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[54] CONTINUOUS CASTING PROCESS

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 34,211, May 4, 1970, abandoned.

[52] **U.S. Cl.** **164/57,** 164/89, 164/125

[51] **Int. Cl.** **B22d 27/20**

[58] **Field of Search** 164/55, 56, 57, 58, 164/59, 122, 125, 82, 89, 281, 283, 275

[56] **References Cited**

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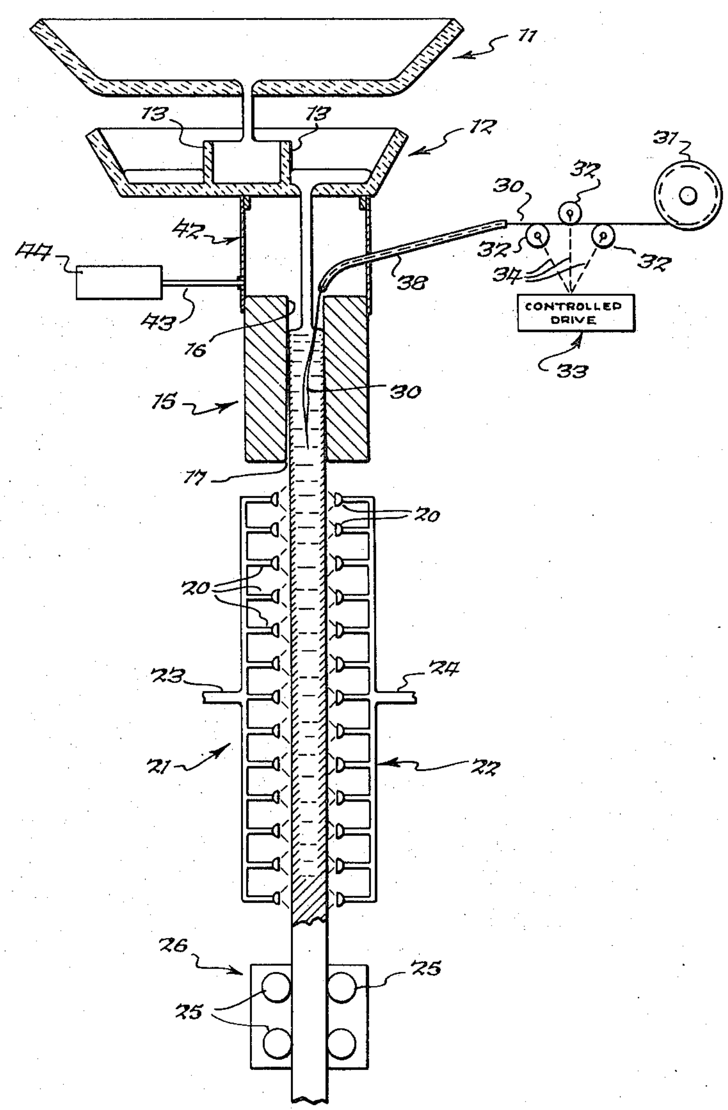
[57] **ABSTRACT**

In conjunction with a method for continuously casting a fusible material such as steel, the manner of withdrawing heat during casting is improved by delivering a metal wire into the molten material at the top of the mold and in the general direction of flow of material through the mold. A low effective superheat is maintained in the molten material being cast. The wire has a cross-sectional area and is delivered by operation of a controlled drive means such that complete melting of the wire occurs at a point in the material above the point where complete freezing of the material is expected to take place. In the casting of steel, freezing is caused to occur at a point spaced from the level of molten steel in the mold as short as one-seventh of the linear distance at which solidification is completed in continuous casting. The resulting cast product has a solid center, equi-axed metal grains in a major portion thereof and the same chemical composition in the grains as is present in the steel prior to casting.

9 Claims, 7 Drawing Figures



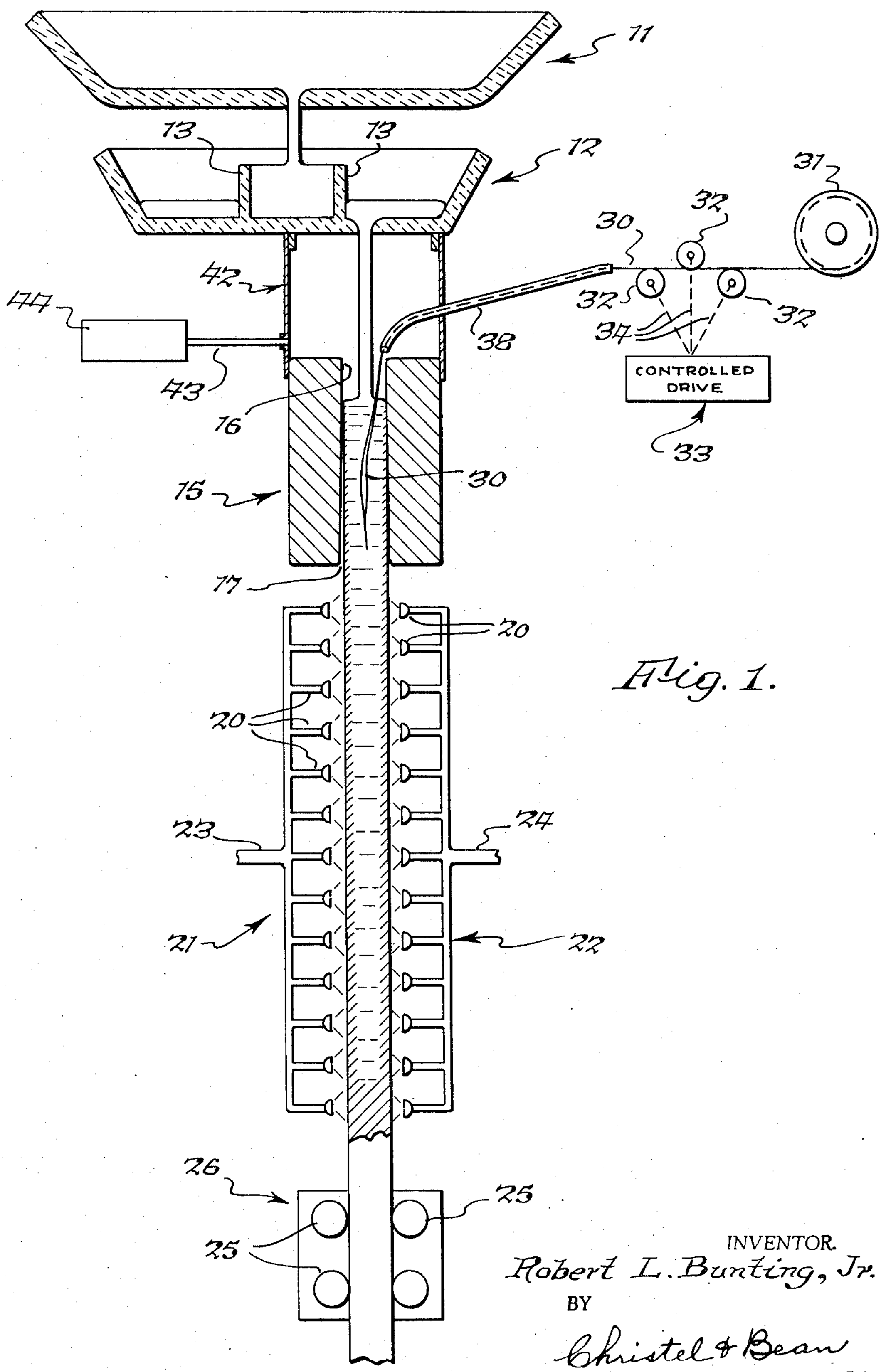


Fig. 1.

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Fig. 2B.

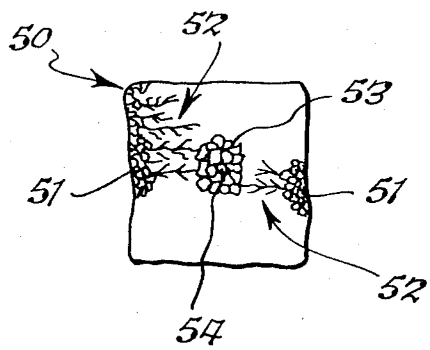


Fig. 3B.

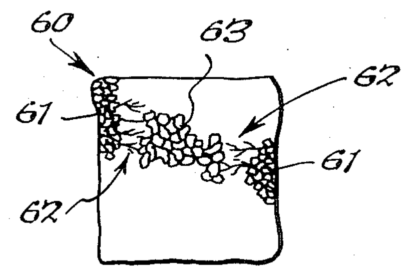


Fig. 2A.

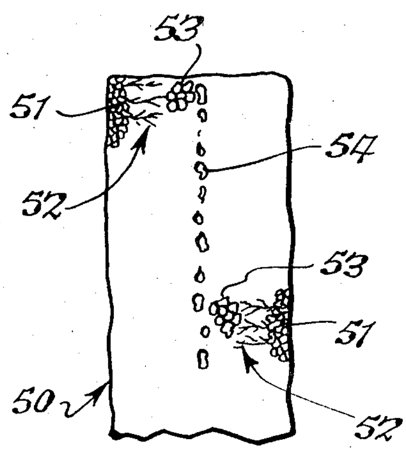
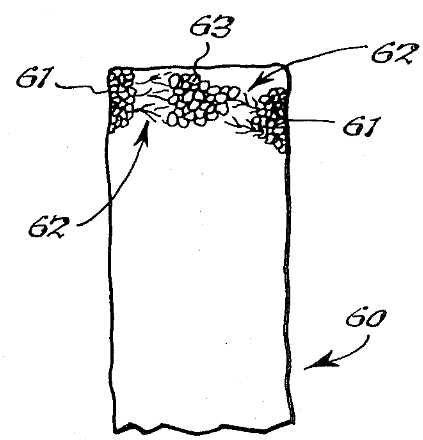


Fig. 3A.



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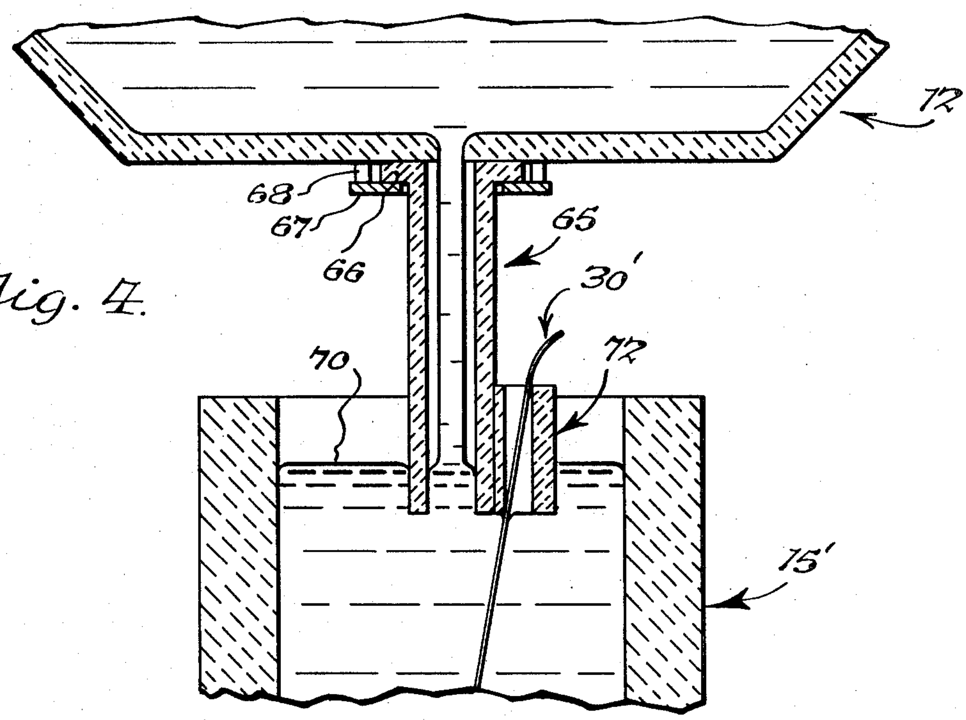

Fig. 4.

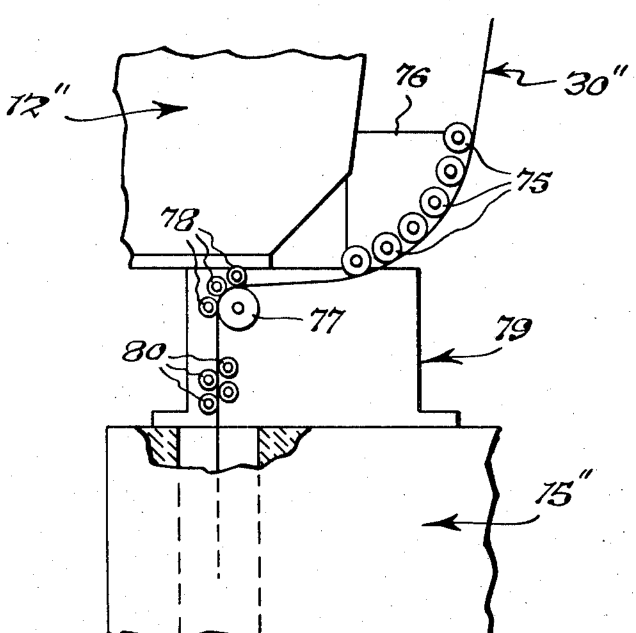

Fig. 5.

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CONTINUOUS CASTING PROCESS

CROSS REFERENCE TO A RELATED APPLICATION

This application is a continuation-in-part of my co-pending application Ser. No. 34,211, filed May 4, 1970, now abandoned, and entitled "Continuous Casting Process."

BACKGROUND OF THE INVENTION

The present invention relates to the continuous casting of steel and the like and, more particularly, to a method and apparatus for improving the manner of withdrawing heat during such continuous casting to obtain a cast structure of superior physical characteristics.

In the continuous casting process molten steel is delivered to a mold at the top thereof whereupon initial freezing of the steel begins immediately as the hot metal comes in contact with the mold. The cast structure is withdrawn continuously from the bottom of the mold, and further solidification of the metal takes place at a controlled rate in a water or spray chamber adjacent the mold. This continuous casting process has been used commercially in the United States since 1964 for the production of carbon and alloy steel billets. The efficiency of this process and the quality of the cast product have been increasing, but a problem remains due to the manner in which heat normally is removed from the molten steel during the process.

In the conventional continuous casting process, solidification beings at the outer surface and proceeds in an inward direction thereby causing the concentration and segregation of impurities or alloying elements in the innermost part of the casting. Frequently dendritic crystals are grown in the casting, with the result that the casting has a nonuniform and usually coarse grain structure and porosity in the region at and along the central axis thereof. In particular, as the molten steel enters the mold, freezing beings and forms an outer shell of solid material which surrounds or contains a liquid metal core of the formed structure. As this shell and core travel from the mold into proximity with the external cooling means, the outer shell progressively thickens as heat is removed from the molten steel until the entire mass is solid. Because the thermal conductivity of the hot steel outer shell is relatively low, complete solidification of the cast structure is relatively slow. Due to the composition of the liquid metal steel, the higher melting constituents of the system freeze first, forming large dendritics, which concentrate and segregate the lower melting constituents of alloy elements to the center of the cast structure. The result is segregation along the center line of the billet. The formation of dendritic grains causes bridges or blockages to be formed in the center of the billet which creates voids or holes along the center line of the frozen billet. The mechanism of bridging and void formation increases center line segregation.

SUMMARY OF THE INVENTION

It is, therefore, an object of this invention to provide an improved method and apparatus for the continuous casting of steel and the like which eliminates the segregation and concentration of impurities to the center region of the cast structure, which eliminates porosity in the cast structure, and which results in a minimum or negligible amount of dendritic crystal growth in the structure during the solidification.

It is a further object of this invention to provide, in the continuous casting of steel, an economical and efficient method and apparatus for improving the withdrawal of heat from the molten steel in a manner eliminating chemical segregation along the center line of the cast structure and minimizing dendritic crystal growth therein.

It is an additional object of the present invention to provide a continuously cast steel structure having relatively fine, uniform, and equi-axed grains through a major portion of the structure and which is free of porosity in the region of the center thereof.

The present invention provides a method and apparatus, for use in a continuous casting operation, for withdrawing or transferring heat from the region of the center of the molten material being cast causing nucleation of equi-axed grains in the molten liquid pool as the cast material is being solidified from its exterior surface in an inward direction. A low effective superheat is maintained in the molten material being cast. This is accomplished by the delivery of a metal wire or wires into the molten material at or near the inlet of the mold and in the general direction of flow of material through the mold. The wire or wires have a cross-sectional area and are delivered at a rate such that complete melting of the wire results at a point in the material above the point where complete freezing of the material is expected to take place. The resulting product has relatively fine, uniform and equi-axed metal grains through a major portion of the cast structure and, in addition, the structure is free of porosity in the region of the longitudinal central axis thereof.

The foregoing and additional advantages and characterizing features of the present invention will become clearly apparent upon a reading of the ensuing detailed description together with the including drawing wherein:

BRIEF DESCRIPTION OF THE DRAWING FIGURES

FIG. 1 is a diagrammatic view illustrating the apparatus of the present invention;

FIGS. 2A and 2B are schematic diagrams showing longitudinal and transverse views, respectively, of a billet formed by a conventional continuous casting operation;

FIGS. 3A and 3B are schematic diagrams showing longitudinal and transverse sectional views, respectively, of a billet formed from a continuous casting process according to the present invention;

FIG. 4 is a fragmentary diagrammatic view illustrating an alternative embodiment of a portion of the apparatus of FIG. 1; and

FIG. 5 is a fragmentary diagrammatic view illustrating an alternative embodiment of a portion of the apparatus of FIG. 1.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENT

FIG. 1 shows an arrangement of apparatus for the continuous casting of steel according to the present invention. After molten steel is tapped from a furnace (not shown) and stored in a tap ladle 11 it is transferred to a tundish **12** at the top of a continuous casting tower. Tundish **12** provides a straining or clarifying of the liquid metal and can be provided with dams **13** in the bottom thereof to control the liquid metal currents. The liquid steel leaves tundish **12** through an opening **14** in the bottom thereof and is transferred in a stream to a mold indicated at **15** in FIG. **1**. Mold **15**, being of the type employed in known continuous casting processes, is generally hollow, square or rectangular in shape and formed from metal, preferably copper. Mold **15** of the present illustration has an inlet or opening **16** at the top thereof for receiving molten steel. Freezing of the steel begins immediately as the molten steel comes in contact with the relatively cool copper mold. The cast steel structure or billet is withdrawn from mold **15** through an opening **17** in the bottom thereof and is passed through external cooling means such as a spray chamber. In the present illustration a plurality of spray nozzles **20** are arranged along rows or banks **21**, **22** which, in turn, are provided with water supply conduits **23** and **24**, respectively. While two rows or banks **21**, **22** are shown, in practice a total of four would be provided and spaced at ninety degree intervals around the region through which the cast structure travels. This movement of the cast steel billet is provided by a series of pinch or withdrawl rolls **25** rotatably supported in a housing **26** and coupled to a suitable drive means (not shown).

The arrangement and operation of the apparatus thus described is characteristic of continuous steel casting methods and apparatus herefore known. Solidification begins within mold **15**, further solidification of the steel takes place in the spray chamber, and solidification is shown to be completed through radiation to the atmosphere. The pinch rolls **25** control the speed of travel of the cast structure or billet from the apparatus and also the level of molten steel in mold **15**.

In accordance with this invention, the apparatus further comprises a length of metal wire or wires **30** contained in a storage means in the form of reel **31**. Wire **30** is withdrawn from reel **31** at a controlled rate by means including a plurality of feed rolls **32** driven by a controlled drive means **33**. In the present instance three rolls **32** are included and drivenly coupled as indicated by the dashed lines **34** to drive means **33**. The latter can comprise, for example, a reversible d.c. motor provided with the appropriate speed control as well as mechanical gearing and coupling to shafts **34**.

The apparatus further includes a guide means in the form of tube **38** cooperatively associated with a portion of wire **30** for directing wire **30** as it is delivered into the molten steel at the top of mold **16**. Tube **38**, which can be of metal such as copper or steel, is disposed so that wire **30** upon leaving tube **38** travels through the molten steel in the general direction of the flow of material through mold **15**.

The apparatus also comprises protective means at the top of mold **15** for preventing the formation of oxides or other undesirable substances on the surface of wire **30** prior to the entry thereof into the molten steel. In preferred form the protective means comprises a walled structure **42** attached at one end to the bottom of tundish **12** so as to surround opening **14** and attached at the other end to the top of mold **15** and surrounding opening **16** in the top thereof. A protective, oxygen-free atmosphere is maintained in the interior of structure **42** by means of a conduit **43** connecting it to a source **44** of an inert gas such as argon. Alternatively, source **44** could deliver nitrogen or could provide a vacuum.

The method of the present invention is performed in the following manner. A fusible material, in the present instance steel, which as a higher density in its solid phase than in its liquid phase, is introduced at a temperature above its fusion temperature to mold **15** at the open top or inlet **16** thereof. As molten steel is transferred from tundish **12** into mold **15**, wire **30** is delivered by the operation of rolls **32** and guided by tube **38** into the liquid metal at the top of mold **15** and in the general direction of the flow of material through mold **15**. Wire **30** is a member of fusible material having a length many times greater then its largest cross-sectional dimension, and wire **30** is at ambient temperature prior to entering the liquid metal. Depending upon the type, size and rate of the steel being cast, it may be desirable to direct wire **30** along the geometric center of the liquid metal pool in mold **15**. Ordinarily this would not appear to be necessary. As wire **30** enters the liquid or molten metal in mold **15** it grows initially to approximately three to three and one-half times its original cross sectional area and then melts in this superheated pool. The melting takes place within one to ten seconds after wire **30** has entered the liquid steel and this time is dependent upon the size of wire **30**.

The method of the present invention decreases the temperature differential between the center of the material being cast and the skin or shell thereof. This, in turn, changes the solidification pattern from dendritic to equi-axed grain formation and growth, as will be described in more detail presently. Reducing the liquid metal temperature in the center of the casting shortens the length of the liquid column therein. According to the method of the present invention there is maintained a low effective superheat in the metal liquid in the caster while having enough superheat in the liquid metal in tundish **12** to start and complete the strand casting process of a full ladle **11** of steel. Superheat is the amount of heat contained in a liquid volume which raises the liquid temperature above the fusion temperature. A uniform effective superheat in the liquid metal in the caster is maintained for the duration of the casting process by regulating the delivery rate or speed of wire(s) **30** as a function of the superheat measured in the liquid metal prior to entering mold **15** (i.e., the liquid metal in tundish **12**), the casting rate, and the cast section size.

Wire **30** has a cross sectional area and is delivered at a rate such that complete melting of wire **30** occurs at a point in the material being cast above the point where complete freezing of the metal is expected to take place. It is desired also that wire **30** not melt until the metal being cast beings to pull away from the inner surface of mold **15**. In the casting of steel, wire **30** is delivered at a rate such that freezing of the steel occurs at a point spaced from the level of molten steel at the top of mold **15** as short as one-seventh of the linear distance at which solidification is completed in conventional continuous casting. For example in casting a typical 4 inch billet at a rate of 15 tons per hour, solidification is complete at 35 feet below the level of molten steel at the top of mold **15**. According to the present invention, freezing will occur at about 5 feet below the level of molten steel at the top of mold **15**. In other words, superheat and heat of fusion are extracted from the liquid metal in the center thereof by adding wire **30** in an amount sufficient to remove superheat and heat of fusion from five feet below the top of the molten metal to the point at which the metal becomes completely frozen which is approximately 35 feet from the top of the metal pool. The foregoing now will be illustrated in detail by way of example.

The method and apparatus of the present invention was employed in one test in the casting of a 7–¼ inch by 6 inch section of grade 1038 steel at a casting rate of 25 tons per hour. The liquidus temperature of 1038 grade steel is about 2735° F, and molten metal flows from tundish **12** at approximately 700 feet per minute at a temperature of about 2800° F. This metal meets metal already present in mold **15** whereupon the flow becomes slower but penetrates along the axis of the bloom for some distance. Eventually this flowing metal meets the resistance of cooler liquid metal in the core area of the bloom.

In a conventional casting process, the hotter metal flows to the shell wall and up along the freezing shell wall toward the liquid metal surface. In the conventional process, the hot current of metal loses superheat as it flows upwardly until it reaches a temperature just above that of the liquidus in a region extending a short distance from the surface of the liquid metal level.

According to the method of the present invention, two wires **30** each having a diameter of 3/16 inch are introduced to the liquid metal in mold **15** adjacent to and generally parallel with the axis of the liquid stream entering mold **15** and the center line of the bloom in the casting apparatus. Wires **30** are delivered at a speed of 36 feet per minute and in an amount of 18 pounds per ton of steel cast. During these tests wire was delivered by Miller wire feeder machines having static controls or by Linde modified solid state controlled welding wire machines. Complete melting of wires **30** occurs in about 5 seconds or at a depth of about 3 feet from the liquid metal surface. As wires **30** pass through the liquid center, metal freezes to them. The superheat in the central liquid core is relatively unaffected. When the wire and the frozen shell on the wire melt, heat is absorbed from the surrounding superheated liquid, and the average decrease in the superheat in the liquid is 35° F. Under these conditions, this temperature in the core area of the bloom is about 2765° F and in the surrounding shell about 2735° F.

At a casting rate of 25 tons per hour, the speed of the moving bloom shell is 60 inches per minute. Data developed for vertical and curved mold low head strand casting machines indicate that a shell having a thickness of one inch is formed in approximately 1 minute of casting time. According to the foregoing example, a 1 inch shell forms about 5 feet from the liquid metal level. All the superheat and heat of fusion in this solidified volume of metal are removed by the cooling water of mold **15** and the water sprayed from nozzles **20**. This volume is 26.5 percent of the volume of the metal entering the casting apparatus. The correction of superheat to 30° F or less, therefore, is made only to the remaining liquid volume.

The number of wires **30** delivered into the molten metal is determined by calculating the melting position of the wires and the position where a one-inch bloom or billet shell is formed. The wire **30** should melt at or above the position of formation of the one-inch shell to insure sufficient metal volume and temperature to completely melt the wire. With wire **30** having a diameter of 3/16 inch according to the foregoing example, it has been found that one or two wires **30** will produce satisfactory results in the range from 9 square inches section size cast at 20 tons per hour with superheat in excess of 150° F to **121** square inches section size cast at 40 tons per hour with superheat as high as 60° F.

Results of further tests performed according to the foregoing example are summarized in the form of data presented in Tables I–III.

TABLE I

Volume of one inch shell as percent of total volume from liquid metal level to point of 1 inch shell thickness

Section size in inches	Section area in square inches	Volume of 1 inch inch shell as % of total volume	Volume of liquid as a % of total volume
3 × 3	9	67	33
5 × 5	25	36	64
7 × 7	49	27	73
9 × 9	81	21	79
11 × 11	121	17	83
12 × 12	144	16	84
10 × 36	360	13	87
10 × 50	500	12	88

TABLE II

Wire feed rate required for correction of liquid metal superheat for various casting rates and for an infinite section size

Equivalent °F of superheat removed from liquid metal	Tundish temperature minus liquidus temp. giving 30° F or less superheat in liquid core in degrees F	Pounds of wire added per ton cast	Wire feed rate in feet per minute Casting rate in tons per hour			
			15	25	35	50
5	35	3.3	9	14	21	30
10	40	6.6	18	29	41	59
15	45	9.9	26	43	62	89
20	50	13.2	35	58	82	118
30	60	19.8	53	86	123	177
40	70	26.4	70	114	164	236
50	80	33.0	89	144	205	295
70	100	46.2	123	201	287	413
90	120	59.4	158	259	369	531
100	130	66.0	176	288	410	590

A single wire having a diameter of 3/16 inch was used in obtaining the data presented in Table II. By infinite section size it is meant that the data of Table II would apply to a situation where a relatively uniform liquid to solid transition would occur without initial formation of the outer shell. Since such a shell does in fact form surrounding the central liquid core, a correction factor must be applied as will be described in detail presently.

TABLE III

Wire feed rate required for correction of liquid metal superheat for various casting rates and for a 7 inch × 7 inch casting size

Tundish temperature minus liquidus temp giving 30°F or less superheat in liquid core in degrees F	Pounds of wire added per ton cast	Wire feed rate, ft./min. Casting rate, tons/hr. 15	20	30	40	50
35	2.4	7	9	13	18	22
40	4.8	13	17	26	35	43
45	7.2	19	25	39	52	57
50	9.6	25	34	52	69	86
60	14.4	38	51	77	113	122
70	19.2	51	69	104	147	173
80	24.0	65	86	129	181	215
100	33.6	89	120	180	249	300
120	43.2	115	154	230	317	390
130	48.0	128	171	257	351	430

A single wire having a diameter of 3/16 inch was used in obtaining the data presented in Table III.

The data presented in Table III is for the particular case of a 7 inch by 7 inch section size or a 49 square inch cross section. By applying the correction factor from Table I to the data of Table II, corresponding data can be obtained for any desired section size listed in Table I. For example, the correction factor for a 7 inch by 7 inch section from Table I is 73 percent. Assume that the measured difference between the tundish temperature and liquidus temperature giving 30° F or less superheat in the liquid core is 35° F. This value is found in the first row of Table II. The correction factor of 73 percent applied to 3.3 pounds of wire added gives the result that 2.4 pounds of wire should be added for every ton of steel cast to provide the desired correction of superheat. In addition, if the casting rate is to be 15 tons per hour, applying the correction factor of 73 percent to the value of 9 ft./min. yields the result that wire should be fed at the rate of 7 ft./min. Since the foregoing example is given for a 7 × 7 cast section size, the results correspond with the data of Table III.

During a casting operation the temperature of the liquid metal in the tundish and the liquidus temperature should be periodically measured. As the temperature difference changes, it will be necessary to adjust the wire feed rate. For example, the typical operating range is from 35° F to about 100° F temperature difference in the first column of Table III. Then, assuming a casting rate of 15 tons per hour, the wire feed rate will need adjustment over the range from 7 to about 89 feet per minute.

Wire **30** can be of carbon steel, and it has been determined that wire **30** does not have to be of the same composition as the material being cast. The composition of wire **30** can include alloying elements from the steel being cast and in varying concentrations. The effect on the chemical composition in the cast steel product will be negligible. In other words, the composition of the resulting steel billet will be substantially the same as the composition of the liquid metal in ladle **11** and will not be affected by the addition of the required pounds of wire per tons of steel being cast.

The chemical composition of wire **30**, on the other hand, is an important variable in controlling the complete melting of wire **30** in the billet or bloom. It has been determined that the carbon content of wire **30** should be equal to or greater than the carbon content of the metal being cast. This is illustrated by Table IV which is a tabulation of carbon content and the approximate metal liquidus temperature for carbon and low alloy steels.

TABLE IV

Approximate liquidus temperature of carbon steel by carbon analysis

Carbon content in percent by weight	Liquidus temperature in degrees F
0.10	2795
0.20	2765
0.40	2735
0.60	2700
0.70	2685

For example, a 1060 grade steel having 60° F superheat does not melt a 0.10 percent carbon wire. Although the shell which fuses to the wire melts, the core wire never reaches liquidus temperature. The liquidus temperature of the wire should be less than or equal to the liquidus temperature of the metal being cast to insure complete melting of the wire.

Since the proper structure is achieved by the addition of a predetermined amount of wire to the molten steel, the total casting rate can be increased and the billet structure will remain constant as long as the number of pounds of wire added per ton of steel being cast remains constant. Casting at a higher rate in terms of tons per hour on the strand requires that either the wire size or the delivery rate be increased. In addition, wire **30** may comprise multiple strands instead of single strand, the number probably being less than four strands. For example, when wire **30** is to have a relatively large cross-sectional area, it may be preferable, for material handling reasons as well as to achieve proper melting, to deliver several strands having a total cross sectional area equal to the required size rather than a single strand of that overall size.

Wire or wires **30** should be clean prior to entering the molten metal at the top of mold **15**. In this connection wire **30** can be cleaned prior to entering guide tube **38** by, for example, mechanical shaving or wire brushing or chemical treatment with acid. Alternatively, wire(s) **30** can be cleaned and packaged prior to use whereupon as it leaves reel or storage means **31** its clean condition is maintained. In either, event, the protective means including structure **42** insures that unwanted oxides and other substances do not form on the surface of wire(s) **30** prior to entering the molten metal.

By virtue of the present invention, there is provided complete melting of the material which is added to the molten steel for improving the withdrawal of heat therefrom. The present invention also provides control of the position of melting of the added material. This is because wire **30** by its nature has sufficient rigidity to be maintained in position at or near the center of the liquid core where the temperature is the highest and where the most effective melting will occur. Wire **30** begins melting at the end first introduced into the molten metal, and the remainder of the wire **30** retains sufficient rigidity to enable the location of the wire **30** in the liquid metal to be controlled. In other words, wire

30 in being a relatively continuous member having considerable length and sufficient rigidity is not influenced by the circulating metal currents described hereinbefore. These currents which flow upwardly along the frozen shell would tend to carry discrete or particulate material along this path and cause such material to be trapped or lodged in the shell. In this connection, it is noted that the speed of wire 30 is sufficiently different from the speed of the cast steel shell moving through the apparatus to cause wire 30 to slide away from the shell if it should happen to contact it, rather than becoming lodged in the shell.

The advantages derived from the method and apparatus of the present invention are readily apparent from an inspection of the cast steel product resulting therefrom. FIGS. 2A and 2B show a billet 50 produced by a conventional continuous casting process. The metallurgical structure of billet 50 includes a thin band or shell of equi-axed grains indicated at 51. By equi-axed, it is meant that the mechanical properties of the grains are the same in the directions of the longitudinal and the transverse axes of the structure. In other words the mechanical properties of the grains are non-directional. Typically, this outer band or shell 51 has a thickness of up to about ¼ inch. Dendritic grains, indicated at 52, grow from the thin shell 51 toward the center of billet 50 and are composed of relatively pure iron with small amounts of alloying elements present in the grain. Between the branches of the dendrites is a liquid constituent of a relatively lower melting point and relatively higher alloy content. In the center region of billet 50, through about a one inch diameter portion of the cross section thereof, are equi-axed grains 53 of the approximate chemical composition of the liquid steel present in ladle 11 prior to casting thereof. Also, in and along the center axis of billet 50 are voids or holes 54 surrounded by metal of a high alloy composition. Typically, holes 54 will be of a size up to about ¼ inch in diameter or cross section.

Chemical segregation of alloying elements around dendrites 52 is microscopic in nature and large variations occur in the alloy composition. By this is meant that the segregation can only be distinguished with the use of a microscope on a sample which is polished and etched and viewed at approximately 100X magnification. The chemical segregation of alloying elements around voids or holes 54 is macroscopic in nature and has a smaller degree of magnitude of alloy variation. The macroscopic segregation can be observed by the naked eye on a sample that has been polished and etched. The observation is one of color contrast, with a major portion of the sample appearing grey, and the segregation around the center having a silver-like appearance. This phenomenon can be seen in both transverse and longitudinal sectional samples. In addition, it can be seen in as-cast products as well as in products resulting after hot working of the as-cast structure.

Billet 50 thus is characterized by center porosity as indicated by the presence of holes or voids 540 Holes or voids 54 result from dendritic grain formation bridging the thin molten core which prevents the flow of molten metal into the voids. This results in the segregation of alloying elements and other impurities along the center line of the structure during casting due to the relatively low thermo-conductivity of the outer steel shell which is first to freeze or solidify. The relatively large dendritic crystal growth, as indicated at 52, caused by this relatively low transfer results in relatively coarse grains which have directional mechanical properties.

FIG. 3A and 3B illustrate a cast structure or billet 60 obtained from the method and apparatus of the present invention. Billet 60 likewise has a relatively thin outer band or shell 61 of equi-axed grains. It also includes dendritic grains 62 which grow from the equi-axed grains 61 toward the center of billet 60. Dendritic grains 62, however, are relatively much shorter in length and smaller in size as compared with dendritic grains 52 in the conventional billet 50. Billet 60 is completed by a region of equi-axed grains 63 throughout the center thereof. In fact, equi-axed grains being in region 63 and shell 61 thus are present in or through a major portion of billet 60.

The cast structure or billet 60 resulting from the method and apparatus of the present invention, because of heat extraction from the center of the structure during the casting process and because of the introduction of the wire creating nucleating points for grain formation has significant structural and chemical differences as compared with the conventional cast structure or billet 50. In particular, billet 60 has an equi-axed grain structure with a chemical composition in each grain equal to the nominal composition of the steel in ladle 11. This comparison of the chemical composition between conventional billet 50 and the present structure 60 is illustrated in Table V. The data presented is for various alloying elements, in particular carbon, manganese, silicon, sulphur and phosphorous as listed in the first column. The second column indicates the typical percentage by weight of these elements present in the molten steel prior to casting and regardless of the process used. The next four columns present data in percentage by weight for a conventional cast structure or billet such as that indicated at 50 in FIGS. 2A and 2B. The last column presents the chemical composition in percentage by weight of the grains in cast structure or billet 60, and it is seen that this composition is the same as that of the alloying elements present in the molten steel prior to casting.

Billet 60 is characterized by a uniform distribution of the alloying elements throughout the structure. In other words, the rapid freezing which occurs both internally and externally of the cast structure eliminates or minimizes the dendritic crystal growth and the segregation of these elements to the center of the structure. In particular, an inspection of FIGS. 2 and 3 will indicate the relatively small size of dendrites 62 in billet 60 as compared with dendrites 52 in billet 50. As a result, billet 60 has a solid center and is free of the porosity which is characteristic of billet 50.

The metal grains of billet 60 are relatively fine, have not been plastically deformed, and have mechanical properties which are non-directional. As a result, billet 60 is ideally suited for forging either by upsetting or by forging transverse to the longitudinal axis thereof. The forged product from billet 60 therefore will have superior mechanical properties as compared with forgings made by either cast billets from conventional processes or from hot rolled billets. FIGS. 2 and 3 for convenience in illustration show only a portion of the metallurgical structure of billets 50 and 60, respectively, it being understood that the same characteristics occur throughout the remainder of the respective structures.

TABLE V

Alloying elements	Nominal composition	Dendrite composition	Composition of material around the dendrite	Composition at equi-axed center structure	Composition around voids	New product
C	.40	<.30	(1)	~.35	~.50	.40
Mn	.80	<.70	>.80	~.75	~.90	.80
Si	.25	N.A.	N.A.	N.A.	N.A.	.25
S	.02	<.02	>.02	~.015	~.025	.02
P	.01	N.A.	N.A.	N.A.	N.A.	.01

[1] Can be greater than 1.00.

NOTE.—N.A.=not available.

FIGS. 4 and 5 illustrate alternative arrangements of apparatus for delivering wire to the molten steel. A tundish 12′, mold 15′ and wire 30′ are shown in FIG. 4 which are identical to tundish 12, mold 15 and wire 30 of the apparatus shown in FIG. 1. According to this embodiment, there is provided a generally hollow cylindrical member 65 for delivering molten steel from tundish 12′ to mold 15′. Member 65 is of refractory material, such as fused silica, and is provided with annular lip or flange 66 at one end thereof to facilitate attachment to the bottom of tundish 12′. In particular, an annular connecting member or ring 67 engages flange 66 and is connected by suitable fasteners 68 to the bottom wall of tundish 12′. As a result, member 66 is attached to the end thereof including flange 66 to tundish 12′, and is positioned so that the interior thereof is in communication with the opening in the bottom wall of tundish 12′. The inner diameter of cylindrical member 65 is greater than the diameter of the opening in the bottom wall of tundish 12′ , and member 65 is of a sufficient length whereby it extends into mold 15 and a short distance under the level of molten metal 70 in mold 15′ during the casting operation.

The apparatus of this embodiment further comprises a second generally cylindrical member 72, also of refractory material such as fused silica, on member 65 for guiding or directing wire(s) 30′ into the molten metal in mold 15′. Member 72 is shorter in length as compared with member 65, and is positioned on member 65 so that one end of member 72 is generally co-terminal with the end of member 65 below liquid metal level 70 and the other end of member 72 is above the level. As a result, wire(s) 30′ enters member 72, travels therethrough and is guided or directed into the liquid metal in mold 15′. Member 72 can be suitably attached or bonded to the outer surface of member 65 or can be formed integrally therewith.

By virtue of this arrangement, wire(s) 30′ enters the molten metal below level 70. This prevents any slag which may happen to accumulate at or near level 70 from contacting wire(s) 30′. Satisfactory results have been obtained with members 65 and 72 extending about 3 to 4 inches below level 70 and with the distance between the axes of members 65 and 72 being about 1–182 inches. The arrangement of FIG. 4 obviates the need for the protective means comprising structure 42, source 44 and conduit 43, but all the other components of the apparatus of FIG. 1 are included in the apparatus of FIG. 4.

In the embodiment of FIG. 5 there is included a tundish 12″, mold 15″ and wire 30″ which are substantially identical to tundish 12, mold 15 and wire 30 of the apparatus shown in FIG. 1. Wire(s) 30″ is withdrawn from storage apparatus and upon traveling toward mold 15″ is guided by a plurality of rollers, each designated 75, which are rotatably supported by a bracket or suitable housing 76 attached to tundish 12″. Wire(s) 30″ then passes between a drive wheel 77 and co-operating rollers 78 which are connected to a housing 79 which in the present illustration is supported on mold 15″. Wheel 77 is connected to a suitable controlled drive means (not shown) in housing 79, whereby wheel 77 provides the total power for withdrawing wire(s) 30″ from the storage apparatus. There is also provided a straightener comprising rollers 80 which operates on wire(s) 30″ after wheel 77 and prior to delivery into mold 15″.

Tundish 12″ is positioned close to mold 15″ to facilitate delivery of molten steel. The operation of wheel 77 and rollers 78 on wire(s) 30″ in this relatively small space causes bending of wire(s) 30″ through or beyond the yield point thereof. Straightener rollers 80 insure delivery of wire(s) 30″ to the molten steel in mold 15″ in a direction along or generally parallel to the axis of the billet being formed.

The method and apparatus of the present invention, characterized by controlled delivery of a solid member having a length many times greater than its largest cross sectional dimension, in the form of metal wire 30, advantageously enables convenient and accurate regulation of wire speed as a function of superheat measured in the liquid metal prior to entering the mold, of the casting rate and of the cast section size. This, in turn, permits control of center porosity and center line chemical segregation over a wide range of casting speeds.

Another advantage derived from the method and apparatus of the present invention is that the relatively more rapid solidification resulting therefrom permits casting rates to be increased thereby enhancing the productivity of existing equipment.

It is therefore apparent that the present invention accomplishes its intended objects. While a single specific embodiment has been described in detail, this has been done by way of illustration without thought of limitation.

I claim:

1. In a method for continuously casting a fusible material which has a higher density in its solid phase than in its liquid phase which comprises introducing said material at a temperature above its fusion temperature to a mold at the inlet thereof, withdrawing heat from the material to cause it to solidify, and continuously withdrawing the cast material from the mold at the outlet thereof, the improvement comprising:

a. delivering a solid member of fusible material having a length many times greater than its largest cross-sectional dimension into and below the surface of liquid material within the mold at or near the inlet thereof and in the general direction of flow of material through the mold; and

b. regulating the speed of delivering said member as a function of the superheat measured in the liquid material prior to entering said mold, of the casting rate, and of the cast section size to reduce the superheat in the region of the liquid material core to a predetermined value;

c. whereby solidification of said material is effected in the interior thereof and in the region along the center axis thereof.

2. A method according to claim 1 wherein said fusible material being cast is steel.

3. A method according to claim 2 wherein said member of fusible material comprises a metal wire.

4. A method according to claim 3 wherein said step of delivering the metal wire is done at a rate such that freezing of the steel occurs at a point spaced from the level of molten steel in the mold a distance as short as one-seventh of the linear distance at which solidification would be completed in absence of delivery of said wire.

5. A method according to claim 3 wherein said wire has a diameter in a range of up to about ½ inch.

6. A method according to claim 1 further including the step of preventing the formation of oxides and the like on said member prior to delivery thereof into said liquid material.

7. A method according to claim 1 wherein said member of fusible material comprises a metal wire having a diameter in a range of up to about ½ inch.

8. In a method for continuously casting steel which comprises introducing steel at a temperature above its fusion temperature to a mold at the inlet thereof, withdrawing heat from the liquid steel to cause it to solidify, and continuously withdrawing the cast steel from the mold at the outlet thereof, the improvement comprising:

a. delivering a metal wire into the liquid steel at or near the mold inlet and in the general direction of flow of steel through the mold; and

b. regulating the speed of said step of delivering wire as a function of the superheat measured in the liquid steel prior to entering said mold, of the casting rate, and of the cast section size to correct the superheat in the region of the liquid steel core to about 30° F or less.

9. A method according to claim 8 wherein said wire has a maximum diameter of about one-half inch and is of steel having a carbon weight percentage equal to or greater than that of the steel being cast.

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