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[54] **DEEP AIR-HARDENED ALLOY STEEL ARTICLE**

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[58] **Field of Search**.........75/128, 128 T, 125, 128 R, 75/128 C, 128 V, 128 W; 148/36, 144

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[57] **ABSTRACT**

A deep air-hardened alloy steel article having high strength and good toughness in its heat treated condition containing 0.07–0.8 percent carbon, 0.5–2 percent silicon, 0.5–1.5 percent chromium, 0.25–1.5 percent molybdenum, 2–5 percent nickel, and 0.65–4 percent copper.

6 Claims, No Drawings

DEEP AIR-HARDENED ALLOY STEEL ARTICLE

This invention relates to alloy steel and, more particularly, to an alloy steel which can be air hardened in large sections which has good temper resistance, and which after being heat treated is characterized by high strength and toughness or high hardness and wear resistance depending upon its carbon content.

As is well known, the attainable as-hardened hardness of alloy steels as well as such properties as strength, toughness, and ductility are affected by the carbon content of the steel. The as-hardened hardness, ultimate tensile strength and yield strength are improved by increasing carbon, but ductility and toughness as measured by reduction in area and elongation and by impact testing are adversely affected.

The capability of being air hardened in large sections throughout a thickness or depth of about six inches is highly desirable especially in the case of relatively large precision parts such as gears, bearings and dies as well as others. It minimizes the possibility of warping or cracking of the part which may often occur when parts are quenched in water or oil from the hardening temperature.

It is therefore a principal object of this invention to provide a low-alloy steel which is deep air hardenable in large sections which, after heat treatment, has good temper resistance with high strength and toughness when its carbon content ranges up to about 0.5 percent, and with higher hardness and wear resistance when its carbon content ranges above about 0.5% to a maximum amount limited to a value which does not exceed the eutectoid forming quantity of carbon in the composition determined by its total alloy content.

It is a further object of this invention to provide such a low alloy steel which in its preferred form is not only deep air-hardenable, but which consistently can be readily produced by means of conventional consumable electrode remelting techniques so as to have a high degree of homogeniety and enhanced properties because such a relatively volatile element as manganese is not required and is not relied on in developing the outstanding properties of the alloy.

The foregoing objects as well as additional advantages of this invention are achieved by providing a low alloy steel which in its broad and preferred forms consists essentially in the approximate amounts indicated in weight percent in keeping with good commercial metallurgical practice of:

	Broad	Preferred
Carbon	0.07–0.8%	0.1–0.5%
Manganese	Up to 1%	Up to 0.4%
Silicon	0.5–2%	0.75–1.25%
Chromium	0.5–1.5%	0.75–1.25%
Molybdenum	0.25–1.5%	0.50–1%
Nickel	2–5%	2.5–3.5%
Copper	0.65–4%	1.5–2.5%
Vanadium	Up to 0.5%	0.05–0.15%

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 one-quarter or one-half percent as in the case of those elements such as aluminum, columbium, titanium, zirconium and calcium which are used as deoxidizers and/or grain refiners.

A minimum of 0.07 percent carbon is required in this alloy to provide deep air-hardenability. As the carbon content is increased up to a maximum for any given total alloy content which does not exceed the eutectoid forming quantity of carbon in the composition for that alloy content, the attainable as-hardened hardness and wear resistance are increased while impact strength and toughness are decreased. As the alloy content of the steel varies from the minimum to the maximum of the stated broad range, the value of the eutectoid forming amount of carbon varies from the maximum of about 0.8 percent, but the exact value for any given analysis can be readily determined. Because of the effect of carbon on the properties of the alloy, it has a broad spectrum of uses in accordance with its carbon content. For example, with about 0.07 percent to about 0.2 percent carbon, this composition is well suited for use as a carburizing or casehardening grade in making such products as gears and bearings. With a larger carbon content of up to about 0.5 percent, the steel of this invention is used with outstanding results in making structural members such as pressure vessels and aircraft landing gear members. And with above about 0.5 percent carbon, there is provided a relatively tough, deep air-hardening tool and die steel for use in making such products as heavy duty punches, mandrels, and others subject to high shock in use.

In this alloy, chromium works to provide resistance to oxidizing media and to minimize scale formation when the alloy is hot worked. To this end, a minimum of 0.5 percent chromium is required while above about 1.5 percent, chromium has a detrimental effect on the impact properties of the alloy at low temperature. For best results, chromium from about 0.75 percent to 1.25 percent is preferred. As little as 0.25 percent molybdenum has a beneficial effect on the impact strength and toughness of this alloy and preferably about 0.5 percent to 1.25 percent is used. Above about 1.5 percent molybdenum adversely affects those impact properties as in the case of chromium. When either of those elements is present in an amount above about 1.5 percent, the hardening temperature of the composition is adversely affected and is raised.

Silicon, nickel, and copper when present in the amounts stated work to provide the outstanding combination of hardenability, toughness and temper resistance characteristic of this composition. To this end, a minimum of about 0.5 percent silicon, 2 percent nickel and 0.65 percent copper is required. Silicon functions as a strengthener, increases the hardenability of the composition and retards tempering so as to permit the use of a relatively high tempering temperature. This permits parts formed of the present alloy to be subjected in use to relatively high temperatures. However, when silicon is present in amounts above about 2 percent, it adversely affects the hardness, strength and ductility of the alloy and tends to raise objectionably the austenitizing temperature of the alloy. For best results, about 0.75 percent to 1.25 percent silicon is used.

The effect of nickel is somewhat similar to that of silicon except that it is an austenite former and not a ferrite former like silicon. Preferably about 2.5 percent to 3.5 percent nickel is present in this composition although as little as about 2 percent can be used to good advantage and as much as 5 percent nickel can be present. However, above about 5 percent nickel results in impairment of the machinability of this alloy. In addition, such large amounts of nickel lead to difficulties in annealing the alloy and to the presence of retained austenite, particularly in the case of carburized products.

Copper, like nickel, is an austenite former, but much less powerful in that regard. A minimum of 0.65 percent copper is required and preferably at least 1.5 percent is included to provide the desired effect upon the hardenability, impact properties and hardening temperature of the alloy. When copper is present in amounts above about 4 percent, precipitation of some of the copper may occur when the alloy is maintained at temperatures of about 750° F. or above for an appreciable time. However, in the range stated herein, the copper appears to be readily retained in solid solution.

Vanadium is not an essential element in this alloy, but up to about 0.5 percent, preferably about 0.05 to 0.15 percent is included as a grain refiner. Manganese is not a desirable addition in this alloy, although up to about 1 percent can be present when it is used as a deoxidizer or for other purposes when, to satisfy less demanding requirements, the alloy is not made by means of a consumable electrode remelting technique. It is an important advantage of this alloy that it can be prepared to a high degree of homogeneity and purity by means of consumable electrode remelting techniques. Consumable electrode remelting of the alloy is preferably carried out under reduced pressure, and with the manganese content limited to no more than about 0.4 percent, the desirable properties available over the broad range as well as the outstanding properties provided when the remaining elements are maintained within their preferred ranges are readily and consistently attainable.

This alloy is readily prepared by means of conventional, well-known techniques. With a carbon content up to about 0.5 percent, the alloy is advantageously normalized or homogenized by heating from about 1,650° to 1,850° F. for about 2 to 12 hours. When the parts are to be carburized, the separate normalizing treatment can be omitted. When the carbon content is above about 0.5 percent, normalizing is omitted if the resulting hardness will cause difficulty in working. The alloy has a broad annealing range, about 1,200° to 1,500° F., but annealing is preferably carried out from about 1,200° to 1,350° F. It advantageously is hardened from a low hardening temperature of no higher than about 1,575° F. and with increasing carbon content, a hardening temperature as low as 1,500° F. can be used. This alloy is not only characterized by good toughness and high strength, but also, when prepared by means of consumable electrode remelting under low pressure, is characterized by an outstanding degree of freedom from notch sensitivity and brittleness. As is to be expected, the alloy loses its toughness as it is exposed to lower and lower temperatures. However, it experiences no sharp transition as it is cooled down to extremely low temperatures as determined from Charpy V-notch impact tests carried out at room temperature, 32° F., −100° F. and −320° F.

EXAMPLE 1

As an example of the present invention, an 8-pound vacuum induction heat having the following analysis in weight percent was melted and cast as an ingot:

Carbon	0.087
Manganese	0.21
Silicon	0.98
Phosphorus	0.005
Sulfur	0.003
Chromium	1.13
Nickel	3.12
Molybdenum	0.72
Copper	1.99
Vanadium	0.12

and the balance iron except for incidental impurities. The ingot was forged from a temperature of about 2,050° F. to a 1-5/16 inch square/16-inch long billet. The billet was annealed at 1,250° F. for 6 hours, cooled in the furnace to 1,000° F. and then air cooled. This was followed by heating at 1,700° F. for 7 hours, furnace-cooling to 1,500° F. and then cooling in air to room temperature as a check on the reaction of the alloy to a typical heat treatment used when carburizing. When air cooled from 1,500° F. and also from 1,550° F. followed by tempering for 1 hour at 300° F test pieces of the billet had a hardness of about R_c36. Other test specimens having a diameter of 25/32 inch and one-eighth inch thick were air cooled from 1,525° F. in the center of cylindrical steel blocks, one 4 inches long by 4 inches in diameter, and the other 6 inches long by 6 inches in diameter. Both specimens were then tested and demonstrated a hardness of about R_c34, demonstrating extremely deep air-hardenability.

EXAMPLE 2

As a further example of this invention, a 200 lb. vacuum induction heat was melted and cast as an ingot which was then remelted under vacuum as a consumable electrode into an 8-inch round ingot having the following analysis in weight percent:

Carbon	0.119
Manganese	0.19
Silicon	0.99
Phosphorus	0.003
Sulfur	0.002
Chromium	1.07
Nickel	3.23
Molybdenum	0.71
Copper	2.04
Vanadium	0.11

and the balance iron except for incidental impurities. The ingot was forged from a temperature of about 2,000° F. to a 4¼ inch square, annealed at 1,250° F., air cooled and then machined to a 3¾ inch round billet. Discs having thicknesses of one-fourth, one-half, and 1 inch were cut from the billet, heated at 1,700° F. for 7 hours, furnace cooled to 1,500° F. and then air cooled. The discs were then heated to 1,525° F., air cooled and tempered 1 hour at 300° F. The discs were then cut in half and were found to have substantially uniform hardnesses throughout their thickness of about R_c36. Other test specimens having a diameter of 25/32 inch and one-eighth inch thick were placed in the center of cylindrical blocks, one 4 inches in diameter and 4 inches long and the other 6 inches in diameter and 6 inches long. Each was heated to 1,525° F., were then air cooled and found to have hardnesses of R_c32. Standard room temperature tensile specimens and Charpy V-notch specimens were prepared from the billet which were heat treated as was just described in connection with the three discs. The results of three tests were averaged to give the following results. The 0.2 percent yield strength was found to be 113,000 psi, the ultimate tensile strength was 169,000 psi with a 19.3 percent elongation and 70.6 percent reduction in area. The average of the three Charpy V-notch tests was found to be 176 foot-pounds.

EXAMPLES 3–5

As examples of this invention, 17-pound vacuum induction heats were melted and cast as 2¾ inch square ingots having the following analyses in weight percent:

	Ex. 3	Ex. 4	Ex. 5
Carbon	0.115	0.25	0.40
Manganese	0.20	0.21	0.21
Silicon	0.97	0.97	0.98
Chromium	1.07	1.07	1.07
Nickel	3.07	3.07	3.04
Molybdenum	0.71	0.71	0.71
Copper	1.97	1.97	2.00
Vanadium	0.12	0.12	0.12

and the balance iron except for incidental impurities including less than 0.005 percent each of phosphorus and sulfur. The ingots were forged from a furnace temperature of 2,000° F. to 5-inch wide billets and were then readily forged to thicknesses of one-half inch and three-fourths inch. They were homogenized at 1,700° F. for 7 hours and then air cooled. Annealing was carried out at 1,250° F. for 6 hours, and again cooling was in air. In this condition, the hardness of the billet material was tested and found to be about Rockwell C 27 for Example 3, Rockwell C 31.5 for Example 4 and Rockwell C 32.5 for Example 5. The various test specimens were then machined or otherwise formed as required. Hardening was carried out by austenitizing at 1,550° F. for about one-half hour and quenching by air cooling. In the as-hardened and quenched condition and after tempering for one hour at 300°, 450°, 800°, 900°, 1,000°, 1,100°, and 1,200° F., the hardness of specimens of each of Examples 3–5 were measured and found to be as indicated in Table I.

TABLE I

Hardness - Rockwell C

Ex.	As Quenched	300°	450°	800°	900°	1000°	1100°	1200°
3	38.5	38.5	39	40	41	40	38.5	32.5
4	50	47	46.5	45.5	45	44.5	42.5	37
5	59	54.5	52	49	49	47.5	45	39

As is apparent from Table I, the hardness increases with increasing carbon content. At the lower carbon levels, hardness remains substantially constant with increasing tempering temperature even as high as temperatures ranging from about 900° to 1,100° F. Even after tempering at 1,200° F., this composition retains an exceptional degree of its hardness. Thus, the composition of this invention is especially well suited for the fabrication of parts having high strength and good toughness which are subjected in use to temperatures well above room temperature. Specimens tempered for one hour at 1,200° F. were subjected to optical microscopic examination, but no evidence of any precipitated copper could be found.

Specimens of each of Examples 3–5 having a diameter of 25/32 inch and one-eighth inch thick were placed at the center of cylinders 4 inches in diameter and 4 inches long and in cylinders 6 inches in diameter and 6 inches long. The assemblies were heated to 1,550° F. throughout and then quenched by cooling in air. The hardnesses were measured and found to be Rockwell C 33.5 for Example 3 after treatment in both cylinders. This compares with the hardness of Rockwell C 38.5 obtained from the small specimen cooled in air from 1,550° F. In the case of Example 4, after treatment in the 4-inch cylinder, the hardness was Rockwell C 42.5, and after treatment in the 6-inch cylinder, the hardness was Rockwell C 39.5. In this instance, the as-quenched hardness of the small specimen was Rockwell C 50. The specimens of Example 5 after treatment in the 4-inch cylinder had a hardness of Rockwell C 52.5 and after treatment in the 6-inch cylinder had a hardness of Rockwell C 49.5 as compared to an as-quenched hardness of the small specimen of Rockwell C 59.

Standard room temperature tensile and notch tensile test specimens were prepared from each of Examples 3–5, heated to 1,525° F., air cooled and then heated for one hour at 300° F. In each case, two specimens of each example were tested, and the average of the two tests is given in Table II where L. and T. indicate specimens, the longitudinal axis of each of which extends parallel and transverse, respectively, to the longitudinal axis of the parent billet.

TABLE II

	Ex. 3	Ex. 4	Ex. 5
Hardness Rockwell C	37.0	47.0	54.5
.2% Yield Strength psi L.	115,500	161,900	207,600
.2% Yield Strength psi T.	120,300	164,000	202,900
Ultimate Tensile Strength L.	169,500	240,800	309,500
Ultimate Tensile Strength T.	172,100	237,500	303,300
Notch Tensile Strength L.	260,700	297,400	238,700
Notch Tensile Strength T.	259,400	302,200	222,300
% Elongation L.	17.9	12.3	8.7
% Elongation T.	18.8	12.0	8.0
% Reduction Area L.	66.0	43.3	27.8
% Reduction Area T.	65.1	43.2	22.4

Charpy V-notch impact values were determined at room temperature, at 32° F., at −100° F., and at −320° F. from specimens of each of Examples 3–5, and the results are set out in Table III. The room temperature results are the average of three tests while those at 32° F. and below are the average of two tests. As in the case of the tensile specimens, the Charpy V-notch specimens were heated at 1525° F., air cooled and then heated for 1 hour at 300° F.

TABLE III

Test Temp.	Ex. 3	Ex. 4	Ex. 5
Room Temp.	100 ft. lbs.	23 ft. lbs.	11 ft. lbs.
+32° F.	105 ft. lbs.	27 ft. lbs.	9 ft. lbs.
−100° F.	66 ft. lbs.	20 ft. lbs.	9 ft. lbs.

−320° F.	13 ft. lbs.	15 ft. lbs.	4 ft. lbs.

These tests demonstrate that the present alloy does not have a distinct ductile-to-brittle transition temperature, but that it retains a definite proportion of its ductility and toughness at extremely low temperatures.

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 deep air hardened alloy steel article having high strength, good toughness and temper resistance consisting essentially by weight of about

Carbon	0.07–0.8%
Manganese	up to 1%
Silicon	0.5–2%
Chromium	0.5–1.5%
Molybdenum	0.25–1.5%
Nickel	2–5%
Copper	0.65–4%
Vanadium	up to 0.5%

and the balance essentially iron and incidental impurities, said article being hardened substantially throughout by cooling in air from an austenitizing temperature no higher than about 1,575°F. and being substantially free of a transition temperature effect when cooled as low as about −320°F as measured by impact tests.

2. The article set forth in claim **1** which contains less than about 0.4 percent manganese.

3. The article of claim **2** which contains about 0.1 to 0.5 percent carbon.

4. The article of claim **3** which contains about

Silicon	0.75–1.25%
Chromium	0.75–1.25%
Molybdenum	0.50–1%
Nickel	2.5–3.5%
Copper	1.5–2.5%

5. The article of claim **4** which contains about 0.05 to 0.15 percent vanadium.

6. The article of claim **1** which contains about 0.07 percent to about 0.2 percent carbon and which is casehardened.

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