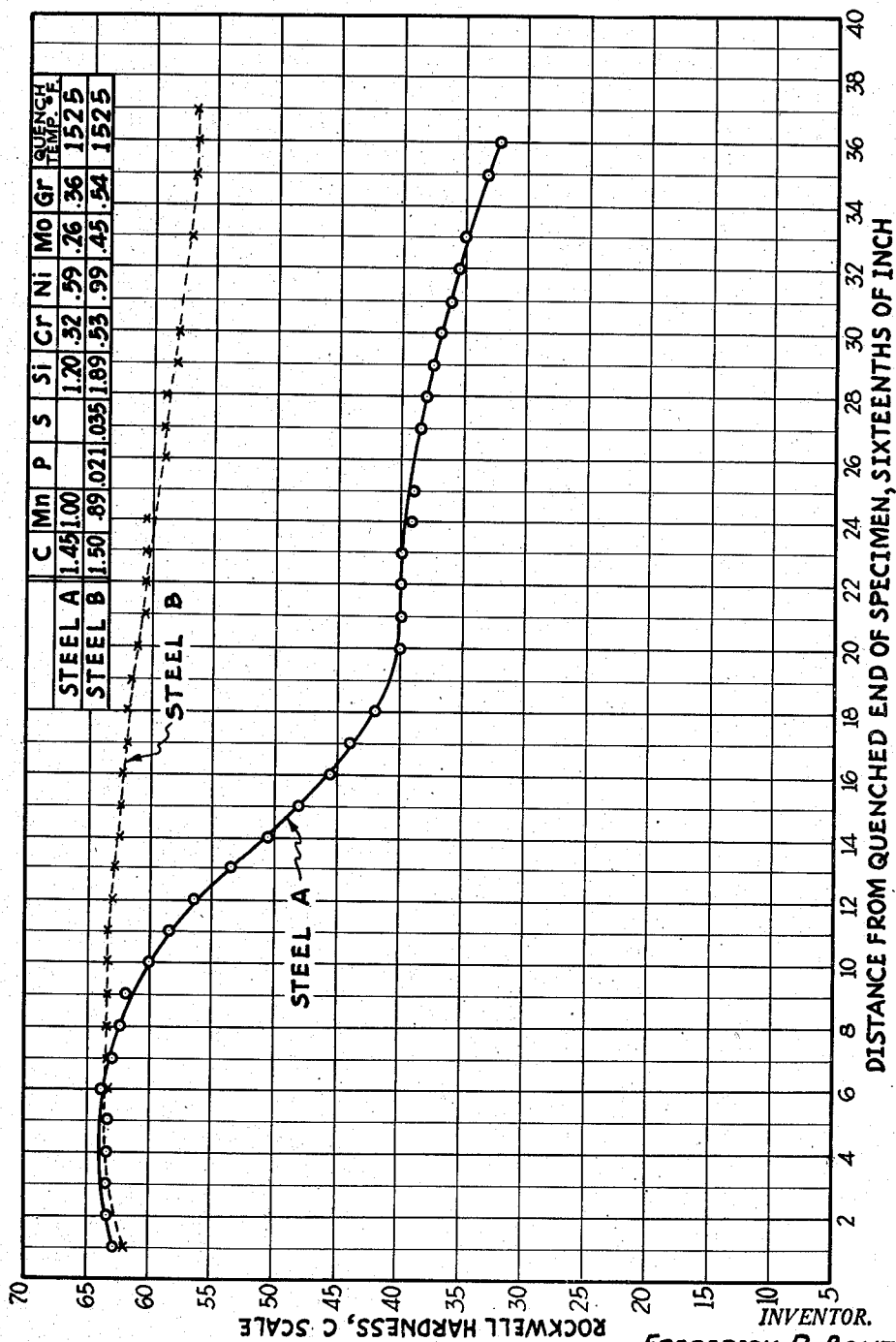


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GRAPHITIC STEEL OF CONTROLLABLE HARDENABILITY
AND ARTICLE MADE THEREFROM
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GRAPHITIC STEEL OF CONTROLLABLE
HARDENABILITY AND ARTICLE MADE
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4 Claims. (Cl. 75-128)

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This invention relates to graphitic steels, and this application is a continuation-in-part of my copending application Serial Number 435,842, filed March 23, 1942; now Patent No. 2,438,267, granted March 23, 1948.

Graphitic steels are well-known, and they are now recognized as comprising a distinct type of steel. These steels are characterized by containing free graphite and by the ability to develop high hardness upon appropriate heat treatment. They possess high resistance to abrasion, metal pick-up, and scoring, and they are classed as being free machining. Such properties coupled with desirable mechanical properties have resulted in very extensive use of the graphitic steels for the making of dies of many kinds, punches, spinning, slitting and forming rolls, broaches, and other tools used for related purposes, especially where high resistance to fatigue and abrasion is requisite.

Certain types of graphitic steels are disclosed in Patent Number 2,087,764, granted July 20, 1937, on an application filed by me. Two types of the steels disclosed in that patent have been used widely. One of them contains about 1.5 per cent of carbon and about 1 per cent of silicon, while the other is of similar composition but contains also a small amount of molybdenum. Another type of graphitic steel is disclosed in my Patent Number 2,283,664, granted May 19, 1942. This steel possesses the properties common to graphitic steels and certain additional unusual properties, and its preferred embodiment contains about 1.5 per cent of carbon, about 0.4 per cent manganese, about 0.5 per cent of molybdenum, about 0.65 per cent of silicon, and about 2.8 per cent of tungsten.

The graphitic steels known prior to the invention of my aforesaid copending application are hardened by liquid quenching, i. e., into oil, water or brine, and none of those earlier known graphitic steels was capable of air hardening. The necessity for hardening by liquid quenching is undesirable in some instances, as in the case of parts of non-uniform section or of relatively great length and small section, because distortion may occur as a result of quenching strains. Also, quenching in a liquid coolant requires special equipment. The steels disclosed in my aforesaid application Ser. No. 435,842 likewise possess the properties characteristic of graphitic steels but are unique in their ability to be air hardened. They contain from about 1 to 2 per cent of carbon, about 0.25 to 1 per cent of chromium, about 0.75 to 1.5 per cent of manganese, about 0.25 to 1 per cent of molybdenum, about 1.5 to 2.5 per cent of nickel, and about 0.75 to 1.25 per cent of silicon,

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The graphitic steels known prior to the present invention have proved to be perfectly satisfactory within their specific fields, and a total of many million pounds of them have been used. However, it is characteristic of all of them that their hardening characteristics are rather definitely fixed in each case. On the other hand, for some purposes deep hardening steels are required, as where the article is subjected to severe wear and can be reground repeatedly but is not subject to severe impact. In other cases shallow hardening is desired to provide a hardened wearing surface backed by a softer and ductile core. In view of the rather definitely fixed hardening characteristics of the graphitic steels known prior to this invention they have not been versatile in the sense that the individual types can be applied, according to need, to satisfy both deep and shallow hardening. As a matter of manufacturing and merchandising practices, and of economy with respect thereto, it would be desirable, on the other hand, to be able to supply both deep and shallow hardening requirements with a single type analysis, whereby production would be simplified, warehouse stocks could be reduced, and related advantages gained.

The major object of this invention is to provide graphitic steels and articles made therefrom in which the properties characteristic of such steels are combined with controllable hardenability, i. e., the ability to harden them shallowly or deeply, according to need, and which are of relatively simple and inexpensive composition and do not require the use of large amounts of alloying elements, and which may be air hardened.

The invention will be described with reference to the accompanying drawing in which the graphs represent the hardening characteristics of two steels as provided by this invention.

I have discovered, and it is upon this that the present invention is predicated, that controllably hardenable graphitic steels are provided by a modification of the analysis disclosed and claimed in my copending application Ser. No. 435,842, and specifically by lowering substantially the content of nickel, by increasing the upper limit for silicon, and by extending downwardly the lower limit for manganese. Desirably the lower limit of molybdenum is decreased also.

In accordance with the present invention graphitic steel articles are made from steels containing about 1 to 2 per cent of carbon, about 0.25 to 1 per cent of chromium, about 0.5 to 1.5 per cent of manganese, about 0.2 to 1 per cent of molybdenum, about 0.25 to 1.4 per cent of nickel, and about 0.75 to 2 per cent of silicon. Phosphorus

and sulfur should be kept low. The remainder of the steels is iron together with impurities in the amounts customarily encountered in such steels, but it will be understood that other alloy-

	C	Cr	Mn	Mo	Ni	Si	P	S
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Steel A -----	1.45	0.32	1.0	0.26	0.59	1.20	0.016	0.034
Steel B -----	1.50	0.53	0.89	0.45	0.99	1.89	0.021	0.035

ing elements may be present provided they do not detrimentally affect the properties which characterize the present invention, for which reason the remainder of the steels may be said to be effectively iron inasmuch as such additional alloying elements do not alter the essential character of products made in accordance with the present invention.

These steels are productive of articles capable of deep or shallow hardening, according to the particular composition within the ranges stated, and in all instances they possess the other properties of graphitic steels including mechanical properties, such as tensile strength, elastic limit, and the like, that are requisite and desirable for the purposes to which graphitic steels are applied. Nickel within the range stated results in less austenite than is the case with the steels of Ser. No. 435,842, but it suffices to supply adequate mechanical properties through its strengthening effect upon ferrite; also it is ample to effect the graphitization necessary to provide graphitic carbon and to confer adequate hardening response.

In the practice of the invention the desired hardenability, deep or shallow, is obtained by control of the contents of manganese and chromium, which are carbide formers, and of the graphitizers, molybdenum and nickel, together with silicon. According to the invention deep hardening is obtained by the use of those five elements toward the upper limits of the ranges stated, which results in relatively high content of graphitic carbon and correspondingly low content of combined carbon, or carbides. On the other hand, when those five elements are toward the lower limits of their stated ranges the content of graphitic carbon is relatively low and that of combined carbon is high. In general this results in the development of up to about 0.35 per cent of graphitic carbon in the case of shallow hardening, and more than about and up to about 0.8 per cent of graphitic carbon in deep hardened steels according to the invention. Of course the compositions are likewise balanced in accordance with known graphitic steel practice, i. e., so that during hot working the carbon will be wholly or substantially wholly, in the combined state, and so that graphitization will occur upon subsequent annealing. Maximum response to hardening occurs with from about 0.5 to 0.9 per cent of combined carbon. With carbon much in excess of the eutectoid, as is the case with these steels, the presence of excess carbides may retard the formation of austenite during heat treatment, and in the practice of this invention it is generally desirable to balance the composition in such a manner that sufficient of the carbon will be converted to the graphitic state to bring the agraphitic carbon content close to the eutectoid. In general, for given contents of Cr, Mn, Mo, Ni and Si varying the C in its stated range is without substantial effect on the hardening characteristics.

The controllable hardening characteristic of the steels and articles in accordance with this invention may be exemplified by the following compositions.

The foregoing steels were made in an electric induction furnace and cast into 30-pound ingots which were hot forged to 1¼ inch rounds which were then subjected to the following annealing (graphitizing) cycle:

Charge at 1000° F.
Heat to 1210° F. at 200°/hr.
Heat to 1310° F. at 100°/hr.
Heat to 1370° F. at 60°/hr.
Heat to 1400° F. at 30°/hr.
Heat to 1430° F. at 10°/hr.
Hold 6 hours
Cool to 1100° F. at 20°/hr.
Discharge to air

Standard end-quench Jominy bars were then machined from the annealed stock, and they were heated for 45 minutes in a neutral salt bath at 1525° F. and quenched in accordance with prescribed Jominy practice. The hardnesses determined from the resulting specimens are shown in the accompanying drawing. It will be observed that steel A is hardenable at 10/16 inch Jominy distance to Rc. 60, showing it to be a shallow hardening steel. In contrast, steel B, containing the same amount of carbon but with greater amounts of alloying elements shows hardenability of 1½ inches Jominy distance to Rc. 60, which shows this steel to be deep hardening. The markedly different hardening characteristics of these two steels demonstrates clearly how both deep and shallow hardening may be obtained in the practice of this invention. Intermediate results are, of course, possible. An analysis similar to A but with only 1.15 per cent of carbon showed a Jominy curve essentially the same as that of steel A, which is generally true of these steels.

The steels provided by this invention may be made in accordance with procedures standard in the art for the production of graphitic steels. Preferably they are made in an electric furnace following standard killed steel practice, the various alloying elements being introduced suitably in the form of ferro-alloys, or otherwise as desired. They are cast in chill molds to avoid formation of graphite in the ingots.

The ingots are treated prior to and during hot working in a manner understood in the graphitic steel art, i. e., so that the carbon will remain substantially entirely in the combined form during hot working. Generally speaking, the ingots should be hot worked, as by rolling or forging, at a temperature not over about 1950° F. or 2000° F. to produce shapes of desired form and size for conversion into final products. In case it is necessary to forge the hot rolled material to form dies or other tools the hot rolled shapes should be heated slowly to 2000° F. and held until they have been heated through, after which they are forged to shape with care taken that the temperature during forging does not fall below about 1750° F.

The shaped articles are then graphitized by

subjecting them to normalizing and annealing treatments. To this end they are normalized by heating above the critical range, suitably at about 1700° F., to cause decomposition and diffusion of carbides. They are then cooled, in accordance with ordinary normalizing practice, by being removed from the furnace and cooled in air. Thereafter the articles are annealed by reheating them into or above the critical range, say by heating to 1450° F. and holding at that temperature for four hours. The articles are then cooled slowly, advantageously at about 20° F. per hour, to below the critical range, after which they are removed from the furnace and allowed to air cool. In this manner the carbides are partially decomposed with production of graphitic carbon and with spheroidization of residual carbides.

Treated in the manner just described, steels of the preferred composition given hereinabove will contain substantial percentages of free graphite, depending on the particular analysis, the remainder of the carbon being in combined form. The graphitic carbon confers surface lubricating qualities desirable in articles provided by the invention, while the carbides provide, upon suitable heat treatment, high wear resistance and a structure possessing other desirable qualities which are detailed hereinafter. The combination of graphitic carbon and spheroidized carbides also causes the steels in this condition to be easily machinable. It is characteristic of products provided by this invention that the graphitic carbon is dispersed in finely divided form, and uniformly, throughout the structure, and that when hardened they possess remarkable non-seizing qualities.

After being graphitized the articles are machined or otherwise finished to shape and size, after which they are subjected to a hardening treatment in which they are heated above the critical range and air cooled. A variety of structures can be produced, depending upon the conditions of the hardening treatment. Austenitic structures may be produced but it is now preferred for most purposes to conduct such hardening heat treatment to produce an austenitic-martensitic structure. It is particularly desirable to use for that purpose a double hardening procedure. With sections up to about 2 inches thick, it suffices usually to pack the articles in a suitable compound, heat to 1625° F., then cool in air, and then to reharden at 1550° F. With sections from about 2 inches to 4 inches thick, the first heating should be about 1650° F., while with sections over 4 inches the first hardening should be at about 1675° F. In both cases rehardening is effected at 1550° F. at which temperature the articles are held until heated throughout, the exact time depending, of course, upon their mass. On the first hardening there will be retained a substantial proportion of austenite. The rehardening step is desirable because it gives increased wearing properties resultant from production of martensite by conversion of some of the austenite. Hardnesses of 60 to 65 Rc. are regularly obtainable through hardening in the manner described.

The controllable hardenability of the steels provided by this invention and of articles made from them, is highly advantageous for reasons that will be clear to those familiar with the art. A further advantage is that, like the steels of my copending application Ser. No. 435,842, it is possible to effect hardening without distortion of

tools of variable section or of considerable length and small section, whose quenching in oil or water is hazardous. Similarly, these steels possess the unusual property of being likewise capable of hardening in oil or water if that is desirable for any reason.

According to the provisions of the patent statutes, I have explained the principle and method of practicing my invention and have illustrated and 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. As a new article of manufacture a hot worked and heat treated alloy steel article formed from steel of controllable hardenability consisting essentially of about 1 to 2 per cent of carbon, about 0.25 to 1 per cent of chromium, about 0.5 to 1.5 per cent of manganese, about 0.2 to 1 per cent of molybdenum, about 0.25 to 1.4 per cent of nickel, about 0.75 to 2 per cent of silicon, and the remainder iron and characterized by austenitic-martensitic structure containing graphitic carbon and spheroidized carbide dispersed finely through the structure, by high resistance to wear, and by being deeply hardened when said elements, other than carbon, are toward the upper limit of the ranges stated, and by being shallow hardened when the said elements, other than carbon, are toward the lower limits of the ranges stated.

2. Alloy steel of controllable hardenability consisting essentially of about 1 to 2 per cent of carbon, about 0.25 to 1 per cent of chromium, about 0.5 to 1.5 per cent of manganese, about 0.2 to 1 per cent of molybdenum, about 0.25 to 1.4 per cent of nickel, about 0.75 to 2 per cent of silicon, and the remainder iron, and characterized by capability of being hot worked and of producing upon heat treatment austenitic-martensitic structures containing graphitic carbon and spheroidized carbide dispersed finely through the structure, and of high resistance to wear, and by being deeply hardening when said elements, other than carbon, are toward the upper limit of the ranges stated, and by being shallow hardening when the said elements, other than carbon, are toward the lower limits of the ranges stated.

3. Shallow hardening steel according to claim 2 containing from 1.15 to 1.45 per cent of carbon, about 0.3 per cent of chromium, about 1 per cent of manganese, about 0.25 per cent of molybdenum, about 0.6 per cent of nickel, and about 1.2 per cent of silicon.

4. Deep hardening steel according to claim 2 containing about 1.5 per cent of carbon, about 0.55 per cent of chromium, about 0.9 per cent of manganese, about 0.45 per cent of molybdenum, about 1 per cent of nickel, and about 1.9 per cent of silicon.

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The following references are of record in the file of this patent:

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