Patented Aug. 14, 1945

2,382,467

UNITED STATES PATENT OFFICE

2,382,467

FINE-GRAINED STEEL HARDENED ARTICLE

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No Drawing. Original application March 11, 1941, Serial No. 382,737. Divided and this application January 12, 1945, Serial No. 572,583

2 Claims. (Cl. 75—123)

This invention relates to steels, and more specifically to steels the hardness of which may be increased by rapid cooling from temperatures within or above the critical range. For the sake of simplicity of presentation, the application of the invention will be described herein principally as it may be applied to carbon steels containing 0.1% to 1% carbon, up to about 2% manganese, and between 0.25% and 2% silicon; but as the description proceeds it will be evident that the invention may be applied to a wide variety of hardenable steels. This application is a division of my copending application Ser. No. 382,737, filed March 11, 1941.

When hardening steels by rapid cooling from high temperatures, it is often desired to produce a deep or thick zone of hardened material rather than a thin or shallow hardened case. The depth to which a piece of steel will harden, at a given rate of heat extraction, is different in different steels. The property of the steel which involves this relative susceptibility to mass effect in hardening seems to be inherent, and for convenience it will be termed herein "deep-hardenability."

An accepted, convenient measure of deep-hardenability is afforded by the "Jominy" test, described in detail in "A Hardenability Test for Carburizing Steel" by W. E. Jominy and A. L. Boegehold, Trans. Am. Soc. for Metals, vol. 26, p. 574 (1938). To summarize briefly, the test is made on a small bar of steel of standardized shape and dimensions, and comprises heating the entire bar to the desired hardening temperature, quickly extracting heat through one end face of the bar, grinding off superficial scale and decarburized skin and producing a flat surface suitable for making a hardness test, and measuring the Rockwell "C" hardness along the length of the bar. As a means for readily expressing the relation between the hardness and distance from the hardened end, the distance from the hardened end at which the hardness becomes less than Rockwell "C" 50 is used and is referred to herein as the "Jominy depth." If the same hardening temperature and cooling conditions be used for a series of steels, the relative depths of the hardened zones indicate the relative deep-hardenability of the steels of that series, each to the others.

The deep-hardenability of steel may be enhanced in some degree by adding in suitable percentages any one of the elements which can be taken into solid solution in steel at high temperatures, for instance silicon, molybdenum, tungsten, chromium, or nickel. These hardening elements differ widely in the minimum percentage required to impart a useful degree of deep-hardenability, and in the maximum degree of deep-hardenability obtainable while maintaining other necessary properties of the steel.

I have found that beryllium may be used to impart an even further enhanced deep-hardenability to steels containing between 0.25% and 2% silicon, without substantially sacrificing other desirable properties of the steels. I have further observed that combination of beryllium with one or more of the further elements: the alkali metals, alkaline earth metals, aluminum, titanium, zirconium, uranium, cerium, thorium, vanadium, columbium, and tantalum, in percentages greater than those required for grain-refinement, considerably enhances the effect of beryllium on deep-hardenability.

The present invention provides a fine-grained quench-hardened beryllium steel article in which beryllium is present in a percentage at least 0.0025% but less than 0.05%, and preferably between about 0.01% and 0.05%. The silicon content is between 0.25% and 2% and preferably between 0.35% and 1%. The carbon content is between 0.1% and 1%, and preferably between 0.2% and 0.8%. The minimum total proportion of said further element or elements to be added is any proportion greater than that required for grain-refinement, and preferably up to several times that required for grain-refinement. The percentage required for optimum grain-refinement will depend to some extent on the kind of steel, the steel-making conditions, and the kind and number of deoxidizing and grain-refining elements used: but the total aggregate percentage of such further elements to be added will be between 0.03% and 1%, and a preferred range is between 0.05% and 0.3%. The steel article of the present invention also contains at least one element of the group consisting of molybdenum, tungsten and chromium, the aggregate percentage of such additional element or elements together with the silicon percentage being at least 0.3% but less than 5% of the steel.

In good steelmaking practice an addition of beryllium amounting to between 0.01% and 0.2% will yield residual beryllium in the final steel within the percentage limits specified above.

For each element and each combination of elements there appears to be an optimum percentage which imparts a maximum depth of hardenability and a frequent result of an increase in percentage beyond the optimum is a decrease of deep-hardenability below that imparted by the optimum, but for reasons of economy, or to ob-

tain a steel having a certain desired combination of physical properties, it will often be desired to add either less or more of the elements than will impart a maximum depth of hardening.

The efficacy of addition of beryllium in increasing the hardenability of steels of different silicon contents may be appreciated from an inspection of the figures, derived from test data, in the table, which indicate the relative Jominy hardenability depths, in hundredths of an inch, of steels containing about 0.50% carbon, 1.70% manganese, the indicated added percentages of other elements, and the remainder iron.

Steel No.	Composition, remainder iron							Jominy depth
	C	Si	Mn	Al [1]	V [1]	Zr [1]	Be [1]	
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Inch*
1	0.44	0.27	1.66	0.04	0.04	0.04	None	0.21
2	0.43	0.29	1.74	0.04	0.04	0.02	0.022	0.33
3	0.50	0.53	1.75	0.07	0.07	0.07	None	0.56
4	0.52	0.49	1.65	0.09	0.08	0.04	0.044	0.67
5	0.49	1.0	1.67	0.14	0.14	0.14	None	0.52
6	0.48	1.0	1.73	0.17	0.15	0.16	0.015	0.63
7	0.51	1.0	1.65	0.18	0.18	0.09	0.088	0.74

[1] Percentage added, all other percentages determined by analysis. Residual beryllium between 20% and 35% of percentage added.

Each of the steels in the table contains a total proportion of the elements aluminum, vanadium, and zirconium above that required for grain-refinement. It will be observed that for a given silicon content those steels which contain a proportion of beryllium within the limits prescribed in this invention exhibit a marked increase in hardenability over steels containing no beryllium but of otherwise similar composition. In order to exhibit the remarkable efficacy of beryllium additions even at the lower end of the specified range, a 1% silicon steel (steel No. 6) was treated with an addition of only 0.015% beryllium. In this steel the hardenability was greatly enhanced over a steel of similar composition containing no beryllium (steel No. 5). The hardenability of this type of steel may be still further enhanced by a somewhat larger beryllium addition as is evidenced by the data on steel No. 7.

The efficacy of beryllium additions in increasing hardenability is by no means limited to steels of the particular compositions shown in the table. These steels were selected only to demonstrate the practical application of the invention which is equally applicable to a wide variety of hardenable steels.

Beryllium may be introduced into the steel with a deoxidizing and grain-refining agent, for instance as an ingredient of complex deoxidizing agents containing 25% to 85% silicon described in Patent 2,221,731, to J. H. Critchett and W. Crafts, or it may be separately introduced into the molten steel either before, during, or after the addition of the deoxidizing and grain-refining agent.

I claim:

1. A fine-grained steel quench-hardened article, other than a nitride case-hardened article, having substantially the composition: 0.25% to 2% silicon, manganese in a substantial proportion up to 2%; 0.1% to 1% carbon; between 0.0025% and 0.05% beryllium, 0.03% to 1% in the aggregate of at least one deoxidizing grain-refining element; and at least one element of the group consisting of molybdenum, tungsten, and chromium, the aggregate percentage of such last mentioned element or elements together with the percentage of silicon being at least 0.3% but less than 5% of the steel.

2. A fine-grained steel quench-hardened article, other than a nitride case-hardened article, having substantially the composition: 0.35% to 1% silicon, manganese in a substantial proportion up to 2%; 0.2% to 0.8% carbon; between 0.01% and 0.05% beryllium, 0.05% to 0.3% in the aggregate of at least one deoxidizing grain-refining element; and at least one element of the group consisting of molybdenum, tungsten, and chromium, the aggregate percentage of such last mentioned element or elements together with the percentage of silicon being at least 0.3% but less than 5% of the steel.

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