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1,941,671

DUCTILE CAST IRON AND METHOD OF MAKING THE SAME

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Fig. 1

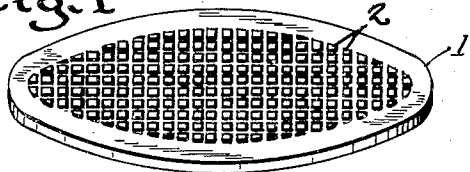


Fig. 2

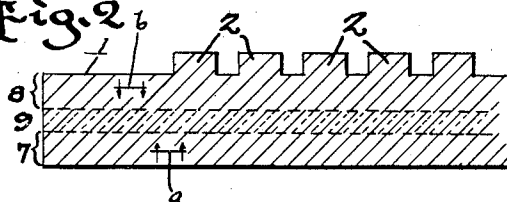


Fig. 3

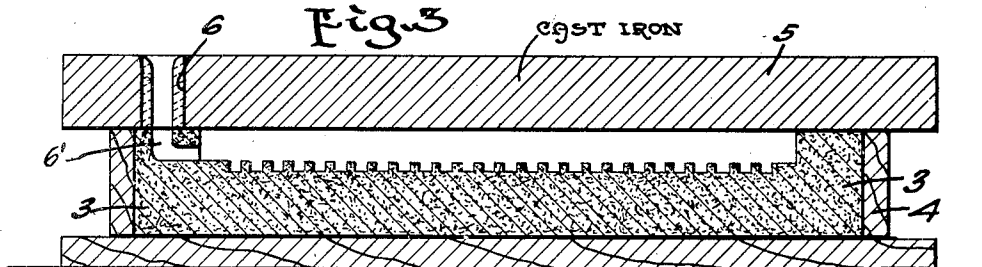


Fig. 4



Fig. 5

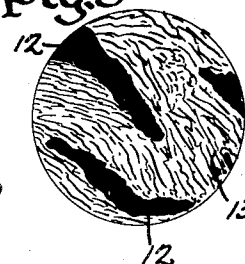


Fig. 7

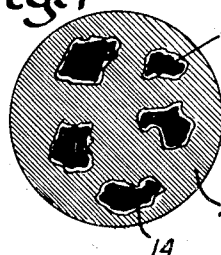


Fig. 9

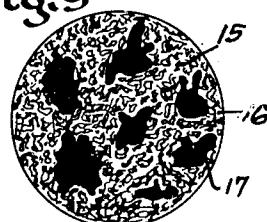


Fig. 6

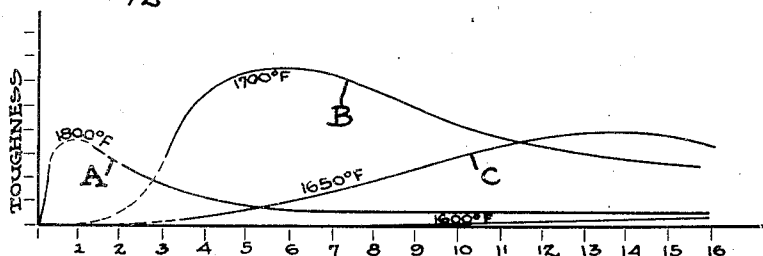
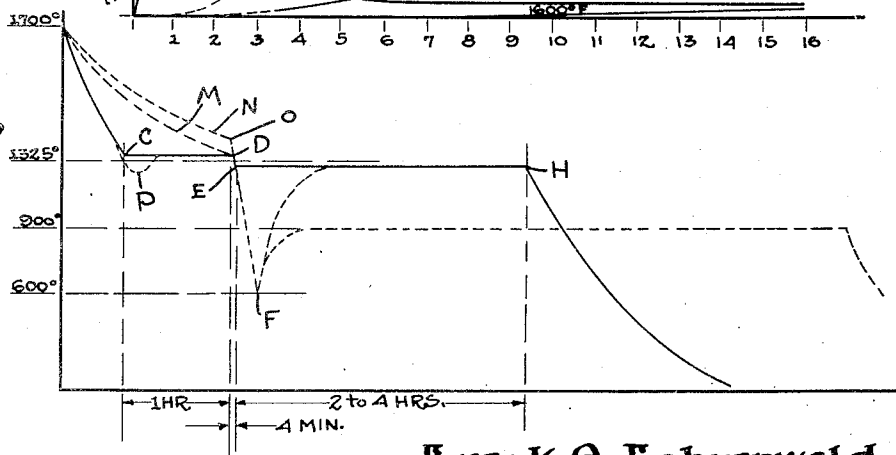


Fig. 8



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DUCTILE CAST IRON AND METHOD OF MAKING THE SAME

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4 Claims. (Cl. 148—21.7)

This invention relates to cast iron articles, regardless of weight or size but more especially to those articles which are of large size, and it has for its objects the provision of increased strength without increase of weight or substantial increase in cost; the provision of cast iron articles retaining the same chemical composition and the same foundry practice as at present but with increased qualities of toughness and with the ability to withstand deformation of shape without breaking; the provision of a composite cast iron article made in a single piece and having malleable and non-malleable portions, the non-malleable portions being capable of being machined; while further objects and advantages of the invention will become apparent as the description proceeds.

An example of the utility of my invention is presented in connection with manhole covers such as are employed for street or pavement use. The large size of such devices necessitated by the constantly increasing bulk of the articles required to be handled through the openings, combines with the constantly increasing weight and speed of traffic to demand a degree of strength in the cover which can be obtained in cast iron only with difficulty, and in any event at the expense of such weight as renders the device extremely difficult to handle. Ordinary malleable cast iron is scarcely suitable for the purpose owing to its deficiency in tensile strength even if it were available on a cost basis; and the softness of malleable iron would cause the original roughness thereof to become obliterated with the production of an excessively smooth plate on which animals and vehicles would slip.

In the drawing accompanying and forming a part of this application I have shown for purposes of illustration the application of my invention to the production of a manhole cover, though without intent to limit myself thereto. Fig. 1 is a perspective view of the completed article; Fig. 2 is a partial sectional view; Fig. 3 is a sectional view through the mold ready for the reception of the molten metal; Fig. 4 is a characteristic photomicrograph at the point *a* of the resulting casting Fig. 2; Fig. 5 is a characteristic photomicrograph at the point *b* of such casting Fig. 2; Fig. 6 is a time-temperature diagram of the first heat treatment; Fig. 7 is a characteristic photomicrograph at the point *a* of the same casting after the first heat treatment; Fig. 8 is a time-temperature diagram of the second heat treatment; and Fig. 9 is a characteristic photomicrograph at the point *a* after

the second heat treatment. The magnification illustrated in the drawing is approximately 400 diameters, but it will be understood that the drawing is somewhat idealized owing to the difficulty of copying with photographic accuracy.

In the production of my improved cast iron articles I employ what I term an "unstable iron-mixture", namely one which will cast gray in a sand mold but white under chilling conditions. Examples of such mixtures are as follows:

	A	B	C
Carbon.....	3.25 to 3.50%	2.75 to 3.10%	2.50 to 2.75%
Silicon.....	.60 to .90%	1.25 to .90%	1.30 to 1.00%
Iron.....	{Balance	{Balance	{Balance
Phosphorus.....	.60 to 0	.60 to 0	.60 to 0
Sulphur.....	.20 to 0	.20 to 0	.20 to 0
Manganese.....	1.00 to 0	1.00 to 0	1.00 to 0

I prefer mixture B, although the others can be used. All of them will cast gray throughout in a sand mold and white to a considerable depth when chilled. I cast this mixture according to usual foundry practice but in a mold made partly of sand or other non-chilling material and partly of metal, (although in some cases it is possible to make the mold all of metal) so that the resulting casting shows the characteristic condition of chilled white-iron in those parts which are adjacent to the metal portion of the mold, and gray-iron in those parts (if any) which harden in contact with sand. For example, if it be desired to make a flat, circular manhole cover 1 as shown in Fig. 1, having studs 2 on top, I form from sand 3 that part of the mold which defines the studs 2, as for example, the portion 4 of the flask which is known as the "drag", and employing in lieu of the usual cope a massive block 5 of suitable metal such as ordinary cast iron. And the pouring can be effected in any suitable manner, the method here employed consisting of forming the metal block 5 with a refractory lined pouring hole 6 registering with the sprue 6' formed in the sand 3 of the drag 4. Many modifications of this arrangement are possible but it is always desirable to retain the advantage of allowing the cast iron to flow readily all over the mold cavity without undue loss of heat and consequently of fluidity, and of coming into contact with the metal 5 and hence undergoing chilling only when the mold has become completely filled. The mold may be positioned in any manner desirable for the casting operation.

It is well known among foundry men that by

slightly changing the relative proportions of the carbon and silicon, any desired depth of chill can be obtained, and my preference is, with a casting of the character described, to chill it approximately one-half way through, as shown at 7 in Fig. 2, the remainder of the thickness consisting of gray-iron, and indicated at 8 in Fig. 2, except for a narrow transition band or layer at 9 which shows an intermediate or mottled condition.

Metallurgically speaking the conditions exhibited by the portions 7 and 8 are as follows: any microscopic section of the portion 7 should exhibit no "primary graphite" but all the carbon should occur in the form of rounded masses 10 (Fig. 4) consisting of iron carbide (known as "cementite") submerged in and embraced by a continuous metal phase 11 having substantially the characteristics of an excessively high carbon character rendered excessively brittle by the sudden quenching from a melting temperature caused by contact with the metal chiller 5. Any microscopic section of the portion 8 should exhibit little or no primary cementite but instead a very large amount of "primary graphite" in the form of thin flakes or scales 12 (Fig. 5) so closely packed as almost to interrupt the metal phase, and so large ordinarily as almost to be visible to the naked eye. These graphite scales or flakes or plates are surrounded and embraced by a continuous metal phase 13 consisting substantially of annealed steel and generally exhibiting a distinct pearlitic structure as attempted to be shown in Fig. 5, which consists of alternating minute layers of secondary cementite and of pure iron known as ferrite. By the term "primary" I refer to a formation produced in the first cooling of the molten metal. By the term "secondary" I refer to a formation produced from a change in a primary constituent. Ordinarily the portion 8 will be entirely free from cementite excepting that which is contained in these minute layers; and the reason for the difference between the two portions of the casting arises solely from the difference in the cooling rates which in the portions adjacent to the sand affords sufficient time for the cementite to become broken down with the liberation of graphite and ferrite, and the metallic phase to arrange itself in layers as shown in Fig. 5, while in the portions adjacent to the chiller the cementite has no time to break down nor does the metal phase have an opportunity to become segregated into layers.

If such a composite casting as I have just described were allowed to cool to room temperature it would probably break into pieces (and perhaps explosively after it fell somewhere below about 600° Fahrenheit); but instead of allowing it to cool in this manner I preferably transfer it immediately to a furnace where it is maintained at some temperature between 1650° Fahrenheit and 1850° Fahrenheit for a sufficient length of time to decompose the primary cementite portions. This decomposition is a function of the temperature and the time, the curves of Fig. 6 showing the approximate relation of toughness to time obtainable with the different temperatures indicated, the composition being the same in each instance. Owing to the essentially unstable character of the chilled iron, which has retained its carbon in the combined form only because of the rapidity of its solidification, this decomposition occurs very readily and its rapidity is remarkably influenced by the temperature. Thus in certain

tests I have made at a temperature of 1800° Fahrenheit the decomposition of the cementite was found to be complete in less than one hour; at 1700° Fahrenheit it was practically completed after eight hours; at a temperature of 1650° Fahrenheit it was well begun after eight hours; and at 1600° Fahrenheit was scarcely noticeable in eight hours. The result of this treatment is indicated in Fig. 7, each of the primary cementite grains being replaced more or less completely by a nodule 14 of pure graphite which occupies the same position and exhibits very much the same outline. This decomposition appears to start inside each cementite grain and progresses toward its exterior and so far as I have been able to determine the composition of the matrix or metallic phase 11* between and around those grains remains unchanged until after the massive cementite has been decomposed; except that due to the fact that the temperature is above the critical (1325° F.), this continuous phase during the heat treatment consists of austenite (carbon dissolved in iron) with a carbon content characteristic of the temperature employed. If the heat be continued over long, the strength was found to fall off very remarkably as shown in Fig. 6. The maximum strength obtainable at a temperature of 1800° Fahrenheit is developed at considerably less than one hour, and owing to the rapidity of the reaction and the corresponding rapidity of the subsequent decline in strength I have been unable to measure the same accurately. At 1700° Fahrenheit, the maximum strength appears to be developed in about four hours and to fall off appreciably after about six or seven hours. I have not determined the maximum strength obtainable at the lower temperatures or the time required, since it is smaller in amount than is obtainable at 1700° and the longer treatment would be uneconomical. The curves shown in Fig. 6 are illustrative rather than exact since different compositions show diverse values though all behave in this general manner.

The theory whereby I account for this loss of strength is largely that the comparatively great masses of graphite produced by the decomposition of these large cementite grains exercise a pronounced effect upon the surrounding matrix metal, either carbonizing or decarbonizing the same with great rapidity, depending upon the subsequent treatment employed. I preferably arrest this first heat treatment at about the period of maximum strength at which time it will be found that the matrix metal is little, if any, altered. It should be noted that the heat treatment so far described has had practically no effect on the gray-iron portion 8 of the casting and comparatively little effect on the mottled portion 9 since the scattered grains of white-iron occurring therein are generally less susceptible to decomposition than the more massive cementite closer to the chilled face.

If this casting be now cooled gradually to room temperature it will be found notably superior in strength to ordinary gray cast iron, the lower layer being tough and tenacious and better fitted to bear the strains of use, the top or wearing portion retaining the characteristic wearing qualities of the gray-iron. The cooling rate which I designate by the term "gradually" is any rate which shall avoid quench-hardness of the matrix metal 15, since the austenite at 1700° or thereabout, and in the presence of so much available graphite, will become so saturated with carbon that sudden cooling will render it brittle. To prevent this

a very slow cooling could be employed and the resulting article, consisting as it would of a hard and wear resisting gray-iron top layer in combination with a tough and shock-resisting bottom layer integral therewith would have (as it actually has) unique advantages; for no kind of heat treatment will have much effect on the gray-iron portion although the treatment hereafter described does in fact improve it to some extent.

Such a slow cooling could be obtained by gradually decreasing the temperature of the furnace or by piling the articles in thermally insulated pits, or such procedures as are employed by the makers of malleable iron after the termination of the heating stage. These procedures will improve the product of my invention whatever may be the effect with malleable iron; for malleable castings are originally made of hard white-iron cast in molds, that is to say, of "stable" white-iron, and the temperatures and times exhibited in Fig. 6 are scarcely sufficient to produce any visible decomposition, while the amount of heating necessary to decompose the stable carbide produces also a decomposition of the matrix metal so that the result of this long continued heating, coupled with the long continued cooling produces a matrix of almost pure ferrite. But the unstable iron after subjection to the short heat treatment I have described still exhibits a matrix metal of true austenitic composition the same as in the portion 8, but differing from the portion 8 in that whereas in the latter the graphite scales are very tiny and thin and so closely adjacent as to leave very little metal between, in the former they are fewer, larger, more rounded and further spaced so as to present a much less interrupted phase.

This austenite has the following properties; it can normally exist only at temperatures above about 1325° Fahrenheit (known as the critical temperature), since iron does not normally hold carbon in solution but above that temperature it exhibits a dissolving power for carbon which varies directly with the temperature; and austenite when mixed with graphite as in these instances tends always toward a condition of carbon equilibrium characteristic of the temperature.

The amount of carbon characteristic of saturated austenite at and immediately above this critical point is approximately .85 percent and is known as the "eutectoid composition", and the material as "eutectic steel". If allowed to cool slowly through the critical range the resulting mass exhibits microscopically the fine layered arrangement shown at 13 in Fig. 5, the same comprising innumerable plates or scales of secondary cementite interspersed with and embraced by a continuous phase of ferrite. This is the characteristic condition of eutectoid pearlite steel. If reheated above the critical temperature the ferrite and cementite portions merge together again forming austenite, if suddenly quenched from this austenite condition so as to prevent this segregation into layers a condition of great hardness is produced known as troostite, martensite, etc. and illustrated at 11 in Fig. 4. If austenite at a higher temperature than the critical, and saturated with carbon at such higher temperature, be suddenly quenched before it has an opportunity to eject any of this carbon, a still higher degree of hardness and brittleness is produced. Hence, if a casting after the heat treatment I have described be cooled with undue quickness the austenite, which has become saturated with carbon at whatever temperature was employed

for such heat treatment, say 1700° Fahrenheit, will be converted into a steel of very great hardness and so brittle as to be deficient in shock-resisting ability, but if cooled more gradually much of this excess carbon will be ejected and presumably absorbed by the graphite nodules until the critical temperature is reached, after which the pearlitic structure will be assumed by the remaining ingredients. This condition is very readily produced by removing these articles from the furnace and stacking them in vertical cylindrical pits formed in a bank of silicocel, kieselguhr, magnesium or even sand, where they are left for one or two days. It should be noted that these considerations relative to the composition, heat treatment and microphysical structure of the continuous phase apply theoretically to the gray-iron portion 8 as well as to the modified white-iron portion 7, but practically the interruption of the continuous phase by the graphite plates or grains is so nearly complete that the modification of strength possible to be achieved in the gray-iron portion is very small as compared with that obtainable in the portion 7 wherein the continuous phase is much less interrupted.

The nodular arrangement of the graphite characteristic of the first heat treatment I have described renders it possible however by an elaboration of this second heat treatment to enhance even further the strength of the resulting article. This, in its preformed form, comprises the successive temperature-time relationships graphically represented in Fig. 8. The article having been removed from the furnace where it was first heat-treated, for example at a temperature of 1700° Fahrenheit, is allowed to cool to the point C which is preferably immediately above the critical temperature, for example, 1350° Fahrenheit, (or even nearer if the apparatus employed be susceptible of such close control). It is kept at this temperature for such length of time as to enable the carbon content to become normal for that temperature, whereupon the articles are quenched quickly through the critical temperature as shown at D—E. The best mode of effecting this is by immersing the same briefly in a bath of molten metal, for example lead, which may be at any temperature above its melting point since it is permissible to cool the article even as low as 600° Fahrenheit as indicated by the point F though I do not recommend the practice. Cold air jets or oil or water spray can also be used for this quenching, though the metal bath is preferable. This produces an extremely hard and somewhat brittle condition, to alleviate which the article is immediately introduced into a succeeding chamber where it is maintained for a suitable length of time at a temperature indicated by the horizontal line E—H, which is always less than the critical temperature, but preferably not very much less, although it may fall as low as 900° to 1000° Fahrenheit if the time of treatment be sufficiently prolonged. The result of this treatment is to allow the cementite, which excepting for the quickness of the quenching would produce the layer-like arrangement characteristic of pearlite, to become segregated from the matrix metal, which it does, not in the form of sharp edged plates characteristic of pearlite, but of tiny rounded masses or globules 15 (Fig. 9) embraced by a continuous phase 16 of ferrite; and due to the greater continuity of this material and its essential toughness, the resultant article, after being cooled to atmospheric

temperature, exhibits a degree of strength and toughness heretofore characteristic only of tempered steel, although a steel impregnated with rounded masses 17 of secondary graphite.

5 The times and temperatures employed are susceptible of considerable variation. I have found a suitable and very satisfactory condition for the treatment indicated at C—D to be a furnace chamber maintained at 1350° Fahrenheit for one hour; the quenching D—E for four minutes in a lead bath at 800° Fahrenheit, and the treatment E—H (or F—H) to be for two to four hours at a temperature of 1300° Fahrenheit, (or for ten hours at 900° Fahrenheit). However, it is entirely permissible to omit the first chamber and cool the article gradually along the curve M, quenching as soon as the critical temperature is approached, or to cool along some other curve as shown at N to a temperature indicated at O, which is higher than the critical, and quench from that point, the only difficulty being that the metal phase then contains a somewhat higher percentage of carbon necessary to be agglomerated. This first chamber when used can also be kept at any temperature up to about 1450° or even 1500° Fahrenheit although the higher temperatures are less desirable because of the increased amount of carbon to be subsequently disposed of. An important advantage of using the first chamber, however, is that it overcomes any disadvantage due to the accidental cooling of the article under the critical point as shown at P. In fact the article can be cooled clear to room-temperature, and subsequently treated by this last refinement of my general process, since any elevation of the temperature above the critical will produce the austenitic condition, and it is imperative that the line E—H must never cross the 1325° Fahrenheit line else a new quenching will become necessary.

Theoretically this heat treatment last described has also strengthened the continuous phase or matrix metal of the portion 8 in the same way as that of the portion 7, but practically its advantageous effect is comparatively small, due to the extent to which that phase is interrupted by the graphite flakes, so that its practical effect is largely confined to the matrix metal of the portion 7.

I have described my improvement with especial reference to manhole covers, since these are simple in shape, exacting in their requirements, and manufactured in very large volume; but my invention is not by any means so limited. It may be applied to the manufacture of grate bars for locomotives and other furnaces; stoking and other fuel burning devices; catch basins and drain gratings; boiler and furnace parts for domestic heat systems; radiators and refrigerating devices; machine bases and parts; wheels and pulleys and even to small articles which can be cast entirely in metal molds. As applied to large devices it is advantageous in enabling the use of molds made partly of sand and partly of metal, since it is only seldom that a device of substantial size can be cast successfully in an all-metal mold. In all sizes of devices my process excels in the rapidity of treatment and in the fact that no containers or boxes are necessary. The result of my improved heat treatment applied to a casting which is partly chilled and partly gray is the production of an ultimate article which is partly toughened and partly unchanged, free from liability to breakage, and

susceptible of ready machining in all its parts, since the toughened portions are essentially steel having graphite inclusions and can be readily worked. As applied to small-sized articles, which can be made in all-metal molds, my invention is superior to the process known as malleableizing in that the cost and deterioration of expensive containers is no longer necessary and the strength of the resulting product is enhanced due to the peculiar after-treatment which I have described. It will therefore be understood that I do not limit myself in respect of products, weights, sizes, shapes, temperatures, or modes of treatment excepting as specifically recited in my several claims, which I desire may be construed broadly each independently of limitations contained in other claims.

I claim:

1. The process of producing a metal article of integral section which consists in casting an unstable mixture of from 2.50% to 3.50% carbon, 1.30% to .60% silicon, and iron under chilling and non-chilling conditions, heating the article to a temperature between 1600° and 1850° Fahrenheit to produce in the chilled part of the article a brittle composition containing nodular graphite, quickly quenching the article through the critical temperature to retain the graphite structure in the brittle composition, heating the article to a temperature below the critical temperature to reduce the brittleness of the chilled part of the article and render this part tough, and in then cooling the article to atmospheric temperature, the heating, quenching and cooling of said article not materially affecting the unchilled part thereof.

2. The process of producing a metal article of integral section which consists in casting an unstable mixture of from 2.50% to 3.50% carbon, 1.30% to .60% silicon, and iron under chilling and non-chilling conditions, heating the article to a temperature between 1600° and 1850° Fahrenheit for a period of from fifteen minutes to eight hours, then quickly quenching the article through the critical temperature, and subsequently reheating the article to a temperature below the critical temperature for a period of from two to four hours and then cooling the article to atmospheric temperature.

3. The process of producing a metal article of integral section which consists in casting an unstable mixture of from 2.50% to 3.50% carbon, 1.30% to .60% silicon, and iron under chilling and non-chilling conditions, subjecting the article to a temperature between 1600° and 1850° Fahrenheit, cooling it to a temperature above the critical temperature, maintaining the article at this temperature for such length of time as to enable the carbon content of the chilled part to become normal for that temperature, quickly quenching the article through the critical temperature to a temperature immediately below said critical temperature, maintaining the article at a temperature between 600° Fahrenheit and the critical temperature to segregate graphite in nodular form embraced in a continuous phase of ferrite in the chilled part, and in then cooling the article to atmospheric temperature, the heating, quenching, and cooling of such article not materially affecting the unchilled part thereof.

4. The process of producing a metal article of integral section which consists in casting an unstable mixture of from 2.50% to 3.50% carbon, 1.30% to .60% silicon, and iron under chilling

and non-chilling conditions, subjecting the article to a temperature between 1600° and 1850° Fahrenheit, cooling the article to a temperature immediately above the critical temperature, maintaining the article at this temperature for about one hour, quenching the article through the critical temperature for a period of about four minutes to a temperature immediately below the critical temperature, maintaining the article at a temperature between 600° Fahrenheit and the critical temperature for a period of from two to four hours, and in then cooling the article to atmospheric temperature, the heating, quenching, and cooling of the article not materially affecting the unchilled part thereof.

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10	85
15	90
20	95
25	100
30	105
35	110
40	115
45	120
50	125
55	130
60	135
65	140
70	145
75	150