

[54] **FERROUS ALLOY AND ABRASIVE
RESISTANT ARTICLES MADE
THEREFROM**

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75/128 V, 75/128 W

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[58] Field of Search 75/126 E, 128 V, 126 A,
75/126 C, 126 H, 128 D, 128 B, 128 W;
148/38, 37

[56] **References Cited**

UNITED STATES PATENTS

1,982,421	11/1934	Emmons	148/31
2,575,219	11/1951	Giles	75/126 E

2,644,747	7/1953	Eder	75/128 V
2,662,010	12/1953	Ahles	75/126 E
2,949,356	8/1960	Hughes	75/128 V
3,692,515	9/1972	Fletcher	75/126 E

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[57] **ABSTRACT**

A very high carbon, high vanadium alloy steel is prepared in which there is a specific relationship between carbon and vanadium, said steel containing chromium and molybdenum levels, together with balanced carbon and vanadium contents, so as to render said steel forgeable. Forged articles made from said steel after heat treatment to a hardness of 59 to 67 Rockwell C are highly resistant to abrasion and are suitable for a wide variety of uses where a wear resistant steel is required and conventional manufacturing techniques are employed.

12 Claims, 3 Drawing Figures

FIG. 1

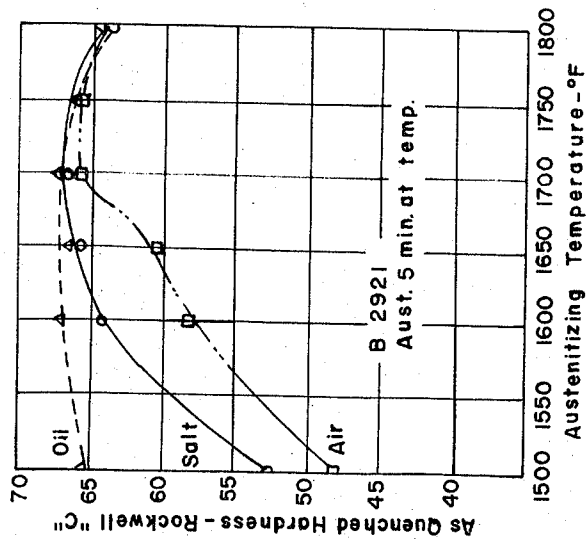


FIG. 2

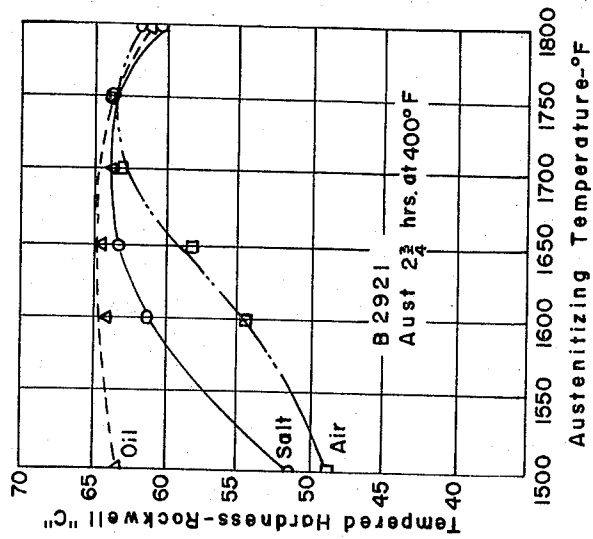
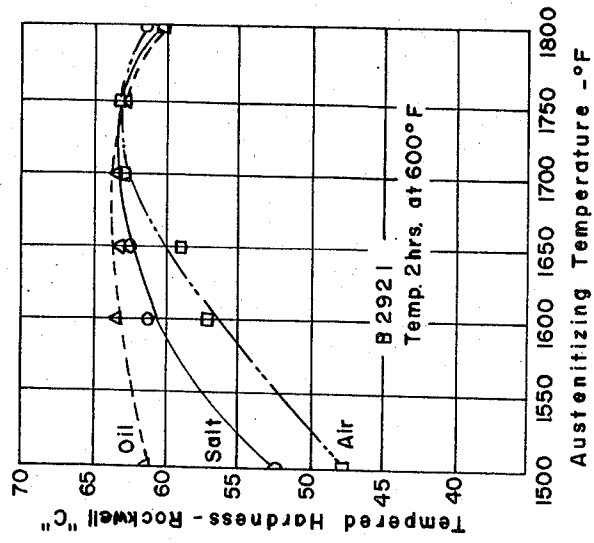


FIG. 3



FERROUS ALLOY AND ABRASIVE RESISTANT ARTICLES MADE THEREFROM

BACKGROUND

For some time it has been recognized that there is a need for more wear resistant steels which can be forged into articles of manufacture. The general term "forging" is used to describe hard or cold working processes performed by drop hammers, presses or forging machines in which the primary force is compressive. It is known in the art that high carbon, high vanadium ferrous alloy steels are wear resistant. Thus, it has heretofore been proposed to make a steel containing 3% carbon and 12% vanadium but an air hardening steel of this analysis is extremely difficult to forge and to cut in the annealed condition. Similarly, forgeable steels can be made with 9% vanadium and 3% carbon but forgeable analyses do not harden all the way through. Steels of this general type are disclosed in U.S. Pat. Nos. 2,174,281 to 2,174,286.

Typical wear resistant alloys which are commercially available are AISI A-7 which has a nominal weight percent analysis of 2.30% carbon, 0.40% silicon, 0.70% manganese, 1.10% tungsten, 1.10% molybdenum, 5.25% chromium and 4.75% vanadium, and AISI D-7 having the same analysis except that the weight percent of manganese content is 0.40, the weight percent of chromium is 12.50, the weight percent of vanadium is 4.00 and the alloy contains no tungsten. Alloys of these general types are described in U.S. Pat. Nos. 2,575,219 and 2,575,218, respectively. Higher carbon-vanadium alloys are not commercially produced because of manufacturing problems.

OBJECTS

One of the objects of this invention is to provide new and improved ferrous alloy steels.

A further object is to provide new and improved ferrous alloy steels which are forgeable.

Another object of the invention is to provide abrasive resistant articles made by forging the aforesaid new and improved ferrous alloy steels.

A further object of the invention is to provide a new and useful ferrous alloy steel which can be forged into various types of articles using standard manufacturing techniques which articles can be heat treated by standard methods and can be hardened all the way through.

Other objects and advantages of the invention will appear from the following description in conjunction with the accompanying drawings.

THE DRAWINGS

In the drawings:

FIG. 1 illustrates graphically the heat treating data for a composition of the invention showing the "as-quenched" hardness as a function of austenitizing temperature for three quenching media;

FIG. 2 illustrates graphically tempering hardness of an article made from a ferrous alloy composition of the invention as a function of austenitizing temperature where the tempering is carried out at 400°F. for 2½ hours; and

FIG. 3 illustrates graphically the tempered hardness of an article made from a ferrous alloy composition of the invention as a function of austenitizing temperature where the tempering is carried out at 600°F. for 2 hours.

BRIEF SUMMARY OF THE INVENTION

In accordance with the invention a ferrous alloy steel is provided having the following chemical analysis:

Ingredients	Percent by Weight
Carbon	2.2-3.5
Chromium	2.5-5.0
Vanadium	6.0-10.0
Molybdenum	1.5-3.0
Silicon	0 -1.0
Sulfur	0 -0.03
Tungsten	0 -1.0
Nickel	0 -3.0
Phosphorus	0 -0.03
Manganese	0 -1.0
Cobalt	0 -5.0

the remainder consisting essentially of iron, the relationship between carbon and vanadium being determined by the equation:

$$C = 1.25 + 0.236[V_B - [0.7 + 0.18(V_B - 0.7)]]$$

where C is carbon, V_B is the level of vanadium within the range of 6.0 to 10.0% and $[0.7 + 0.18(V_B - 0.7)]$ is the amount of vanadium dissolved in the steel matrix.

Despite the high carbon and high vanadium contents, a steel of the foregoing commercial analysis is forgeable provided suitable chromium and molybdenum levels are used. The weight ratio of chromium to molybdenum is preferably within the range of 1.35:1 to 1.85:1, preferably 1.35:1 to 1.45:1. These steels are forgeable at temperatures within the range of 2,050°F. to 2,200°F. Forged articles produced from these steels can be heat treated to a Rockwell C hardness within the range of 59 to 63 by conventional methods and within a range of 65 to 67 by deep freezing at -100°F. for 1 hour. Their wear resistance as shown by a standard grindability test is approximately three times greater than a commercial wear resistant steel AISI A-7.

DETAILED DESCRIPTION OF THE INVENTION

Within the range of chemical composition previously given, especially good results are obtained by preparing ferrous alloy steels containing 2.9% to 3.1% by weight carbon, 2.5% to 3.0% by weight chromium, 8.75% to 9.25% by weight vanadium, 1.8% to 2.2% by weight molybdenum, 0.75% to 1.0% by weight silicon, a maximum of 1.0% by weight tungsten, a maximum of 1.0% by weight nickel, 0.4 to 0.6% by weight manganese, a maximum of 1.0% by weight cobalt, a maximum of 0.03% sulfur and a maximum of 0.03% phosphorus.

In evaluating the compositions of the invention different alloys having chemical analyses within the aforementioned limits were prepared and pieces 21 inches long and 7 inches in square cross section were forged on a 1,000 ton press at a temperature within the range of 2,050° to 2,150°F. These pieces were then subjected to heat treatment in order to produce a Rockwell C hardness within the range of 59 to 63. They were also subjected to a deep freeze treatment at -100°F. for 1 hour to raise the Rockwell C hardness to within the range of 65 to 67.

In a typical heat treatment, the ferrous alloy article is austenitized for 30 minutes at 1,750°F., quenched in air or in a straightening press, tempered for 2 hours at 350°F. with air cooling and tempered for 2 hours at

300°F. with air cooling. This will usually produce a hardness of 61/62 Rockwell C.

Additions of silicon, manganese and tungsten may be made to the ferrous alloy composition in amounts up to 1% to suit accepted melting practices without detrimental effect.

dard grindability test in which grindability is determined as a ratio of volume of metal removed from the specimen to volume removed from the grinding wheel. Comparisons were also made with other wear resistant steels and the results are shown in the following table (Table I):

TABLE I

Grade	Austenitizing Temperature °F.	Tempering Temperature °F.	Grindability Indices			Hardness Rockwell "C"
			1	2	Avg.	
B-2921	1500	400	.28	.24	.26	60.8
	1750	400	.28	.30	.29	61.1
	1750	600	.30	.30	.30	60.1
AISI A-7	1775	275	.91	.85	.88	65.2
AISI T-15	2250	1000	.52	.49	.51	67.3
AISI M-4	2225	1000	.56	.55	.56	65.5

Additions of cobalt up to 5% and nickel up to 3% may be made without detriment to performance but are not recommended since these elements raise cost without substantially improving performance.

While the actual equation showing the relationship between carbon and vanadium is the one previously stated, a simplified equation to obtain the best combination of wear resistance and forgeability is: C is approximately 1.1 + 0.2% V where C is carbon and V is vanadium. Materially higher carbon contents reduce forgeability and response to heat treatment. Materially lower carbon contents reduce forgeability and wear resistance.

The invention will be further illustrated but is not limited by the following examples in which the quantities are by weight unless otherwise stated.

EXAMPLE I

Two short 7 inch ingots (300 pounds) were cast from air induction furnaces. The chemical compositions were as follows:

Heat B2920	Element	Heat B2921
2.61	Carbon	2.93
.42	Silicon	.76
.30	Manganese	.23
.013	Sulfur	.018
.009	Phosphorus	.011
1.05	Chromium	2.74
8.55	Vanadium	8.76
1.03	Molybdenum	1.96

An attempt was made to forge the ingots on a 1,000 ton press at temperatures within the range of 2,050°F. to 2,150°F. Heat B2920 did not forge. Heat B2921 forged surprisingly well.

Forged specimens from heat B2921 were then heat treated as shown in FIGS. 1 to 3. FIG. 1 represents the "as quenched" hardness as a function of austenitizing temperature for three quenching media. The specimens were hardened to a minimum hardness of 65 Rockwell C in oil, salt and air by quenching from 1,500°F., 1,625°F. and 1,675°F., respectively. Tempering data as presented in FIGS. 2 and 3 show the tempered hardness as a function of austenitizing temperature. The general curve shape is the same for tempered and "as quenched" data. Maximum hardness is about 65 Rockwell C for a 400°F. temper, 63 Rockwell C for a 600°F. temper, after austenitizing at 1,750°F.

The various specimens were then subjected to a stan-

In the foregoing table B-2921 represents a composition of the invention and the last three compositions are commercially available steels. The chemical composition of AISI A-7 has previously been given herein. AISI T-15 is a high speed tungsten-cobalt type steel containing the following weight percentages of chemical elements:

1.55%	carbon
0.30%	manganese
0.30%	silicon
4.50%	chromium
5.00%	vanadium
13.00%	tungsten
0.50%	molybdenum
5.00%	cobalt

AISI M-4 is a tungsten-molybdenum type high speed steel containing the following weight percentages of chemical elements:

1.30%	carbon
0.30%	manganese
0.30%	silicon
4.50%	chromium
4.00%	vanadium
6.00%	tungsten
4.50	molybdenum

The chemical analysis of AISI A-7 is described in the literature in Tool Steels, 3rd Edition, by Roberts, Hamaker and Johnson, published by American Society for Metals, pages 526-527. AISI T-15 and AISI M-4 are described in the same publication on page 593.

It will be seen from the foregoing evaluation in Table I that the grindability index of heat B-2921 of 0.26-0.30 is extremely low and the wear resistance is approximately three times the wear resistance of AISI A-7 and approximately twice the wear resistance of AISI M-4 and AISI T-15.

EXAMPLE II

Heat A-9641 was prepared with the following chemical analysis in weight percentages:

2.90%	carbon
0.97%	silicon
0.37%	manganese
0.03%	sulfur
0.007%	phosphorus
2.96%	chromium
2.03%	molybdenum
8.60%	vanadium

This composition forged well and the laboratory test for wear resistance showed a grindability index of 0.29. A brick mold liner prepared from this composition was used effectively in the manufacture of 7,100 bricks whereas a similar mold liner made from AISI A-7 was effective for the manufacture of only 3,000 bricks. In additional tests the ferrous alloy from heat A-9641 has out-performed AISI A-7 by a margin of 3:1.

The invention makes it possible to prepare high carbon, high vanadium ferrous alloys which are forgeable. Articles made from these alloys have a wear resistance approximately three times as great as commercially acceptable materials such as AISI A-7. Generally accepted heat treatment methods can be used to obtain desired properties and generally accepted manufacturing techniques can be employed to make various types of articles.

The ferrous alloys of the invention are especially useful for the manufacture of liners for brick molds, liners for shot blasting equipment, liners for sand slingers, extrusion dies for ceramics, blanking rings and punches for saws, deep drawing dies, drawing dies for wire and special shapes, crane roller bushings, meat slicer blades, wear plates, rolls, forming dies, gauges, slitters and cutters, and wear edges.

Inasmuch as the grindability index of articles made from ferrous alloy steels in the manner previously described usually does not exceed three tenths, it will be recognized that the invention is applicable to many high wear applications in the refractories industry and in other industries.

The invention is hereby claimed as follows:

1. A ferrous alloy steel having the following chemical analysis:

Ingredients	Percent by Weight
Carbon	2.2-3.5
Chromium	2.5-5.0
Vanadium	6.0-10.0
Molybdenum	1.5-3.0
Silicon	0-1.0
Sulfur	0-0.03
Tungsten	0-1.0
Nickel	0-3.0
Phosphorus	0-0.03
Manganese	0-1.0
Cobalt	0-5.0

the remainder consisting essentially of iron, the relationship between carbon and vanadium being determined by the equation:

$$C = 1.25 + 0.236 [V_B - (0.7 + 0.18(V_B - 0.7))]$$

where C is carbon, V_B is the level of vanadium within the range of 6.0 to 10.0% and $[0.7 + 0.18(V_B - 0.7)]$ is the amount of vanadium dissolved in the steel matrix, said composition capable of being forged, austenitized, quenched and tempered to produce a substantially tempered martensitic structure which shows a hardness of about 59-67 Rockwell "C" and a grindability index not exceeding approximately 0.3.

2. A ferrous alloy steel as claimed in claim 1 in which the ratio of chromium to molybdenum is within the range of 1.35 to 1.85.

3. A ferrous alloy steel as claimed in claim 1 having the following chemical analysis:

Ingredients	Percent by Weight
Carbon	2.9-3.1
Chromium	2.5-3.0
Vanadium	8.75-9.25
Molybdenum	1.8-2.2
Silicon	0.75-1.0
Sulfur	0-0.03
Tungsten	0-1.0
Nickel	0-1.0
Phosphorus	0-0.03
Manganese	0.4-0.6
Cobalt	0-1.0.

4. A ferrous alloy steel as claimed in claim 3 in which the ratio of chromium to molybdenum is within the range of 1.35 to 1.45.

5. A ferrous alloy steel as claimed in claim 1 having the following approximate chemical analysis in weight percentage:

carbon	2.93%
silicon	0.76%
manganese	0.23%
sulfur	0.018%
phosphorus	0.011%
chromium	2.74%
vanadium	8.76%
molybdenum	1.96%

6. A ferrous alloy steel as claimed in claim 1 having the following approximate chemical analysis in weight percentage.

carbon	2.90%
silicon	0.97%
manganese	0.37%
sulfur	0.03%
phosphorus	0.007%
chromium	2.96%
molybdenum	2.03%
vanadium	8.60%

7. An abrasion resistant article formed by forging, austenitizing, quenching and tempering a ferrous alloy steel having a composition as claimed in claim 1, said article having a substantially martensitic structure, a Rockwell "C" hardness within the range of 59 to 67 and a grindability index not exceeding approximately 0.3.

8. An abrasion resistant article formed by forging, austenitizing, quenching and tempering a ferrous alloy steel having a composition as claimed in claim 2, said article having a substantially martensitic structure, a Rockwell C hardness within the range of 59 to 67 and a grindability index not exceeding approximately 0.3.

9. An abrasion resistant article formed by forging, austenitizing, quenching and tempering a ferrous alloy steel having a composition as claimed in claim 3, said article having a substantially martensitic structure, a Rockwell C hardness within the range of 59 to 67 and a grindability index not exceeding approximately 0.3.

10. An abrasion resistant article formed by forging, austenitizing, quenching and tempering a ferrous alloy steel having a composition as claimed in claim 4, said article having a substantially martensitic structure, a Rockwell C hardness within the range of 59 to 67 and a grindability index not exceeding approximately 0.3.

11. An abrasion resistant article formed by forging, austenitizing, quenching and tempering a ferrous alloy steel having a composition as claimed in claim 5, said

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article having a substantially martensitic structure, a Rockwell C hardness within the range of 59 to 67 and a grindability index not exceeding approximately 0.3.

12. An abrasion resistant article formed by forging, austenitizing, quenching and tempering a ferrous alloy 5

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steel haaving a composition as claimed in claim 6, said article having a substantially martensitic structure, a Rockwell C hardness within the range of 59 to 67 and a grindability index not exceeding approximately 0.3.

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