and 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, but it is recognized that various modifications are possible within the scope of the invention claimed.

What is claimed is:

1. A stainless steel having good hot workability, which is hardened by heating at about 2100°F and tempered to a room temperature hardness of at least about Rockwell C60 and a hot hardness greater than about Rc 50 at 1000°F, and which in its heat treated condition is substantially free of retained austenite, which by weight consists essentially of about

Carbon	0.9–1.4%
Manganese	1% Maximum
Silicon	1% Maximum
Chromium	13–19%
Molybdenum	1.5–2.75%
Vanadium	0.3–2.5%
Columbium	0.10–0.55%

the balance being essentially iron and incidental impurities.

2. The stainless steel set forth in claim **1** which contains about 0.95–1.15% carbon.

3. The stainless steel set forth in claim **2** which contains about 13.5–14.5% chromium.

4. The stainless steel set forth in claim **3** which contains about 1.75–2.5% molybdenum.

5. The stainless steel set forth in claim **4** which contains about 0.75–1.25% vanadium.

6. The stainless steel set forth in claim **5** which contains about 0.20–0.35% columbium.

7. The stainless steel set forth in claim **6** which contains less than about 1% retained austenite.

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