

Oct. 28, 1941.

C. H. LORIG

2,260,998

MALLEABLEIZING CAST IRON

Filed Dec. 9, 1940

2 Sheets-Sheet 1

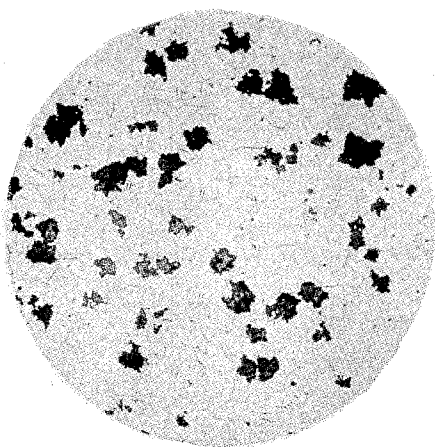


Fig. 1

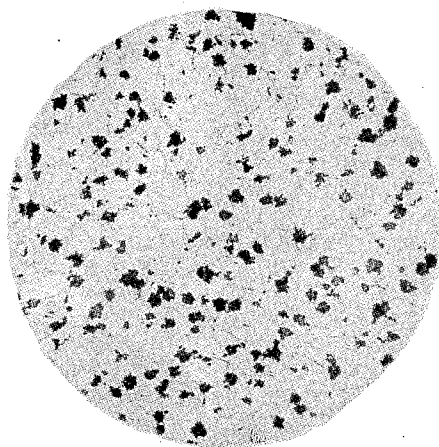


Fig. 2.

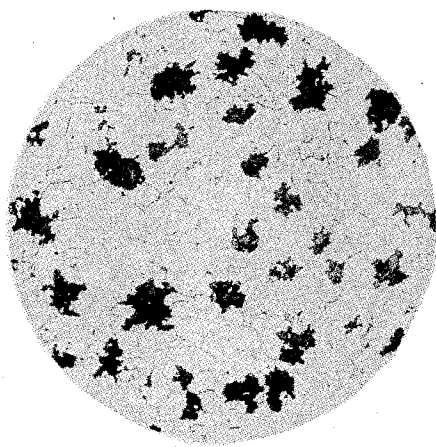


Fig. 3.

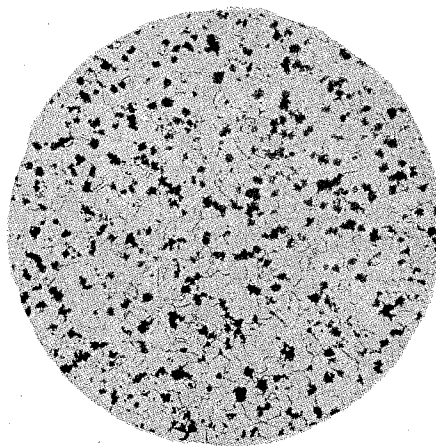


Fig 4.

INVENTOR
Clarence H. Lorig

BY *Corbett, Mohrney*
+ *Miller*
ATTORNEYS

Oct. 28, 1941.

C. H. LORIG

2,260,998

MALLEABLEIZING CAST IRON

Filed Dec. 9, 1940

2 Sheets-Sheet 2



Fig. S



Fig. B.

INVENTOR
Clarence H. Lorig.

BY *Carbott, Mahoney*
+ Miller
ATTORNEYS

UNITED STATES PATENT OFFICE

2,260,998

MALLEABLEIZING CAST IRON

Clarence H. Lorig, Columbus, Ohio, assignor, by mesne assignments, of two-thirds to Interlake Iron Corporation, Chicago, Ill., a corporation of New York, and one-third to The Youngstown Sheet and Tube Company, Youngstown, Ohio, a corporation of Ohio

Application December 9, 1940, Serial No. 369,183

4 Claims. (Cl. 148—3)

My invention relates to malleableizing cast iron. It relates to irons which have substantially all the carbon in the combined state and which are subsequently annealed or heat-treated to decompose some or all of the carbide to temper carbon and iron. More specifically, it relates to improvements in the malleabilization of white cast iron and in the resultant malleableized product.

White cast irons contain two major constituents, i. e., massive or free iron carbide and pearlite. The nature of these constituents is such as to make the castings, when taken from the molds, hard and brittle. A malleableizing treatment is given for the purpose of decomposing both the free carbide and that contained in the pearlite. The malleableizing cycle may be divided into three parts according to its effect upon the structural constituents of the castings, (a) the first-stage anneal at some temperature between 1450 and 1800° F. for the purpose of graphitizing the massive or free carbide, (b) a slow cooling period from the first-stage annealing temperature to the transformation range for the purpose of graphitizing the carbide thrown out of solid solution as the temperature falls, and (c) a second-stage annealing or holding period just below the temperature at which the iron-carbide solid solution remaining transforms into the eutectoid or pearlite. Graphitization in all three divisions of the annealing cycle produces a casting which consists of two structural constituents, i. e., soft and ductile ferrite or nearly pure iron and temper carbon nodules interspersed throughout this matrix. The presence of any considerable amount of combined carbon in the annealed castings reduces the ductility and machinability and is avoided in fully malleableized iron. On the other hand there are certain materials such as the pearlitic malleables and graphitic steels in which some pearlite is retained and hence the ductility is intentionally sacrificed for a gain in strength.

Complete graphitization requires a great deal of time depending, of course, upon the composition of the iron being treated. A typical cycle for a stationary batch-type furnace is given by the American Society for Metals Handbook, 1939 edition, page 643, as follows:

Time heating to 1500° F.-----	45
Time holding above 1500° F.-----	50
Time cooling-----	60

In the malleabilization of white cast iron many factors are known to influence profoundly the annealing or malleableizing rate and the microstructure and properties of the malleableized iron. The composition of the iron, particularly as regards the silicon and carbon contents and, in iron that is further alloyed, the relative amounts of so-called carbide stabilizing and

graphite promoting elements, is naturally a factor of prime importance. The effects of composition and compositional changes can, however, usually be predicted with some degree of success.

On the other hand the effects of some other factors are not only less predictable but the mechanisms by which they influence the malleabilization process are not understood. The rate of heating to the annealing temperature is an example of the latter type of factor. Smith and Palmer (Transactions American Institute of Mining and Metallurgical Engineers, 1935, vol. 116, pages 363-385) and later Boegehold (Transactions American Society for Metals, 1938, vol. 26, pages 1084-1121) have shown the importance of the speed of heating to the malleableizing temperature. Both investigations disclosed that in commercial white irons slowly heated to the malleableizing temperature, the temper carbon precipitates out in more numerous, closely spaced, small particles, while in irons rapidly heated to temperature, the precipitated temper carbon particles are fewer in number, therefore, larger in size, and widely spaced apart. Heating the white irons to the malleableizing temperature rapidly was also found to diminish the rate at which the iron malleableized, which is explained logically by the fact that carbon in the matrix has to diffuse through a greater distance in order to reach, and precipitate upon, the large widely spaced nodules. In the past this has militated against the possibility of reducing the malleableizing cycle for an iron by heating it more rapidly to the malleableizing temperature. It has been proposed to heat the white iron more slowly to the malleableizing temperature to effect refinement in the temper carbon particle size and to accelerate malleabilization. According to this prior art method, it has been proposed to subject the white cast iron to a range of temperature between 1500° F. and 1700° F., the latter temperature being the malleableizing temperature, and to make the rate of heating purposely slow so as to promote the formation of a large number of temper carbon particles.

Various other factors are of the same type as the rate of heating to the malleableizing temperature with regard to their effect upon malleableizing rates for white cast iron. Among these factors are, (1) the melting practice followed in producing the white iron, (2) the nature of the materials used in the melting furnace charge, (3) the cross-sectional dimensions of the casting, (4) the temperature reached before the iron is cast, and (5) the composition of the atmosphere in the annealing furnace. In commercial operations, each of these, as well as many other factors, are known to affect the response of the iron to malleableizing and the quality of the malleableized iron. It cannot be explained, in the light

of present day metallurgical knowledge, why white irons show the unusual sensitivity, from the malleabilization standpoint, to manufacturing variables, though it has been postulated that the gas content of the iron bears some relation to its response to malleabilization.

One of the objects of this invention is to reduce the holding time during both the first and second stage annealing operations in the malleabilization cycle.

Another object of my invention is to obtain superior and unique properties in the finished malleableized product.

Another object of my invention is to eliminate sensitivity to the rates of heating of the iron to the maximum annealing temperature.

Another object of my invention is to permit the use of irons with lower amounts of graphitizing agents, silicon for example, and thus avoid primary or flake graphite formation during the solidification of the original castings in the molds.

Still another object of this invention is to extend the malleable field to products or articles of much larger section sizes than can be produced, and annealed in a reasonable time, at present.

I have discovered that the variability in the response to malleabilization of white cast iron can be largely eliminated by a low temperature treatment before the malleableizing operation, while at the same time, the rate of malleabilization can be greatly accelerated through an unusual increase in the number of temper carbon particles that are found after malleabilization as a result of the low temperature treatment. I have also discovered that the treatment of the molten metal with hydrogen, or hydrogen-containing materials, prior to its being cast, further accentuates the effect of the low temperature treatment.

Therefore, my invention contemplates heating white cast iron, prior to its annealing or malleabilization. This iron may or may not be first treated in the molten state with hydrogen, or hydrogen-containing materials. It is heated to some temperature below the lower critical temperature but above room temperature for a period of time to effect a refinement in the size of the temper carbon particles upon subsequent malleabilization, a marked shortening of the malleableizing period with its attendant operating economies, and to obtain a material having unique structural and physical characteristics.

The above-mentioned low temperature treatment may be utilized during the course of malleableizing iron in various ways such as (1) by heating the iron to a temperature below the critical but above room temperature and holding it at that temperature for a prescribed period of time and then cooling to room temperature, the iron subsequently being malleableized, or (2) by heating the iron to a temperature below the critical but above room temperature and holding it at that temperature for a prescribed period of time and then malleableizing without cooling the iron to room temperature, or (3) by heating and holding the iron in a range of temperatures below the critical but above room temperature for a prescribed period of time and then cooling to room temperature, the iron subsequently being malleableized, or (4) by heating and holding the iron in a range of temperatures below the critical but above room temperature for a prescribed period of time and then malleableizing without cooling the iron to room temperature, or (5) by inter-

rupting the cooling of the iron from the casting temperature and holding it at a temperature or in a temperature range below its critical temperature but above room temperature for a prescribed period of time and subsequently malleableizing the iron. The malleableizing procedure after the low temperature pretreatment may be any one of the many which are suitable or which are now employed on the different grades of iron responsive to malleabilization. The low temperature pretreatment does, of course, permit a shortening of the malleabilization period. On the other hand, due to the more active response of the iron to malleabilization, lower maximum malleabilization temperatures may be employed.

An intensive investigation has been conducted to study the effect of preliminary heat treatment of white cast iron, according to my invention, at different temperatures below the critical temperature and for different lengths of time at the same temperature below the critical temperature. The shortening of the malleableizing period obtainable by employing the preliminary heat treatment of my invention and the effect of treating the liquid iron with hydrogen, and with hydrogen-containing materials, such as gases and hydrides according to my invention, constituted other important phases of the problem. Various laboratory prepared and commercially made materials were used. They ranged in composition from the so-called quick-anneal malleable irons and high carbon steels, containing sufficient amounts of graphitizing elements to cause them to malleableize upon annealing, to the so-called standard malleable irons and irons of the higher carbon contents.

The following description of tests on white cast irons of the so-called quick-anneal malleable iron type, illustrates the scope of my invention. This work was done to show the effect of the low temperature treatment on the temper carbon structure of the irons, to determine the effective temperature range and time for the low temperature treatment, to determine the effect of the low temperature treatment on the rate of malleabilization, and to determine the influence of the hydrogen treatment.

The chemical compositions of the irons used were as follows:

Iron No.	Carbon	Silicon	Manganese	Sulfur	Phosphorus
	Percent	Percent	Percent	Percent	Percent
FM 21	2.14	1.55	.32	.07	.109
FM 26	2.13	1.52	.32	.08	.118
FM 19	2.09	1.57	.33	.08	.110
FM 23	2.04	1.46	.25	.08	.118

Irons No. FM 21 and FM 19 were straight melts which had no gas treatment, whereas, irons No. FM 26 and FM 23 had hydrogen bubbled through them for ten minutes before they were poured.

In order to determine what pretreatment temperatures would be most effective, specimens of irons FM 21 and FM 26 were pretreated at the following temperatures, 300°, 600°, 800° and 1100° F. Individual specimens from each of the melts were pretreated for different lengths of time up to eight hours so that some idea could be obtained as to the length of time required to obtain the maximum benefit from the low temperature treatment. Specimens which received the 800° F. and the 1100° F. treatment were held for ½, 1, 1½, 2, 4 and 8 hours, while specimens receiving 300° F. and 600° F. treatment were held for ½, 1,

1½, 4, 6 and 8 hours. In addition, one specimen was heated 14 hours at 200° F. in order to circumscribe the lower temperature limit for the pretreatment. The pretreated specimens and untreated specimens of the same irons were then given a malleabilizing anneal which comprised heating to 1790° F. in 1¾ hours, holding at that temperature for 5¾ hours to complete the first stage of graphitization, cooling to 1450° F. in 1 hour, cooling to 1350° F. in 2 hours, cooling to 1325° F. in 2½ hours and finally cooling to 800° F. in 2½ hours, making a total of 15¼ hours to complete the malleabilization cycle. The microstructures of the irons were then examined to determine the effect of the temperature and time of pretreatment on the temper carbon size. Representative microstructures, at a magnification of 100 diameters, are shown in the accompanying drawings wherein:

Figure 1 is the structure of iron FM 21 after annealing, when the iron has received no pretreatment.

Figure 2 is the structure of iron FM 21 after annealing, when the iron has been pretreated at 600° F. for 8 hours.

Figure 3 is the structure of iron FM 26 after annealing, when the iron has received no pretreatment.

Figure 4 is the structure of iron FM 26 after annealing, when the iron has been pretreated at 600° F. for 8 hours.

Figure 5 shows the structure of iron FM 26 in the as-cast condition, the specimen having received no pretreatment.

Figure 6 shows the structure of iron FM 26 in the as-cast condition but after a pretreatment at 600° F. for 8 hours.

In Figures 1 to 4, inclusive, the more or less equiaxed dark nodules are temper carbon, while the fully white matrix is ferrite, indicating complete malleabilization.

The accompanying table gives the relative sizes of the temper carbon nodules for different holding times at different pretreating temperatures. The temper carbon nodule sizes are expressed as the percent of the size of the temper carbon nodules in the untreated specimens.

ceived no gas treatment, and four-fold, in the case of the hydrogen-treated iron FM 26. Furthermore, the treatment was effective at all temperatures, though the most effective range was from somewhat above 300° F. to somewhat below 800° F. The lower limit of the low temperature treatment scale is somewhat above 200° F., for prolonged heating at 200° F., before malleabilizing, did not produce a noticeable refinement in the temper carbon. There is no limit in the upper range of the scale, since irons pretreated at temperatures up to the lower critical temperature, or about 1325° F. responded to the treatment, but not to the same degree as did the irons pretreated in the range from 400° F. to 700° F.

One half to four hours at the pretreatment temperature is necessary to gain full advantage of the process. Very rapid reductions in the size of the temper carbon occur with increased time of pretreatment over the first two hours, while longer times decrease the size only a small additional amount. The time at low temperature to effect optimum reduction in the size of the temper carbon nodules is dependent on the temperature of pretreatment, the time being more prolonged at 300° F. than at 600° F., for example. The holding of the iron at the pretreatment temperature, or in the range of temperature for pretreatment, may vary from minutes to hours. While longer holding times than 8 hours are permissible, within the scope of my invention, since they have no adverse effects, costs of the pretreatment dictate that it should not be prolonged unnecessarily.

The above described low temperature pretreatment process differentiates from methods which call for heating the metal to and holding it at a temperature sufficient to precipitate some of the carbon relatively slowly to form a large number of relatively small temper carbon nuclei which, on subsequent heating of the metal to a higher temperature to complete the graphitization, serve as centers upon which the remaining carbon precipitates. One differentiation is in the range of temperatures used for the low temperature pretreatment and in the fact that none of

Table

Pretreatment at 1100° F.		Pretreatment at 800° F.		Pretreatment at 600° F.		Pretreatment at 300° F.	
Time in hours	Temper carbon size percent of size of untreated specimen	Time in hours	Temper carbon size percent of size of untreated specimen	Time in hours	Temper carbon size percent of size of untreated specimen	Time in hours	Temper carbon size percent of size of untreated specimen
STRAIGHT MELT—FM 21							
½	74.0	½	54.0	½	65.0	½	83.0
1	74.0	1	57.0	1	64.0	1	65.0
1½	74.0	1½	50.0	1½	60.0	1½	83.0
2	66.0	2	57.0	2	60.0	2	64.0
4	60.0	4	65.0	4	42.0	4	53.0
8	60.0	8	54.0	6	35.0	6	45.0
				8	33.0	8	45.0
HYDROGEN MELT—FM 26							
½	37.0	½	40.0	½	40.0	½	39.0
1	45.0	1		1	35.0	1	54.0
1½	39.0	1½	38.0	1½	60.0	1½	45.0
2	42.0	2	35.0	2	32.0	2	54.0
4	53.0	4	35.0	4	30.0	4	36.0
8	35.0	8	30.0	6	27.0	6	32.0
				8	26.0	8	30.0

The results shown in this table indicate that the pretreatment reduces the temper carbon size as much as three-fold for iron FM 21, which re-

ceived no gas treatment, and four-fold, in the case of the hydrogen-treated iron FM 26. Neither chemical analyses nor microscopical ex-

amination of irons after the low temperature pretreatments, revealed the presence of temper carbon nuclei. The absence of temper carbon after the pretreatment is illustrated in the two microstructures shown in Figures 5 and 6.

Figure 5 shows the structure of iron FM 26 in the as-cast condition. The specimen received no pretreatment. It was etched with picric acid and alcohol and photographed at 100 diameters. Figure 6 also shows the structure of iron FM 26, but after a pretreatment at 600° F. for 8 hours. The specimen was etched and photographed using the same procedure as in Figure 5. No visible difference could be observed in the microstructure of the iron after the low temperature pretreatment.

An important effect of my low temperature pretreatment of white cast iron is to accelerate the decomposition of the cementite, that is, to accelerate the malleabilization rate during the first stage of the annealing operation as well as during the second stage. Studies of decomposition of primary cementite in pretreated and untreated specimens during the first stage of the annealing operation and studies of the effect of cooling pretreated and untreated specimens at different rates through the critical range, second stage of the annealing operation, were conducted in order to determine the magnitude of the effect the pretreatment might have on the malleabilization rate. The results obtained on two irons, FM 19 and FM 23, are illustrative of the extent to which the pretreatment speeds up the malleabilization rate for iron of the quick malleable type. Iron FM 19 received no gas treatment, whereas iron FM 23 was treated with hydrogen while it was molten.

Groups of specimens, consisting of samples which received a low temperature pretreatment at 600° F. for 8 hours, and comparative samples which received no pretreatment, were heated at the same rate to an annealing temperature of 1790° F. At intervals, groups of specimens were taken from the furnace and quenched in water. Groups were removed and quenched after 5, 10, 15, 30, 45, 60, 75, 90, 105 and 120 minute intervals at the annealing temperature. The speed of decomposition of the primary cementite was followed by observing the disappearance of the free cementite in the microstructure. The absence of primary cementite, easily detected under the microscope, indicated complete malleabilization in the first stage of the annealing operation.

In the case of samples of iron FM 19, which was not treated with hydrogen while in the molten state, the malleableizing time for first-stage annealing with and without the low temperature pretreatment at 600° F. for 8 hours, was 10 minutes and 30 minutes, respectively, or a three-fold increase in the malleableizing rate due to the low temperature pretreatment.

An even greater increase in the malleabilization rate was observed for iron FM 23 which received the hydrogen treatment before it was poured. Malleabilization of this iron without the low temperature pretreatment required between 30 and 45 minutes at 1790° F. to complete the first stage of the annealing. After a treatment at 600° F. for 8 hours this iron showed complete malleabilization in the first stage of the annealing in less than 5 minutes, or an increase, due to the low temperature pretreatment, of at least from 6 to 10 times.

It was also observed that the malleabilization

rate for the iron receiving the low temperature pretreatment is independent of the rate at which the iron is heated to the malleableizing temperature for first-stage annealing. This observation is extremely important since the low temperature pretreatment permits heating the iron to the malleableizing temperature in as short a time as possible without in any way affecting the size of the temper carbon particles in the malleableized iron or the malleableizing temperature and makes possible the shortening of the malleableizing cycle owing to the time saved in heating the iron for first-stage annealing.

As mentioned previously, the malleableizing cycle also includes a cooling period, the second stage of annealing, during which the iron is brought below the critical temperature. Cementite in solution in the iron at the malleableizing temperature is decomposed on cooling. However, at the present state of the art of malleabilization, to decompose all cementite so that the final casting is fully malleableized the cooling rate down to and through the critical range must be quite slow. Tests on white cast irons verified the fact that the rate of cooling necessary to complete malleabilization during the second stage of annealing is also profoundly affected by an initial low temperature pretreatment of the irons. This may be illustrated by tests on iron FM 19 and iron FM 23, the same irons used to study malleableizing rates during first-stage annealing. In these tests, groups of specimens receiving a low temperature pretreatment and others that were not treated were annealed to complete malleabilization in the first stage by heating to 1790° F. in ½ hour, holding at 1790° F. for 1 hour, and cooling to 1450° F., a temperature above the lower critical, in 1 hour. The specimens were then cooled at different rates from 1450° F. to 1200° F., the latter temperature being below the lower critical temperature. Cooling rates from 1450° F. to 1200° F. covered the range from 30° F. per hour to that obtained by allowing the specimens to cool in the air. The former rate was sufficiently slow to complete the second stage of annealing for all irons while cooling in air was too rapid for any of the irons to be fully malleableized. Rates of cooling used in the tests were 30, 40, 50, 60, 70, 80, 100, 120, 300, 570 and 900° F. per hour and also cooling in air. The latter exceeded a rate of 900° F. per hour.

The maximum cooling rates from 1450° F. to 1200° F. to completely anneal the irons during the second stage were determined. For iron FM 19, which received no hydrogen or gas treatment in the molten state and which did not receive a low temperature pretreatment before annealing, the maximum cooling rate was 40° F. per hour. This rate was increased to 250° F. per hour for the same iron by giving it the low temperature pretreatment at 600° F. for 8 hours. In the case of iron FM 23, which was treated with hydrogen before casting, the maximum cooling rate without the pretreatment was 35° F. per hour and 700° F. per hour after a low temperature pretreatment at 600° F. for 8 hours.

For iron FM 19, without the hydrogen treatment, the low temperature pretreatment permitted a six-fold increase in the cooling rate through the critical range, before malleabilization during the second stage of annealing was incomplete.

For iron FM 23, treated with hydrogen before casting, the low temperature pretreatment per-

mitted a twenty-fold increase in the cooling rate through the critical range, before malleabilization during the second stage of annealing was incomplete.

While the tests herein reported pertain to irons of the quick malleable type, similar studies on standard malleable irons, on cupola malleable irons, and on other irons having substantially all the carbon in the combined state, and which subsequently are annealed to decompose some or all of the carbide to temper carbon and iron, showed that the low temperature pretreatment reduces the annealing time substantially and effectively refines, after malleabilization, the temper carbon particles. It also overcomes the dependence of the malleabilizing or annealing process upon the rate of heating the iron to the malleabilizing temperature.

The speeding up of the malleabilizing process by utilizing a low temperature treatment is new and novel. Also, the effect of hydrogen bubbled through the melt upon the response to subsequent graphitizing treatments has not been reported. Some investigators* of malleable iron have recently claimed that "hydrogen from any source very greatly retards the graphitizing reaction" and that "hydrogen does not seem to affect the nodule number of the resulting malleable cast iron."

* For example, see H. A. Schwartz, G. M. Guiler and M. K. Barnett, "The significance of hydrogen in the metallurgy of malleable cast iron," Trans. Amer. Soc. for Metals, 1940—Paper presented at the Cleveland meeting, October 21 to 25th.

My disclosures above, although in opposition to the views held by some authorities, constitute an important development in the malleable iron and kindred fields. To illustrate their importance a few advantages may be cited as follows:

1. The process involving low temperature pretreatments can be used to treat irons of both the quick annealing and standard malleable compositions as now employed in industry and:

a. Decrease the time of heating to maximum temperature and time of holding at the maximum temperature, increase the rate of cooling or decrease the holding time for the second-stage annealing and, also, increase the rate of cooling between first and second-stage annealing and yet obtain complete malleabilization. These advantages lead directly to substantial savings in fuel cost and permit increased tonnages to be obtained from a given annealing plant installation.

b. Produce microstructures in the castings that are highly desirable and which result in superior mechanical properties. (See Figures 1 to 4, inclusive, for a comparison of temper carbon nodule size in treated and untreated irons.)

c. Lower the maximum annealing temperature and thus prevent excessive warping and scaling of both the castings and of furnace parts.

2. The process can be used, employing present time-temperature annealing cycles, to decrease graphitizing elements in the melt and thus avoid primary graphitization during the solidification of the castings. Malleable irons are made with just as high silicon content as can be used without producing flake graphite (even a very small amount of flake graphite makes the castings worthless) in order that the irons will not be too sluggish in their response to the subsequent malleabilizing treatment. The low temperature pretreatments of an iron with lower silicon content than ordinarily used causes it to malleabilize

at a rate equal to untreated irons containing higher percentages of graphitizing elements.

3. The process can be employed with irons containing lower percentages of graphitizing agents to cast larger section sizes than can be successfully made at present and yet fully graphitize the castings under conventional malleabilizing cycles. Castings of large section sizes naturally cool slowly in the center and, with normal percentages of graphitizing agents, flake graphite forms during solidification. Lower silicon content, for example, eliminates this tendency but, ordinarily, the irons would not respond to malleabilization. Also, it has been shown by many investigators that the coarse iron carbide structure in the center of large sections, which do freeze completely white, graphitizes very slowly, as compared with finer structures near the surfaces or those existing throughout a thin section. The pretreatment counteracts this sluggishness through the formation of more numerous temper carbon nodules and, hence, brings larger section sizes into the malleable iron field.

From the above description, it will be understood that I have provided a novel process of malleableizing cast iron and which results in a product having superior and unique properties. Many advantages of the process and the resulting product have been discussed above and others will be readily apparent.

Having thus described my invention, what I claim is:

1. The method of malleableizing cast iron having substantially all the carbon in the combined state which comprises bubbling a hydrogen-containing gas through the iron while it is in a molten state, casting the iron, subjecting the cast iron to a temperature above 200° F. but below the lower critical temperature for a period sufficient to effect a refinement in carbon dispersion upon subsequent malleabilization and then subjecting the casting to a malleableizing heat treatment.

2. The method of preparing ferrous articles for subsequent malleabilization which comprises bubbling a hydrogen-containing gas through the molten metal, casting the metal, and subjecting the cast metal to a temperature above 200° F. but below the lower critical temperature for a period of time sufficient to effect a refinement in carbon dispersion upon subsequent malleabilization.

3. The method of malleableizing cast iron having substantially all the carbon in the combined state which comprises bubbling a hydrogen-containing gas through the iron while it is in a molten state, casting the iron, subjecting the cast iron to a temperature of from 400 to 700° F. for a period sufficient to effect a refinement in carbon dispersion upon subsequent malleabilization, and then subjecting the casting to a malleableizing heat treatment.

4. The method of malleableizing cast iron having substantially all the carbon in the combined state which comprises contacting the molten metal throughout with hydrogen and casting the metal, subjecting the cast iron to a temperature above 200° F. but below the lower critical temperature for a period sufficient to effect a refinement in carbon dispersion upon subsequent malleabilization, and then subjecting the casting to a malleableizing heat treatment.

CLARENCE H. LORIG.