CASTING STEEL INGOTS

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FIG. 1.

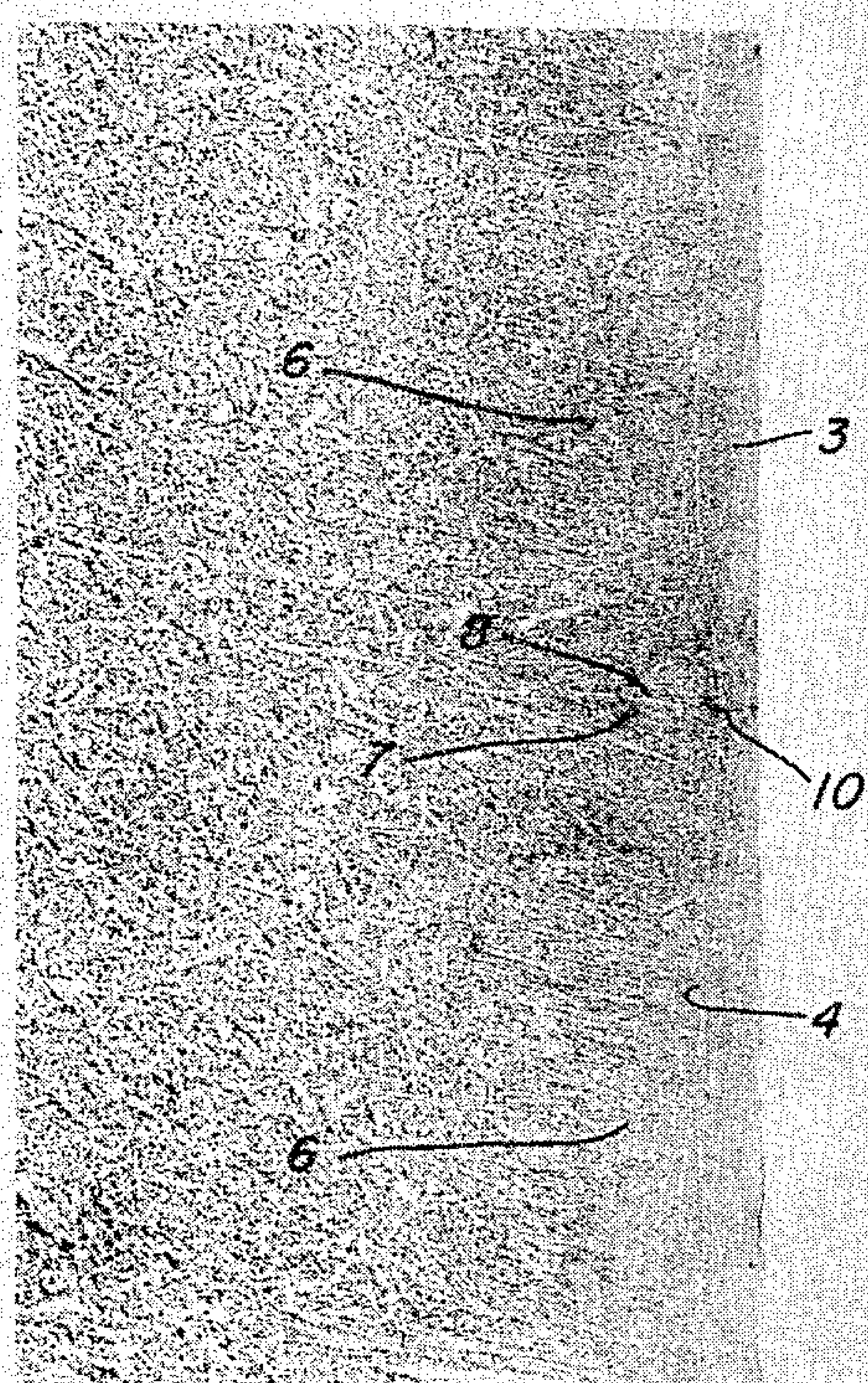


FIG. 2.

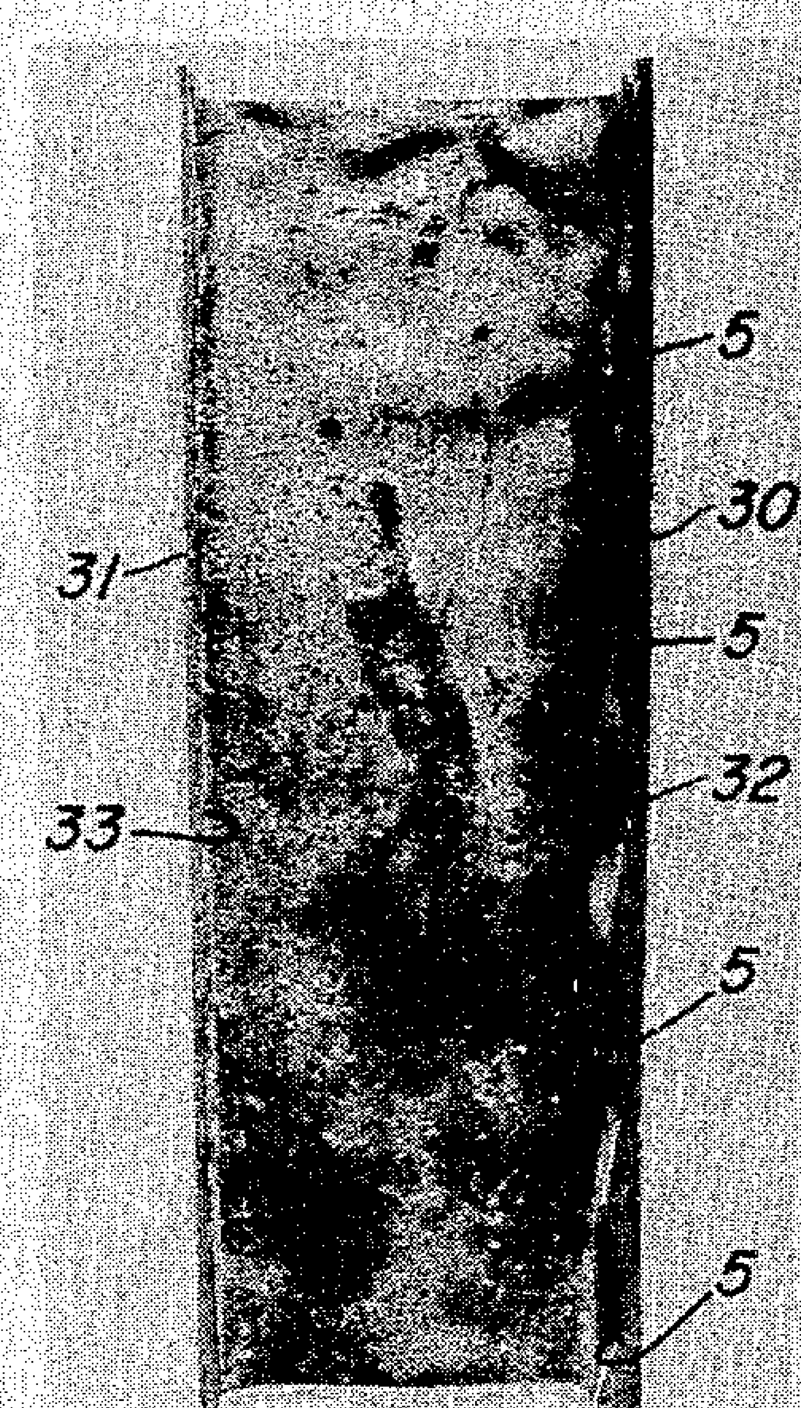
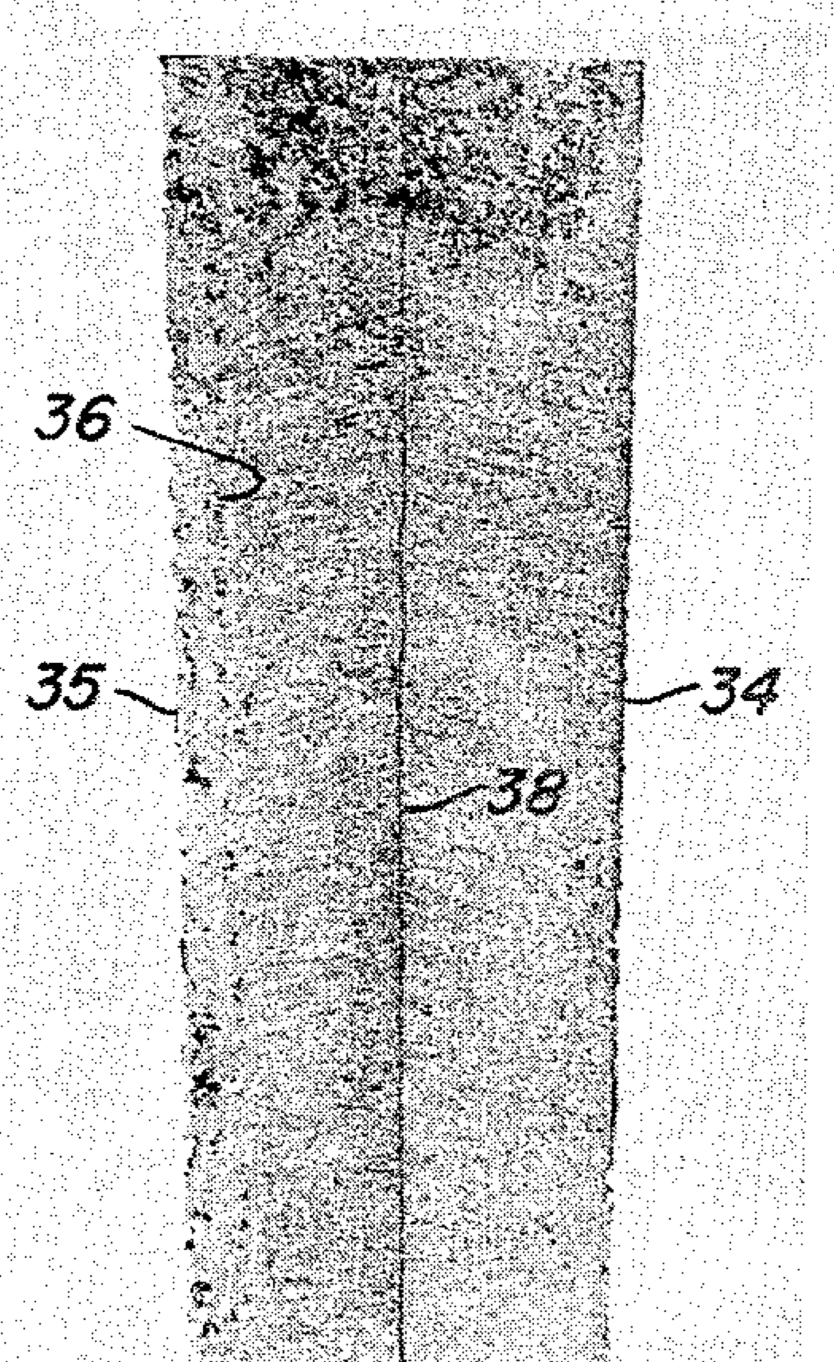


FIG. 3.



INVENTORS:
NORBERT R. ARANT and
MICHAEL A. OREHOSKI,
BY: Donald G. Dalton
their Attorney.

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FIG. 4.

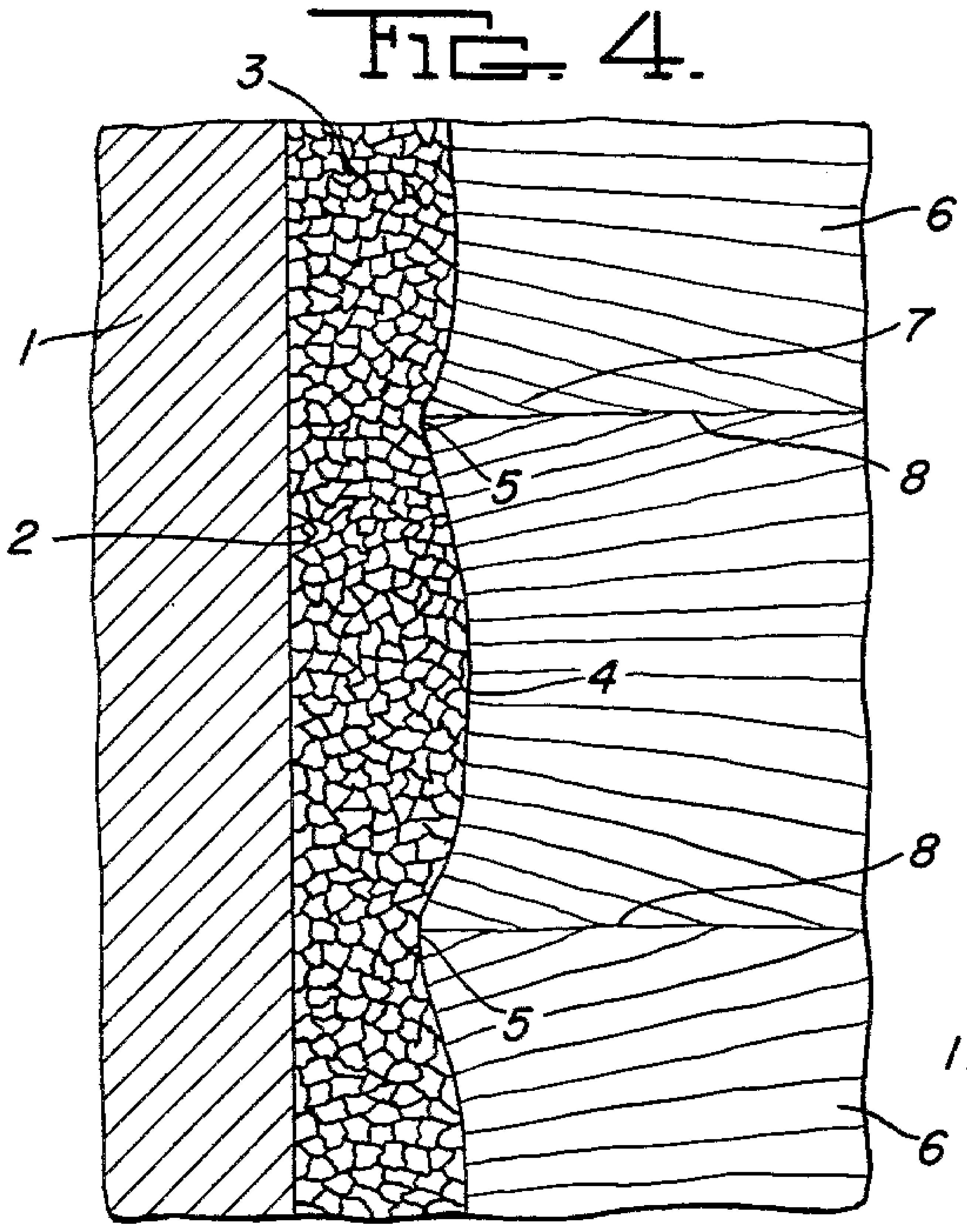


FIG. 5.

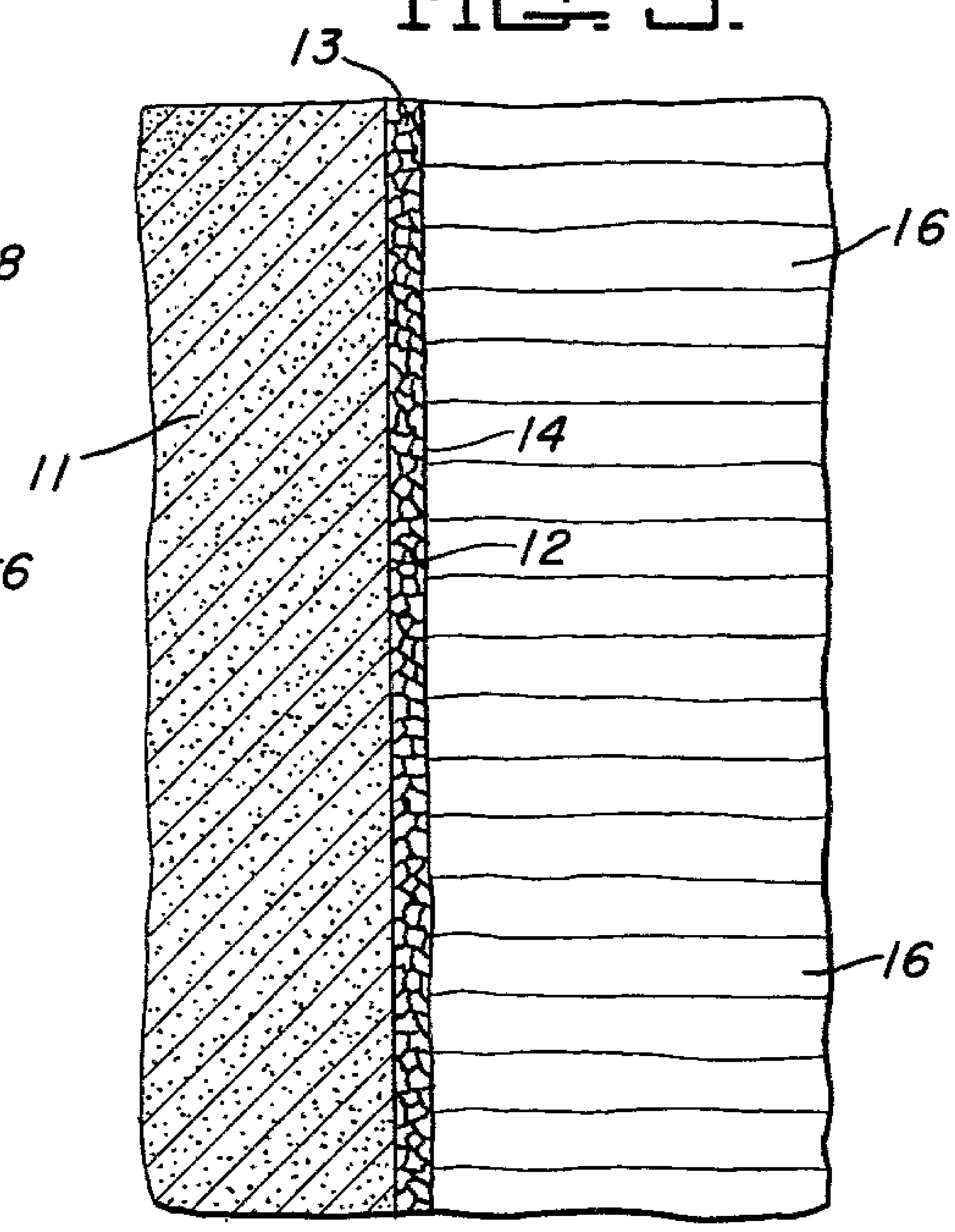
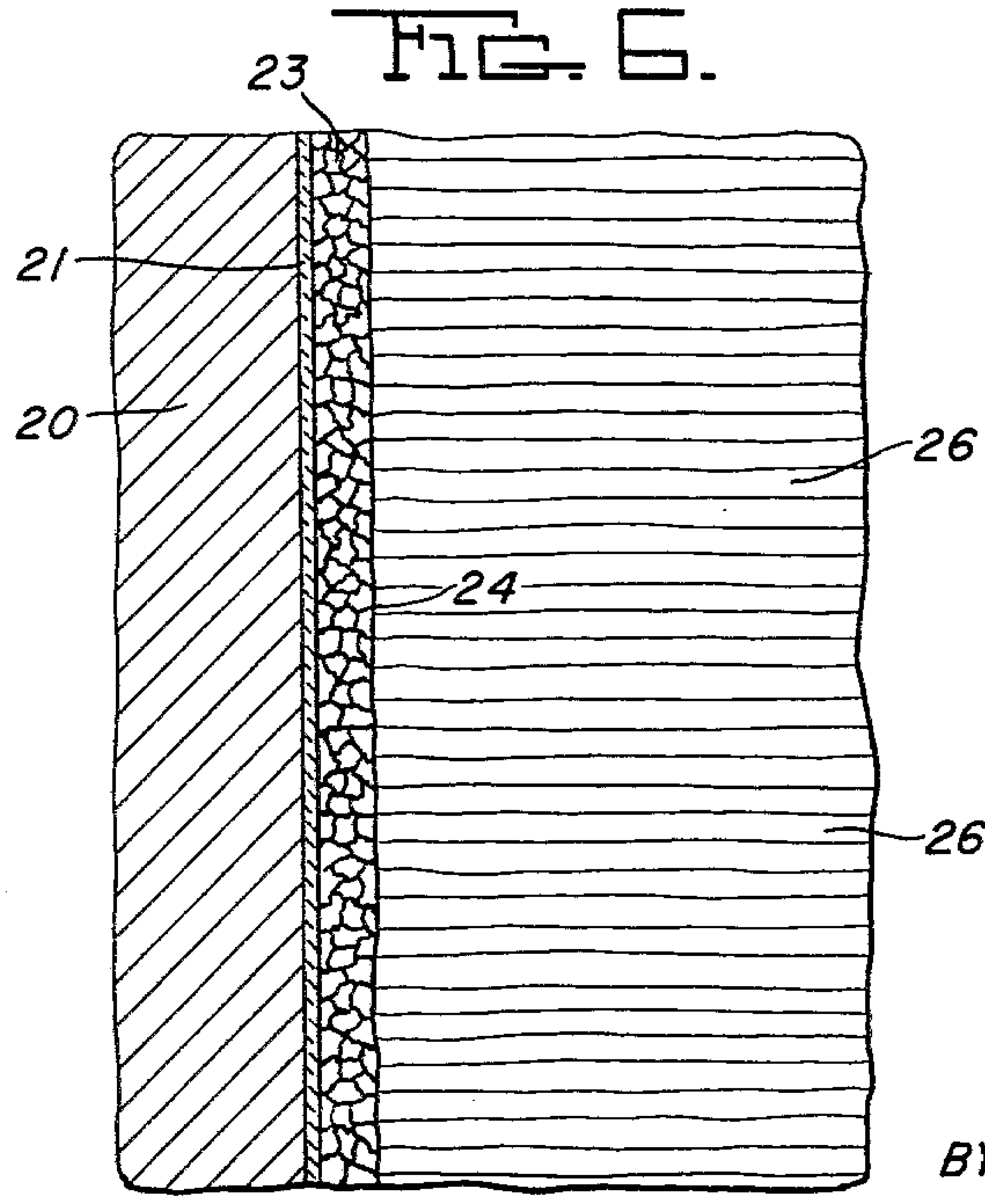


FIG. 6.



INVENTORS:
NORBERT R. ARANT and
MICHAEL A. OREHOSKI,
BY: Donald G. Dalton
their Attorney.

United States Patent Office

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CASTING STEEL INGOTS

Norbert R. Arant, Pittsburgh, and Michael A. Orehoski, Duquesne, Pa., assignors to United States Steel Corporation, a corporation of New Jersey

Filed Mar. 24, 1959, Ser. No. 801,667
16 Claims. (Cl. 29—187)

This application is a continuation-in-part of our copending application, Serial No. 463,362, filed October 20, 1954, now abandoned.

This invention relates to cast-steel ingots that have a solid cross section and are to be worked to a smaller cross sectional size by forging or rolling. It is directed generally to the problem of obtaining an improved ingot skin structure and, more particularly, pertains to an ingot casting process that effects a reduction of both cracks and peripheral inclusions of nonmetallic materials as well as other surface defects in a cast-steel ingot. The improvements of the invention are obtained by controlling the initial freezing of molten steel teemed into a mold through the appliction to the internal mold surfaces of a thin layer of high thermal insulating material in a manner to be described.

Ingot surface defects such as cracks, peripheral nonmetallic inclusions, folds, laps, scabs, double seams and the like, are a serious problem in the steel industry and require expensive scarfing operations to condition slabs, blooms or billets for subsequent rolling or forging. Surface cracks and peripheral inclusions are particularly troublesome, especially in killed and semi-killed steels, since they may not be visible during inspection for removal by scarfing, and may thus first appear as defects in the rolled or forged product. While conventional practices require careful regulation of the ingot teeming operation in order to maintain such defects at a minimum, steps taken to reduce one type of defect frequently result in an increase of others. The improved ingot skin structure and the casting process of this invention involve a radical departure from accepted theory and ingot casting principles and may be best explained by reference first to conventional ingot casting practices as a basis for comparison.

According to conventional practice, steel ingots for rolling or forging purposes are cast in different sizes and shapes by teeming molten steel into cast-iron or cast-steel molds which may have smooth or corrugated walls of a thickness usually between four and six inches depending on the size of the ingot being cast. Molds of cast-iron or cast-steel are universally used since the resulting ingots have the well known columnar structure that is particularly suited for working by forging or rolling. Such ingots have a skin of dense randomly oriented equiaxed crystals which is formed by the chilling action of the mold sidewalls on the molten metal as it rises in the mold. The molten metal freezes at a rapid rate as long as it has contact with the mold walls, but in a short period of time thermal expansion of the mold and contraction of the ingot skin cause the ingot to pull away from the mold and a gap forms between the ingot shell and the mold walls. This gap together with the increased temperature of the mold reduces the rate at which heat is transferred from the ingot metal through the mold walls, thereby decreasing the rate of growth of the ingot skin, which at this point must have sufficient thickness and strength to enable it to withstand the ferrostatic head of molten metal within the ingot without rupturing. Subsequent freezing of the ingot metal continues at a slower rate with the formation of larger crystals, dendrites, which grow inwardly normal to the internal surface of the ingot skin. The thickness of the ingot skin is determined in part by the rate and temperature at which molten steel

is teemed into the mold. In this respect slow teeming rates and low metal temperatures produce a thick ingot skin while faster teeming and higher temperatures decrease its thickness.

The incidence of surface cracks in steel ingots that are cast conventionally in uninsulated iron molds is usually regarded according to conventional theory as varying inversely with the thickness of the ingot skin. To obtain a thick ingot skin and thereby a minimum of ingot cracks, conventional casting procedures, stated as a general rule, are directed to practices that promote the transfer of heat through the mold walls. For example, fluted or corrugated mold walls are frequently used to increase the inner mold wall area and thus promote faster freezing and a thicker ingot skin. Since the corollary of this rule requires the avoidance of anything that decreases the transfer of heat through the mold walls and thus the rate at which the ingot metal freezes, it will be understood for purposes of definition that the term "conventional" as applied herein to both casting practices and steel ingots means the casting of steel ingots in an "uninsulated" cast-iron or cast steel mold. While mold washes are frequently used for obtaining an improved ingot surface, conventional procedures as presently practiced recognize that they should be applied carefully in a manner that will not reduce initial ingot solidification and thus induce ingot cracks, and it will be accordingly further understood for purposes of definition that a cast-iron mold having a conventional mold wash thereon is an "uninsulated" mold within the above definition of conventional practices.

While a thick ingot skin is required by conventional practices to reduce ingot cracks, the teeming temperatures and rates that may be used for this purpose are limited since teeming rates and temperatures that are too low may result in other ingot surface defects. For example, low metal temperatures and teeming rates may produce ripples, folds, double skin, and entrapped inclusions of non metallic refractories in the ingot skin that may cause cracks or tears upon rolling. It is thus necessary under conventional practices to adopt teeming conditions which are a compromise between those that will produce a thick ingot skin and avoid cracking and those that will reduce folds and peripheral inclusions. Attention is particularly directed to the fact that the procedures required by conventional practices from the standpoint of obtaining a thick ingot skin and reduced ingot cracks can normally be expected to increase the other defects mentioned above.

This invention, contrary to conventional casting procedures and principles particularly with respect to the requirement of a thick ingot skin to avoid cracking, is based on the discovery that both ingot cracks and peripheral inclusions are avoided and an improved steel ingot structure is obtained by retarding during an initial period of short duration the transfer of heat through the walls of a cast-iron mold in which the ingot is being cast to thereby retard the rate at which the ingot metal freezes upon initial contact with the mold side walls. The heat transfer retarding action required to produce the improved ingot structure of this invention need exist only for a relatively short period of time, for example, the time required to teem the molten metal in the mold, and has been accordingly designated an "initial retarding action." This is accomplished in accordance with the principles of this invention by applying a lining of refractory insulating material to the internal surfaces of an iron mold in which the ingot is to be cast, which has a thickness and insulating properties of a character to be described such that the desired initial retardation of heat transfer is effected. While the resulting ingot has a thinner skin compared to steel ingots produced conventionally by casting in uninsulated cast-iron molds, the practice of the invention in this respect has been found to reduce both the incidence of ingot cracking as well as other surface defects such as peripheral inclusions of non-metallics, and to reduce by as much as 50% for scarfing required to condition the resulting ingots for rolling.

In addition to correcting surface and subsurface defects common in conventional ingots, this invention has as one of its principal objects the provision of a steel ingot having an improved columnar structure in which its skin has a planar internal surface compared to the wave-like internal skin surface of conventionally cast ingots, and in which its dendritic columnar crystals are more uniformly arranged relative to each other but are of a size not substantially different compared to those in conventionally cast ingots. This improved columnar structure, by reason of the more uniform arrangement of its dendritic columnar crystals and the corresponding freedom from intersecting lines or planes of cleavage therebetween, relieves factors causing cracks to form in the surface of the ingot both before and during rolling and, as indicated above, is obtained by the initial heat retarding action of the refractory heat insulating lining on the internal surfaces of a cast-iron mold. The nature of the refractory insulating coating effective for this purpose may be characterized further as being such that it provides during an initial period, corresponding to the time of pouring, the action of a slow cooling mold formed from sand or other insulating refractory material and during a subsequent period the more rapid chilling action of a conventional iron mold. In this manner, the advantages of casting ingots in uninsulated cast-iron molds with respect to size of dendritic columnar crystals are retained while obtaining a uniform arrangement of such crystals relative to each other similar to that produced in sand castings or the like.

As is well known, steel cast in sand molds is not suitable for rolling purposes since its dendritic columnar crystals are so coarse and large that excessive cracking will take place if an attempt is made to roll the casting. The coarse structure of sand cast steel is due to the high insulating properties of the mold material and the resulting slow solidification of the casting metal which affords time for the formation and growth of dendritic columnar crystals. However, the internal surface of the skin structure of a sand casting of this character has a substantially planar shape with respect to which its columnar crystals are uniformly arranged relative to each other and thus free of intersecting lines or planes of cleavage, and this property is retained by the ingot and process of this invention. This is accomplished by the insulating coating of this invention which provides during an initial period of solidification of the ingot metal a heat transfer action comparable to that of a mold of sand or material of similar insulating properties.

Compared to sand casting, the more rapid chilling action of the ingot metal when cast conventionally in iron molds, either with or without a splash repelling mold wash, provides advantages rendering the resulting ingot more suitable for rolling. The iron mold, in conducting the heat of the molten metal away more rapidly, not only enables earlier stripping for soaking purposes but, in addition, reduces the time required for solidification of the ingot metal and therefore the time for the formation and growth of its dendritic columnar crystals. As a result, its dendritic columnar crystals are smaller and thus less likely to split or cleave apart in the form of cracks when the ingot is reduced in size by rolling as is the case with larger crystals formed by slower solidification in a sand casting. The smaller size of dendritic columnar crystals obtained by conventional casting in iron molds is retained by the ingot and process of this invention. This is accomplished by limiting the thickness and insulating properties of the insulating coating of this invention in such manner that it is not noticeably effective, after its initial heat retarding action has served its purpose, to further slow the rate of solidification of the ingot metal, the final rate of solidification after formation of the ingot skin structure taking place at a rate not substantially different than that of conventionally cast ingots whereby the dendritic columnar crystals have a size not significantly different than the size of such crystals in conventionally cast ingots.

By controlling the initial rate of solidification of the ingot while its skin structure is being formed in accordance with the principles of this invention, the skin structure of the resulting ingot will have a planar internal surface and the dendritic columnar crystals extending inwardly from such surface will be parallel as in a slowly coiled sand mold casting, and will also have a size substantially the same as obtained in a rapidly coled iron mold casting. In addition, the initial retardation of the rate of ingot metal solidification is effective to eliminate one of the disadvantages of conventionally cast ingots. In the conventional casting of steel ingots in iron molds, either with or without conventional mold washes, the initial heat transfer action through the sides of the mold is uncontrolled and the molten metal freezes at a rapid rate thereby producing a thick ingot skin, but the turbulence of the molten metal in the mold has a washing action against the ingot skin that results in its internal surface having an irregular and wave-like shape. Since the dendritic columnar crystals grow perpendicular to the internal surface of the skin, they intersect and form weak points along lines or planes of cleavage extending inwardly particularly from low areas in the wave-like internal surface of the skin. Ruptures or cracks often form at these points during cooling of the ingot or later when the ingot is being rolled. By providing an ingot having a skin structure with a planar internal surface, this source of cracking regarded as unavoidable in conventional casting practices is eliminated.

Of particular importance to steels which are killed by the addition of strong deoxidizers, one of the objects of this invention is to reduce peripheral nonmettallic inclusions entrapped beneath the surface of the ingot skin. Upon rolling of the ingot, these materials frequently tear through the surface and produce the surface defect commonly designated by the term "slivers." By retarding initially the rate of solidification of the ingot metal, the resulting ingot has a skin or surface structure of a transverse depth which is significantly less than and about ⅓ of the transverse depth of a conventionally cast ingot and a significantly smaller quantity of nonmetallic oxides and ingot scum is entrapped in the skin, a greater percentage of these materials floating on the teeming molten metal to the upper end of the ingot.

The refractory insulating coating of this invention, in retarding the initial rate of solodification, is additionally effective in decreasing folds and scabs due to surging and splashing of the metal as it is teemed in the mold.

Other objects and advantages of the invention will be apparent from the following description.

In the practice of the process of this invention, a mixture or slurry of a liquid vehicle and a high-temperature insulating refractory composition is applied in the form of a coating or lining to the internal surfaces of a cast-iron or steel mold. It is applied by brushing, spraying, dipping, or swabbing, and its consistency is regulated according to the intended manner of application. It is applied in a thickness of a character to be described such that it provides an initial retarding action on the transfer of heat through the walls of the mold as described above. After the coating is dried to remove the liquid vehicle, and this may take place rapidly if the iron mold is hot or heated, the ingot is cast and stripped in conventional fashion. When the ingot is stripped, the insulating lining separates and is removed from the iron mold which may be used again after applying another coating to its internal surfaces as described.

An insulating composition siutable for the purposes of this invention consists primarily of a heat-insulating refractory, a bonding material, a suspending agent, and a liquid vehicle which may be mixed in varying proportions.

The heat-insulating refractory should be inorganic and preferably is one containing minutes voids for improving its insulating properties. Materials providig proper heat insulation and refractoriness are as follows: asbestos, diatomaceous earth, perlite, vermiculite, or alumina bubbles (hollow spheres of fused alumina) and the like. Any heat insulating material having comparable or lower coefficients of heat transfer are suitable for the purposes of this invention.

To promote adherence of the insulating coating to the mold walls, suitable bonding materials are as follows: bentonite, cereal binder, china clay, core oil, corn flour, dextrin, ethyl cellulose, fire clay, gum arabic, ground resin, methyl cellulose, molasses, phenolic resin, urea formaldehyde, water glass, or pitch.

As a suspending agent, and for the purpose of decreasing the settling tendency of the solid particles in the coating prior to its application, suitable materials are as follows: aluminum hydroxide, bentonite, china clay, or gum arabic. If these materials are used as a bonding agent, no further addition is necessary.

The liquid vehicle, or carrier, not only facilitates application of the coating by brushing, spraying, dipping or swabbing, but also aids in obtaining a coating of uniform thickness. Materials suitable for this purpose are as follows: alcohols, kerosene, ketones, or water.

In addition, increased coverage materials may be added to increase the amount of surface area that may be covered with the mold coating. Such materials are as follows: alumina, ball clay, chamotte, chrome ore, dolomite, fire clay, flint clay, forsterite, glass wool, graphite, kaolin, limestone, mineral wool, blast-furnace slag, open-hearth slag, magnesia, magnesite, rutile, silicates, silica, silicon carbide, or zircon.

The above materials may be combined to provide in different proportions many coating compositions suitable for the purposes of this invention, the only requirement being that the insulating coating when applied provides an insulating effect with maximum and minimum limits as hereinafter described. Two examples of mold coatings that were used to retard initial solidification during the time of pouring and were effective in decreasing the incidence of ingot cracks and sliver defects are as follows:

EXAMPLE I.—PERCENT BY WEIGHT OF SOLIDS

Diatomaceous earth	20.0
Glutrin	5.0
Ball clay	2.0
Western bentonite	3.0
Silica flour	70.0

EXAMPLE II.—PERCENT BY WEIGHT OF SOLIDS

Perlite	10.0
Methyl cellulose	1.0
Western bentonite	4.0
Zircon flour	85.0

Sufficient water was added to each of the above examples to enable their being spread as a coating by brushing on the internal surfaces of a cast-iron mold. More particularly the composition of Example I is applied in accordance with the principles of this invention in an amount sufficient to provide when dried an insulating coating having a minimum thickness of from .020 to .250 inch, and preferably between 1/32 and 1/16 inch, the minimum thickness being increased in a manner to be described with increased pouring time and ingot sizes. For an explanation of the requirements of the mold lining of this invention from the standpoint of its minimum thickness and insulating properties, reference will be made to the accompanying drawings in which:

FIGURE 1 is a photographic reproduction of a vertical section of a conventionally cast ingot;

FIGURE 2 is a photographic reproduction of an ingot shell which furnishes a comparison of the skin structure of an ingot obtained by the practice of the process of this invention with the skin structure of a conventionally cast ingot;

FIGURE 3 is a photographic reproduction of a vertical section of an ingot which furnishes a comparison of the results of this invention with conventional casting practices; and

FIGURES 4, 5 and 6 are schematic drawings illustrating, for the purpose of explaining the theory of this invention, the comparative results of casting conventionally in iron molds, casting in sand, and casting in accordance with the method of this invention.

As indicated above, the ingot and practice of the method of this invention is effected in a conventional iron mold which has a refractory insulating coating applied to its inner surfaces in a manner to be described. Since conventional iron molds have wall thicknesses of from four to six inches and greater depending upon the size of the ingot to be cast and the insulating coating has a thickness in the nature of 1/32–1/16 inch, no attempt has been made in the drawings to show the relative proportions of the cast-iron mold and coating and the mold has been shown only fragmentarily. While FIGURES 4, 5 and 6 are respectively intended to illustrate the relative crystal structures obtained by casting steel in conventional iron molds, in sand, and in an insulated iron mold according to this invention, it is to be understood that they have not been prepared from microphotographic studies and that the relative sizes of dendrites illustrated are not accurate. Their respective showings are diagrammatic and are solely for the purpose of explaining the principles of this invention.

In FIGURE 4, the numeral **1** designates a portion of the wall of a conventional uninsulated cast-iron mold which may or may not be provided with a conventional mold wash on its internal surface **2**. When metal is teemed in the mold **1**, a skin structure **3** essentially of equiaxed crystals is formed by the chilling action which takes place as the metal is cooled by the mold wall **1**. It will be noted that the inner surface of the skin **4** has an irregular or wave-like contour, depressions being indicated at the points **5**. After the ingot skin **3** has formed in this manner continued cooling of the metal results in dendritic columnar crystals **6** growing inwardly from the skin surface **4**. The crystals **6** grow in a direction substantially normal to the inner skin surface **4** and, because of this, the crystals in the areas **7** opposite the low points **5** intersect along lines **8**. The lines **8** represent weak points at which cracks are likely to occur upon cooling of the ingot or when it is rolled.

In the photographic reproduction of a vertical section of a conventionally cast ingot in FIGURE 1, similar numerals have been applied to designate like parts of the ingot structure referred to in connection with FIGURE 4. This reproduction is a section of a typical ingot structure after stripping and before rolling, and it will be noted that a crack **10** in the skin **3** has already appeared at the point **5** along the line **8** of intersection of dendritic columnar crystals.

As distinguished from the crystal structure obtained by the conventional casting of an ingot in a cast-iron mold, the diagrammatic showing of FIGURE 5 illustrates the structure that is obtained by casting steel in a hot mold fabricated of sand or other similar refractory insulating material. In this showing, the numeral **11** designates a sand mold having an internal surface **12**. When metal is teemed in the mold **11**, the chilling action of the mold results in the formation of a skin **13** of equiaxed crystals similar to those in the skin **3** of FIGURE 4. However, it will be noted that the internal surface **14** of the skin **13** is parallel to the mold surface **12** and of a planar shape which is free of indentations such as the depressions **5** in the structure of FIGURE 4. It will also be noted that the skin **13** has a considerably smaller transverse depth than does the skin **3**, the lesser depth of the skin **13** being due to the fact that the sand in the mold **11** does not have the same initial chilling effect as does the cast-iron of the mold **1**. It will also be noted that the dendritic columnar crystals **16** growing inwardly from the skin surface **14** are much larger than the crystals **6** of FIGURE 4. The larger size of the crystals **16** is due to the high heat insulating properties of the mold **11** by reason of which solidification of the cast metal takes place at a much slower rate thus affording more time for the crystals to grow to the relative size indicated. However, it will be noted that the crystals **16** are parallel and more uniformly arranged relative to each other and thus free of intersecting lines such as the line **8** of FIGURE 5. While the elimination of intersecting cleavage lines **8** is desirable, this casting is not suitable for rolling for the reason that it would tend to crack along the lines between adjacent dendritic columnar crystals **16**.

As distinguished from conventional casting practices and the structures illustrated by the showings of FIGURES 4 and 5, FIGURE 6 illustrates the casting practice and ingot in this invention. In this showing, numeral **20** designates a cast-iron mold having a coating **21** on its inner surface of refractory insulating material, the coating **21** being for example one corresponding to Example I above and applied in a thickness such that it provides an initial heat retarding action according to the principles of this invention. When metal is teemed in the mold **20**, a skin **23** of equiaxed crystals is first formed along the surface of the coating **21**. As distinguished from the undulating surface **4** shown in FIGURE 4, the skin **23** has surface **24** which is planar and free of depressions **5** similar to the skin surface **14** of the sand casting of FIGURE 5. However, it will be noted that the dendritic columnar crystals **26** are of substantially the same size as the crystals **6** of a conventional casting but have the uniform arrangement of the crystals **16** of the sand casting. While the skin **23** has a transverse depth larger than the depth of the sand cast skin **14**, its depth is considerably less than and in the nature of, as illustrated, about ⅓ that of the conventionally cast skin **3**. The planar shape of its surface **24** is due to the fact that the insulating coating **21** is effective during the time of pouring to provide an insulating effect similar to that of the sand of the mold **11**. The size of its dendritic columnar crystals **26** indicates that the heat transfer through the mold wall **20** after the insulating coating **21** has completed its retarding action is substantially the same as the rate of heat transfer through the walls of a conventional mold such as the mold **1**.

FIGURES 2 and 3 are photographic reproductions of ingot specimens that furnish a comparison of the ingot structure of this invention with ingot structures obtained by conventional casting procedures. The specimen shown in FIGURE 2 was cast in a laboratory size cast-iron mold which had an internal mold cavity of about 15″ deep tapering from a width of about 3¾″ at the top to about 3⅜″ at the bottom, the ingots obtained from such molds usually weighing about 60 pounds. The specimen shown in FIGURE 3 was cast in a slightly larger mold having a depth of about 19″ tapering from a width of about 4½″ at the top to about 3¾″ at the bottom, the ingots cast in such molds weighing about 100 pounds. In preparing each specimen one of two opposite side walls of the mold was coated with the composition of Example I above to provide an insulating lining thereon that had a thickness of about 1/32 inch, and the other had nothing thereon and thus corresponded to conventional practice.

FIGURE 2 shows a vertical section of an ingot shell that was obtained by filling a laboratory mold prepared as explained above with molten metal and dumping the mold as soon as the pouring operation was completed. In producing this shell, the pouring operation required about 30 seconds to fill the mold, and the mold was dumped in about 3 to 5 seconds after pouring was completed. The shell thus obtained represents the portion of the ingot that solidifies during the time of filling the mold and is representative of the skin of an ingot. In this showing, the numeral **30** designates the wall or skin structure which formed against the uncoated or conventional side of the mold, and the numeral **31** designates the wall or skin structure which formed against the side of the mold having the insulating coating of this invention. It will be noted that the conventional skin structure **30** has an interior surface **32** of wave-like shape and a transverse depth roughly three times the thickness of the skin structure **31** of this invention. In addition to having a lesser transverse depth, attention is directed to the fact that the skin structure **31** has an internal surface **33** which is essentially planar in shape compared to the wave-like contour of the conventional skin surface **32**. The differences in transverse depths of the skin structures **30** and **31** furnishes an illustration of the manner in which the insulating coating of this invention provides an initial retardation of heat transfer during the time of pouring. Since the dendritic columnar crystals grow inwardly from and in a direction substantially normal to the internal surfaces of the ingot skin structures as explained above, a comparison of the inner surfaces **32** and **33** furnishes an indication that the dendritic columnar crystals will be more uniformly arranged relative to the planar surface **33** than in conventionally cast ingots and particularly with respect to freedom from weak points such as the points **5** as shown in FIGURES 2 and 4.

The ingot shown in FIGURE 3 was cast from killed steel and the metal was retailed in the mold until completely solidified. The skin **34** thereof was adjacent the coated side of the mold and the skin **35** was adjacent the uncoated or conventional side of the mold. The dark spots along the skin **35** are entrapped non-metallic inclusions and their arrangement along the line **36** indicates the inner boundary of the skin **35**. Attention is particularly directed to the fact that the edge or skin **34** formed according to the practice of this invention contains a smaller number of dark spots or non-metallic inclusions. The vertically extending crack or shrinkage cavity **38** furnishes an indication of the line along which final solidification of the ingot took place, and by reason of its substantially central location, it will be apparent that the heat transfer through both mold walls after formation of the skins **34** and **35** was substantially the same. The line **38** is actually positioned closer to the edge **34** by an amount representing the difference in the depths of the skins **34** and **35** and thus furnishes an additional indication of the initial retarding action of the coating of this invention.

As indicated, a 1/32″ thick lining **21** prepared from the composition of Example I and applied to 60 and 100 lb. laboratory cast-iron molds as explained above was effective in producing thin planar shaped ingot skins **31** and **34** as shown in FIGURES 2 and 3 of the drawings. In producing these examples of the invention pouring times of 30–35 seconds were used to fill the molds. However, further laboratory investigations of a similar type developed that the minimum thickness of linings prepared from the composition of Example I, could be varied with different rates of pouring and reduced to about .018–.020 inch for faster pouring times of about 20 seconds. Linings that had a thickness less than .018–.020 inch, for example, did not produce the desired results from the standpoint of ingot surface structure, but resulted in ignot skins that had a wave-like internal surface similar to those obtained by casting conventionally in uncoated cast-iron molds. From this it was concluded that a lining thickness of about .020″ was the minimum that could be used for the purposes of this invention, and that the insulation or lining thickness should be increased for increased pouring times.

The foregoing laboratory determinations concerning the requirement that the minimum lining thickness be increased with increased pouring times has been verified by plant trials in casting steel ingots in commercial sizes ranging from a cross-sectional size of 19 x 22 inches to 24 x 64 and 34 x 66 inches. These ingots were cast with pouring times of from about 30 seconds for smaller sizes to about 2½ minutes for the larger sizes. While a lining **21** of the insulating composition of Example I above applied in a thickness of 1/32 inch provided significantly improved results in all cases and particularly for the shorter pouring times of from 30–90 seconds, these trials demonstrated that a thickness of 1/16" for the longer ingot pouring times of about 2–2½ minutes is required to obtain the maximum benefit of the invention. These trials further indicated that lining thicknesses of ⅛" for ingots having pouring times of four minutes and that lining thickness of as much as ¼ inch may be required for still larger steel ingots having pouring times up to 10 minutes, for example, those weighing in excess of 20 tons.

From the foregoing it will be apparent that a cast-iron or cast-steel mold having a refractory insulating lining **21**, prepared from the composition of Example I above or its equivalent and applied in an increasing thickness of from .020–.250 inch according to ingot teeming times of from 20 seconds to 10 minutes, is required for the purposes of this invention. With reference to ingots of the commercial sizes indicated above that are to be rolled into plates or into rails or billets, it will be understood that a lining thickness between 1/32" and ⅛" of the Example I composition for teeming times of from 30 seconds to 2½ minutes represents the preferred practice of the invention.

The thickness of the lining **21** as indicated above is based on the use of the composition of Example I, but it will be understood that such thickness for other compositions will vary directly with the coefficient of thermal conductivity (K) of such other compositions. While the actual thermal coefficient of conductivity of the composition of Example I has not been determined, its K-value can be assumed as being essentially that of diatomaceous earth since this material forms the bulk of the composition and has greater insulating properties than the other materials therein. Since reference to available textbooks and scientific publications containing tables listing the K-values of insulating materials indicates that diatomaceous earth has a coefficent of thermal conductivity of about 0.60 at a mean temperature of 400° F. and that asbestos and vermiculite have coefficients that are not substantially higher, it will be apparent that linings **21** formed essentially from the latter materials should be applied in a thickness of .020–.250 inch as explained above in connection with the Example I composition linings. While specific K-values could not be found in published literature for the materials perlite and alumina bubbles in the list of heat-insulating refractories mentioned above as being suitable high-heat insulating materials for the purposes of this invention, such materials have high insulating properties that are essentially similar to those of diatomaceous earth and should therefore be applied as linings having the same thickness range. For materials having different K-values the thickness range may be defined as lying between

$$\left(\frac{K\times.020}{0.60}\right) \text{ inch and } \left(\frac{K\times.250}{0.60}\right) \text{ inch}$$

where K is the thermal coefficient of conductivity of the material used expressed as B.t.u.$\cdot$hr.$^{-1}\cdot$ft.$^{-2}\cdot$°F.$^{-1}$. It will of course be understood that the use of materials having K-values substantially above 0.60 should be avoided since they will require increased lining thicknesses that may have the undesired effect of retarding the transfer of heat through the mold walls after the ingot skin has formed and thus produce larger dendrites approaching the condition of sand castings shown in FIGURE 5.

The requirement that the lining **21** be as thin as possible and the manner in which the insulated mold of this invention provides a heat transfer action equivalent

to that of a conventional iron mold after formation of the ingot skin can be explained best by considering in detail first the heat transfer action of a conventional mold. When molten metal is teemed in a conventional mold, the walls of the mold initially are in contact with the molten metal and conduct heat away quite rapidly so that the skin structure is formed in a relatively short time, about 60 seconds for normal casting procedures. However, as the metal of the skin solidifies, it contracts and pulls away from the sides of the mold to form a gap between the ingot skin and the mold. The formation of this gap materially decreases the rate of heat transfer through the mold, the effective coefficient of heat transfer changing from that of the cast-iron mold walls to that of the mold walls plus the gap and this change accounts for the slower solidification period in which dendritic columnar crystals are formed.

Turning now to the casting procedure of this invention, the initial coefficient of heat transfer is that of the cast-iron mold walls plus that of the insulating lining **21**. This coefficient of heat transfer being less than that of a conventional mold results in a thinner skin as explained above. Since the skin is thinner, shrinkage will be less and the initial gap between the surface of the skin and the surface of the lining **21** will not be as great as in the conventional mold. While the lining **21** continues to exert its insulating effect, the smaller gap results in a total insulating effect such that the rate of heat transfer to the mold walls is substantially the same as for the larger gap formed when ingots are cast conveniently, and this furnishes a further test for the maximum thickness of the lining **21**. The thickness of the lining **21** should not exceed a dimension such that its insulating action together with that of the gap between it and the ingot skin is materially greater than that of the gap which forms about the skin of a conventionally cast ingot. The maximum thickness of the lining **21** in this respect has not been determined since no advantage would be provided by linings of a thickness greater than the minimum specified above.

In addition to improving ingot sub-surface structure by minimizing slivers from nonmetallic inclusions and the formation of cracks upon cooling and during rolling, the refractory insulating lining or coating of this invention provides an improved ingot surface structure in that it is effective in eliminating scabs or folds. By reason of the high initial insulating effect of the lining **21**, molten metal surging and splashing against the sides of the coated mold during teeming does not freeze and adhere to the sides of the mold as in conventional casting operations. Molten metal surging and splashing against the surface of the coating **21** will either flow downwardly into the body of molten metal rising in the mold or will not be chilled to such a low temperature such that it cannot reunite with the molten metal as its level rises in the mold. Regardless of the theory of the action of the lining **21** in this respect, the external surface of an ingot cast according to the present invention has a noticeably improved appearance from the standpoint of freedom of scabs and surface defects as compared to ingots cast conventionally in uncoated cast-iron molds or molds coated with conventional splash-repelling mold washes.

From the above, it will be apparent that the ingot of this invention has an improved surface and sub-surface structure as compared to conventionally cast ingots. Its sub-surface structure reduces the incidence of ingot cracks resulting from an irregular growth of dendritic columnar crystals and reduces sliver defects from sub-surface entrapment of nonmetallic inclusions, and its surface is relatively free of imperfections such as scabs and the like. These improvements are obtained by applying to the internal surfaces of a cast-iron mold a high heat insulating lining of the character described above. Attention is particularly directed to the fact that the minimum thickness of such linng is one which will retard the transfer of heat through the mold walls during teeming so as to provide during this period the insulating effect of a mold constructed entirely of a high-temperature refractory insulating material and to thereby obtain an ingot having a skin structure of a thickness significantly less than, and in the nature of about ⅓ the depth of conventionally cast ingots, the internal surface of such skin structure being smooth and of planar shape with the dendritic columnar crystals growing inwardly therefrom being arranged parallel and relatively free of intersecting lines of cleavage. It will also be apparent that the lining **21** of this invention acts as a temporary thermal barrier during the teeming period when the turbulence of the molten metal in the mold is at a maximum and thus results in an ingot skin that has a planar internal surface as described above. Its action in this respect is temporary since it becomes heated through during this period to a temperature approaching that of the ingot metal with the result that it loses most of its initial temperature gradient and its original insulating action.

While a preferred practice of the invention has been described it will be understood that modifications may be made without departing from the scope of the following claims.

We claim:

1. A method of casting steel ingots which comprises applying to the internal surfaces of a cast-iron mold a coating of a liquid dispersion containing solids in proportions by weight comprising diatomaceous earth 20%, glutrin 5%, ball clay 2%, bentonite 3% and silica flour 70%, drying said coating to provide an insulating lining on said internal surfaces, said coating being applied in an amount such that said lining when dried has a thickness of between 0.020 inch and 0.250 inch, and then teeming molten steel in said mold.

2. The method defined in claim **1** characterized by applying said coating in an amount such that said lining when dried has a thickness between 1/32 inch and ⅛ inch.

3. A method of casting steel ingots which comprises applying to the internal surfaces of a cast-iron mold a coating of a liquid dispersion containing solids in proportions by weight comprising diatomaceous earth 20%, glutrin 5%, ball clay 2%, bentonite 3% and silica flour 70%, drying said coating to provide an insulating lining on said internal surfaces, and teeming molten steel in said mold at rates providing teeming periods of from 20 seconds to 10 minutes, said coating being applied in amounts according to the length of the teeming period and such that said lining when dried has a thickness of between 0.020 inch and 0.250 inch, the thickness of said lining being increased with teeming periods of increased duration.

4. A method of casting steel ingots which comprises applying to the internal surfaces of a cast-iron mold a coating of a liquid dispersion containing solids in proportions by weight comprising diatomaceous earth 20%, glutrin 5%, ball clay 2%, bentonite 3% and silica flour 70%, drying said soating to provide an insulating lining on said internal surfaces, and teeming molten steel in said mold at rates providing teeming periods of from 30 seconds to 4 minutes, said coating being applied in amounts determined by the length of the teeming period and such that said lining when dried has a thickness of between 1/32 inch and ⅛ inch, the thickness of said lining being increased with teeming periods of increased duration.

5. A method of casting steel ingots which comprises applying to the internal surfaces of a cast-iron mold a high-temperature insulating lining comprising an inorganic refractory material and having a coefficient of thermal conductivity (K) of substantially 0.60, teeming molten steel in said mold at rates providing teeming periods of from 30 seconds to 4 minutes, said lining being applied with a thickness according to the length of teeming period and lying between 1/32 inch and ⅛ inch, the thickness of said lining being increased with teeming periods of increased duration.

6. A method of casting steel ingots in cast-iron molds which comprises applying to the internal surfaces of the mold a refractory insulating lining having a minimum insulating value effective during an initial period corresponding to the time of pouring to provide the action of a mold formed entirely of high insulating material, and a maximum insulating value such that it is ineffective during a subsequent period to reduce the transfer of heat through the walls of the mold below that which is had in a conventional uninsulated cast-iron mold, and teeming molten steel in said mold.

7. A method of casting steel ingots which comprises applying to the internal surfaces of a cast-iron mold an insulating lining having a minimum thickness and heat insulating properties effective to retard significantly the initial rate of solidification of the ingot during an initial period corresponding to the time of pouring as compared to an ingot cast in an uninsulated cast-iron mold and to thereby produce an ingot having a skin structure of uniform depth with its inner surface substantially smooth and free of wave-like irregularities and a center portion of columnar structure in which its dendritic columnar crystals are parallel and free of intersecting lines of cleavage, said lining having a maximum thickness and insulating properties during a period subsequent to said initial period such that said dendritic columnar crystals have a size comparing favorably to those obtained in ingots cast in uninsulated cast-iron molds, and teeming molten steel in said mold.

8. A method of casting steel ingots which comprises applying to the internal surfaces of a cast-iron mold an insulating lining having a thickness between maximum and minimum limits, the minimum thickness of said lining being one providing insulating properties effective to retard the transfer of heat through the mold walls during an initial period corresponding to the time of pouring by an amount sufficient to provide the action of a mold constructed entirely of a high heat insulating material and to thereby obtain an ingot having a skin structure of a transverse depth significantly less than the depth of conventionally cast ingots, the internal surface of such skin structure being smooth and of planar shape with dendritic columnar crystals growing inwardly therefrom being arranged uniformly relative to each other and free of intersecting lines of cleavage, the maximum limit of thickness of said lining being one providing an insulating effect operative to provide for the transfer of heat through the mold walls during a subsequent period, corresponding to the time of completion of ingot solidification after said initial period or pouring time when its skin is being formed, at a rate substantially the same as is had through the walls of a conventional uninsulated cast-iron mold, and teeming molten steel in said mold.

9. The method defined in claim **8** characterized by said skin structure having a transverse depth in the nature of about ⅓ the transverse depth of the skin structure of an ingot cast in an uninsulated cast-iron mold.

10. A steel ingot having skin and dendritic columnar crystal structures formed by casting molten metal in a cast-iron mold having a high heat insulating coating on its internal surfaces, which is effective during an initial period corresponding to the time of pouring to provide the heat transfer action of a mold formed entirely of a high heat insulating material, and which is ineffective during a subsequent period to appreciably reduce the heat transfer through the walls of the mold below that which is had by casting in uninsulated cast-iron molds, said skin structure having an internal surface of planar shape and a transverse depth significantly less than the transverse depth of conventionally cast ingots, said dendritic columnar crystals extending inwardly from the internal surface of said skin structure and having a uniform and parallel arrangement relative to each other substantially free of intersecting lines of cleavage and being of a size comparable to those in ingots cast in uninsulated cast-iron molds.

11. An ingot as claimed in claim **10** characterized by the said transverse depth of said skin structure being in the nature of ⅓ the transverse depth of the skin structure of an ingot cast in an uninsulated cast-iron mold.

12. A method of casting steel ingots which comprises applying to the internal surfaces of a cast-iron mold an insulating lining having a minimum thickness and insulating properties effective to retard the transfer of heat through the mold walls during an initial period corresponding to the time of teeming metal in said mold by an amount sufficient to provide the action of a mold constructed entirely of high heat insulating material and to thereby produce an ingot having a skin structure of uniform depth with a substantially smooth inner surface and center portion of columnar structure in which its dendritic columnar crystals are parallel and free of intersecting lines of cleavage, said lining having a maximum thickness such that its insulating action plus that of the air gap that forms between the internal surface of said lining and the external surface of said skin structure during a subsequent period, corresponding to the time of completion of ingot solidification after said initial period when its skin is being formed, provides for the transfer of heat through the mold walls at a rate substantially the same as is had through the walls of a conventional uninsulated cast-iron mold, whereby said dendritic columnar crystals have a size comparing favorably to those obtained in ingots cast in uninsulated cast-iron molds, and teeming molten steel in said mold.

13. A steel ingot of columnar structure characterized by its dendritic columnar crystals having the relative uniform and parallel arrangement of those in a casting formed in a mold of high thermal insulating material and having the size of those in an ingot formed in an uninsulated cast-iron mold.

14. A steel ingot comprising an outer peripheral skin structure of equiaxed and randomly oriented crystals having an internal surface of planar shape and a transverse depth significantly less than the transverse depth of the skin structure of an ingot cast in an uninsulated cast-iron mold, and dendritic columnar crystals extending inwardly from said internal surface and having a size comparing favorably to those of an ingot cast in an uninsulated cast-iron mold.

15. A steel ingot having a dendritic columnar structure comprised of a skin structure and dendritic columnar crystals growing inwardly from the inner surface of said skin structure, said skin structure having a uniform transverse depth with its said inner surface substantially smooth and free of wave-like irregularities, and said dendritic columnar crystals having the relative unifrom and parallel arrangement obtained by casting in a mold fabricated of a material having a high insulating value, said dendritic columnar crystals further having a size comparable to those obtained by casting in an uninsulated cast-iron mold.

16. A steel ingot comprising a skin structure of equiaxed and randomly oriented crystals and an inner structure of dendritic columnar crystals extending inwardly from said skin structure, said skin structure having an internal surface of planar shape similar to that obtained in a casting formed in a mold of said and having a transverse depth significantly less than the transverse depth of the skin structure of an ingot cast in an uninsulated cast-iron mold, said dendritic columnar crystals extending inwardly from said internal surface and having the uniform and parallel arrangement of those in a casting formed in a mold of sand but having a size substantially the same as those in an ingot cast in an uninsulated cast-iron mold.

References Cited by the Examiner

UNITED STATES PATENTS

1,662,354	3/1928	Williams	22—192
1,722,098	7/1929	Kimber	117—5.3
1,764,544	6/1930	Baumgardner	106—38.27
1,961,399	6/1934	Snook	22—200
1,982,763	12/1934	Russell	22—192
2,005,175	6/1935	Adams	29—187
2,018,025	10/1935	Lemmerman	22—192
2,028,244	1/1936	Perry	29—187
2,031,538	2/1936	Langenberg	22—192
2,234,152	3/1941	Archer	22—192 XR
2,399,606	4/1946	Schuh	22—192
2,544,598	3/1951	Kalina	22—136
2,623,809	12/1952	Myers	22—192
2,882,568	4/1959	Leaberry et al.	22—139
2,951,272	9/1960	Kiesler	22—126

FOREIGN PATENTS

522,086	6/1940	Great Britain.

J. SPENCER OVERHOLSER, *Primary Examiner.*

NEDWIN BERGER, WHITMORE A. WILTZ, WILLIAM J. STEPHENSON, MICHAEL V. BRINDISI, *Examiners.*

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,230,056 January 18, 1966

Norbert R. Arant et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 4, line 13, for "coiled" read -- cooled --; line 14, for "coled" read -- cooled --; same column 4, line 52, for "solodification" read -- solidification --; column 5, line 5, for "minutes" read -- minute --; line 6, for "providig" read -- providing --; column 8, line 31, for "retailed" read -- retained --; line 65, for "ignot" read -- ingot --; column 14, line 5, for "unifrom" read -- uniform --; line 15, for "said" read -- sand --; line 34, for "Lemmerman" read -- Langenberg --; same column 14, line 36, for "Langenberg" read -- Lemmerman --.

Signed and sealed this 3rd day of January 1967.

(SEAL)

Attest:

ERNEST W. SWIDER

Attesting Officer

EDWARD J. BRENNER

Commissioner of Patents