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GRAPHITIC STEEL

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This invention relates to graphitic steels of special composition which are capable of being pierced to form seamless tubes, particularly thin walled seamless tubes, and to seamless tubes of graphitic steel which embody the advantages of known graphitic steels together with properties rendering them adapted to a variety of uses to which seamless steel tubing is adapted.

The commercially available graphitic steels have a number of advantages and desirable properties in comparison with conventional non-graphitic alloy steels such, for instance, as good machinability, better wear resistance at equivalent microstructures, excellent dry lubrication and lubricant retaining characteristics, excellent non-seizing or non-galling characteristics, adequate toughness and ductility at all hardness levels, and low coefficient of friction in dry metal to metal contact, for instance a coefficient of friction of 0.18 for normalized 100 percent lamellar structure, and a coefficient of 0.20 in the hardened and tempered condition. The graphitic steels are also equivalent to or better than cast irons in these respects, at least where comparative data are available.

Seamless tubing containing graphite in the microstructure thus would appear to be ideal for the manufacture of a variety of commercial items having a finished hollow cylindrical shape and requiring wear resistance and lubricant retaining properties, especially for such uses as automotive cylinder linings, piston rings, slush pump and conventional pump liners, seal rings, and seal wear rings, where the use of products containing graphite, such as cast iron, has already been firmly established. However, the graphitic steels heretofore available have not been adapted to being pierced satisfactorily and processed into seamless tubing to develop properties adequate for such purposes.

An object of the invention is to provide steel compositions of low alloy content for producing pierced graphitic steel tubing which is capable of thermal treatment to develop desired microstructures, hardnesses, and graphite contents in the final tubing, and having desirable tempering characteristics.

Still another object is to provide graphitic steels in accordance with the foregoing object especially adapted for uses to which pearlitic cast irons have been used.

Yet another object is to provide such graphitic steels and seamless tubing and other wrought products made therefrom that can be heat treated to desired microstructures and hardness ranges from tempered martensite in the Rockwell C range, Rc 60 and above, to complete spheroidized structures of hardnesses from about 170 up to 217 Brinell, or to substantially completely lamellar structures ranging in hardness from 180 to 400 Brinell.

Still another object is to provide such graphitic steels that are easily converted to seamless tubing and attain the various foregoing objects.

Yet another object is to provide graphitic steels in accordance with the foregoing objects that may be pierced satisfactorily to provide seamless tubing in a wide variety of outside diameters and wall thicknesses, including thin walled tubing, and seamless tubes which in the spheroidized annealed condition can be successfully cold reduced 60 percent in cross sectional wall area by rotor-rolling, or 15 percent by cold drawing.

A further object is to provide such graphitic steels and

seamless tubing made therefrom which when subjected to graphitizing treatment contain in the preferred embodiment not more than about 0.5 percent of graphitic carbon but which under special conditions or for special purposes may contain up to about 0.7 percent of graphitic carbon.

The objects of the invention are attained with steels containing from about 1.25 to 1.55 percent of carbon, about 0.50 to 0.70 percent of manganese, about 0.55 to 0.85 percent of silicon, and about 0.05 to about 0.35 percent of aluminum, and the remainder essentially iron, that is, iron together with impurities and incidental alloying elements in amounts that do not adversely affect the properties that characterize the invention, among which chromium should no exceed about 0.20 percent, nickel should not exceed about 0.25 percent, and molybdenum should not exceed about 0.06 percent. In the preferred embodiment of the invention the steels contain about 1.35 to 1.45 percent of carbon, about 0.60 percent of manganese, about 0.70 percent of silicon, about 0.10 percent of aluminum, and the remainder iron containing not over about 0.15 percent of chromium together with minor amounts of other impurities incidental to the production of such steels. Sulfur and phosphorus should not exceed about 0.025 percent each in these steels.

These steels provided by the invention may be forged or rolled to billets readily at 1950° to 1975° F. They likewise pierce readily at temperatures of, for example, 1850° to 1900° or 1950° F. with excellent recovery, or yield, of pierced tubing of wall thicknesses as low as 0.211 inch. Moreover, these compositions are of balanced character such that there is less than 0.1 percent of graphite present at forging or piercing temperatures, in air cooled forgings or in wrought stock reheated to at least 1900° F. and quenched, although the finished products may be graphitized readily upon annealing at, for example, 1400° to 1850° F. and heat treated, as indicated above, to produce a variety of desired microstructures and hardnesses, as will appear more in detail hereinafter.

In the practice of the invention it is desirable that if the ingots are to be rolled the molds stand for about 3 hours after pouring and are not stripped until 6 hours after pouring; if the ingots are to be forged, they should be cooled in the molds. Before heating for forging or rolling the ingots are most suitably equalized at about 1200° F. and they are then forged or rolled at 1950° F. to 1975° F. and finished as hot as possible. In making seamless tubes billets are most suitably pierced at 1850° to 1900° F.

The finished tubing or other wrought product may be annealed for the production of graphite and particular microstructure. For 100 percent spheroidized structure the tubing may be heated to about 1460° to 1480° F., held for 4 hours, cooled at less than 100° F. per hour to 1200° F., and then air cooled, which should result in an annealed hardness of 187 to 217 Brinell. The pierced tubes may be reheated for annealing and development of a 100 percent lamellar pearlitic structure by austenitizing at 1800° to 2100° long enough to equalize the temperature, furnace cooling to 1450° F. and holding 2 hours for development of graphite, and further cooling at a rate to develop desired hardness as follows: for hardnesses between 200 and 229 Brinell cool from 1450° to 1200° F. at 100° per hour, for hardnesses between 229 and 248 Brinell cool at 200° F. per hour, and for hardnesses between 248 and 285 Brinell cool at 500° F. per hour. Lamellar pearlitic structures may be obtained directly off the piercing mill provided the tubes are not cooled below 1650° F. by placing the tubes from the mill immediately in a furnace at 1450° F. and holding for 2 hours to cause graphitization, after which they may be cooled to develop

hardnesses between 200 and 285 Brinell by cooling at the rates just specified.

The spheroidized products can be straightened, cold drawn, or rotorolled easily; however, the products of 100 percent lamellar microstructure cannot be drawn or rotorolled effectively.

Hardening to a full martensitic structure in the Rc 60 range is accomplished by oil quenching from the full austenitic condition.

The pierced tubes may be annealed to develop a 100 percent lamellar pearlitic structure of about 223 Brinell to match the structure, graphite and hardness requirements of automotive engine cylinder liners of cast iron by passing them through a roller hearth on the following schedule:

1st zone 1850° F.	40 minutes.	
2nd zone 1850° F.	40 minutes.	
3rd zone 1450° F.	40 minutes.	
4th zone 1450° F.	40 minutes.	
5th zone 1390° F.	40 minutes.	90° F./hour average cool.
6th zone 1330° F.	40 minutes.	
7th zone 1260° F.	40 minutes.	
8th zone 1200° F.	40 minutes.	

For hardening the steels may be heated to, for example, 1475° to 1550° F. and oil quenched or water quenched according to the section thickness. The hardened products may be tempered, in general by heating 2 hours at

300° F. for Rockwell C of 63.0 minimum
400° F. for Rockwell C of 61.0 minimum
500° F. for Rockwell C of 58.0 minimum

The desirable characteristics of the steels of this invention are based upon the action of the limited content of aluminum which controls the graphitizing property in the range 1400° to 2100° F., coupled with the ability to develop by heat treatment the structures and hardnesses stated above. The effect of aluminum in these steels is believed to be due to its exerting control on graphitization in consequence of the formation of aluminum nitride and its subsequent effect in controlling graphitization by removal of nitrogen from carbon nucleation sites.

As evidencing the benefits to be derived from the invention, reference may be made to a 25-ton electric furnace heat which was melted and cast into 19-inch round 3950 pound ingots. This heat contained 1.38 percent of carbon, 0.60 percent of manganese, 0.70 percent of silicon, 0.11 percent of aluminum, 0.16 percent of chromium, and 0.10 percent of copper.

This heat was poured into 19-inch round, 3950 pound ingots which were bloomed into billets 9½ x 9½ inches and also 11 x 11 inches which were rolled to piercing mill billets ranging from 3¾ inches round to 7½ inches round. These billets were pierced on a piercing mill, rolled, and reeled to sizes varying from 2.233 inches O.D and of wall thickness 0.349 inch to 7.497 inches O.D and 1.184 inches wall thickness.

Some of the tubes in the spheroidized state were cold reduced. Thus, tubing of 3.300 inch O.D and 0.569 inch wall thickness was rotorolled to 2.500 inches O.D and 0.281 inch wall thickness, representing about a 60 percent reduction in cross sectional wall area. Tubes of 3.946 inches O.D and 0.349 inch wall thickness were cold drawn to 3.770 inches O.D and 0.312 inch wall thickness, representing 15 percent reduction in cross sectional wall area.

For best machinability on wear seal rings and other applications requiring full hardening, by oil quenching, a 100 percent spheroidized structure can be produced from this heat, or a 100 percent lamellar pearlitic structure can be produced for direct use without hardening which is desirable in some instances because heat treating distortion is avoided and the product can be finish machined directly, and although machinability of this structure is not as good as that which is 100 percent spheroidized, it is nevertheless satisfactory.

This composition when hardened from 1450° to 1550° F., a desirable low hardening range, develops on the standard end quench bar a Rockwell C. 60.0 hardness at a minimum of 2/16 inch and a maximum of 2.5/16 inch.

Typical room temperature properties developed with this heat were as follows:

TABLE I

Typical Tensile Properties of the Foregoing Heat, Treated to 100% Spheroidized and 100% Lamellar Structure

Condition	.2% yield strength	Ultimate tensile strength	Percent elongation	Percent reduction of area	Brinell hardness
A. Specimen production treated to 100% lamellar structure:[1]					
As treated	50,000	114,000	8.5	9.5	229
As treated and tempered at 400° F.[2]	57,500	114,500	7.5	9.5	235
As treated and tempered at 1,100° F.	50,750	114,000	8.0	10.0	229
As treated and tempered at 1,200° F.	49,000	113,000	8.2	10.0	229
As treated and tempered at 1,300° F.	46,750	110,000	9.7	11.5	217
B. Specimen spheroidize annealed:[3] As annealed	50,000	92,600	24.0	40.0	183

[1] Austenitized 1,850° F., furnace cooled to 1,450° F., then 100°/hour to 1,200° F. and air cooled.
[2] Tempers applied because one possible end use of this steel, automotive engine cylinder liners, requires structural and hardness stability up to about 1,100° F.
[3] Used standard Graph Mo Cycle for convenience—Austenitized 1,450° F., cooled 10°/hour to 1,300° F., then 20°/hour to 1,100° F. Discharged below 1,200° F.

The effect of other rates of cooling and other tempering operations upon the tensile and impact properties of 100 percent lamellar structures of this heat were as follows:

TABLE II

Effects of Faster Cooling in Annealing and of Additional Tempering Operations on the Tensile and Impact Properties of 100% Lamellar Structures in this Steel

[Specimens treated as follows: Austenitized 1,850° F., furnace cooled to 1,450° F., then 200° and 500° F./hour to 1,200° F., and air cooled]

TENSILE PROPERTIES

Condition	.2% yield strength	Ultimate tensile strength	Percent elongation	Percent reduction of area	Brinell hardness
200°/hour cool, not tempered	49,500	124,000	3.0	5.0	241
200°/hour cool, tempered at 400° F.	54,200	129,800	3.0	4.8	248
200°/hour cool, tempered at 1,100° F.	49,600	122,500	7.5	7.0	235
200°/hour cool, tempered at 1,200° F.	48,500	124,700	7.5	9.0	235
500°/hour cool, not tempered	58,400	134,000	4.0	5.0	255
500°/hour cool, tempered at 1,000° F.	60,000	135,000	4.5	5.5	269
500°/hour cool, tempered at 1,100° F.	59,500	134,000	5.0	7.5	261
500°/hour cool, tempered at 1,200° F.	57,000	134,000	5.5	7.5	255

UNNOTCHED IZOD IMPACT

Condition	200°/hour cool		500°/hour cool	
	Ft.-lbs.	Brinell hardness	Ft.-lbs.	Brinell hardness
As treated, no temper	63.0	231	48.0	255
As treated, 400° F. temper	53.0	235	40.0	255
As treated, 1,000° F. temper	74.0	235	52.0	250
As treated, 1,200° F. temper	71.0	221	56.0	245

Pearlitic cast irons as used for automotive engine liners show values of only 1 to 5 ft.-lbs unnotched Izod, and the impact strengths given in the last table show that the material of this invention is much superior in this respect. The following table shows the effect of tempering at various temperatures on the oil quenched hardness of this steel:

TABLE III

Effect of Tempering Temperature on Quenched and Tempered Steel of the Foregoing Heat

[¾" square sections, oil quenched from 1500° F., tempered 2 hours at indicated temperature]

Treatment	Hardness Rockwell "C"	Retained austenite
As quenched	65.0	19.0
300° F	63.0	16.5
400° F	61.5	14.5
500° F	61.0	
600° F	59.0	
700° F	55.0	
800° F	49.0	
900° F	44.5	
1000° F	39.5	
1100° F	34.0	
1200° F	27.0	
1300° F	21.5	

According to the provisions of the patent statutes, I have explained the principle of my invention and have 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. A forgeable and graphitizable steel consisting essentially of 1.25 to 1.55 percent of carbon, 0.5 to 0.7 percent of manganese, 0.55 to 0.85 percent of silicon, 0.1 to 0.35 percent of aluminum, and the remainder essentially iron, and characterized in the annealed state by containing up to about 0.7 percent of graphitic carbon.

2. A forgeable and graphitizable steel consisting essentially of 1.35 to 1.45 percent of carbon, about 0.6 percent of manganese, about 0.7 percent of silicon, about 0.1 percent of aluminum, and the remainder essentially iron, and characterized in the annealed state by containing about 0.5 percent of graphitic carbon.

3. A seamless steel tube of a steel consisting essentially of 1.25 to 1.55 percent of carbon, 0.5 to 0.7 percent of manganese, 0.55 to 0.85 percent of silicon, 0.1 to 0.35 percent of aluminum, and the remainder essentially iron, a portion of the carbon up to about 0.7% being in the form of graphitic carbon.

4. A seamless steel tube wrought article of manufacture of a steel consisting essentially of 1.35 to 1.45 percent of carbon, about 0.6 percent of manganese, about 0.7 percent of silicon, about 0.1 percent of aluminum, and the remainder essentially iron, a portion of the carbon up to about 0.7% being in the form of graphitic carbon.

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