

May 23, 1967

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METHOD OF COOLING CONTINUOUS CAST METAL IN THE MOLD

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2 Sheets-Sheet 1

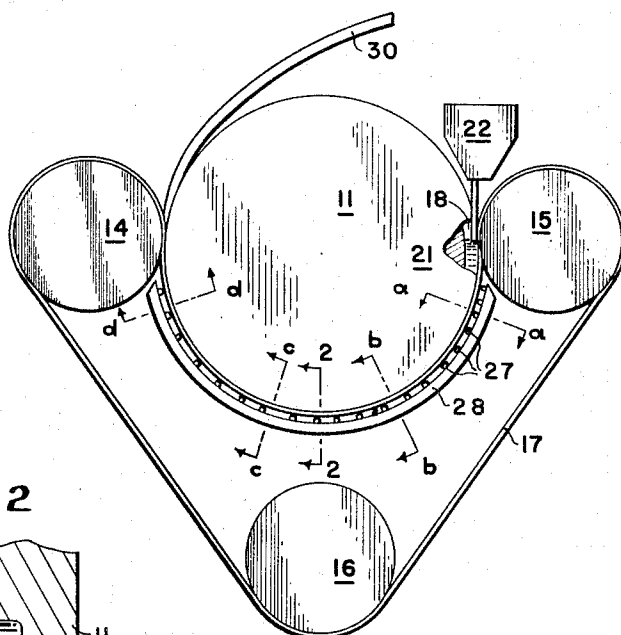


Fig. 1

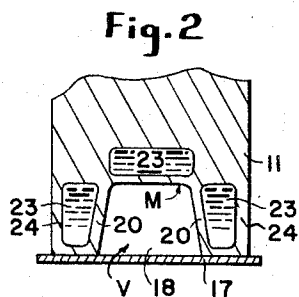
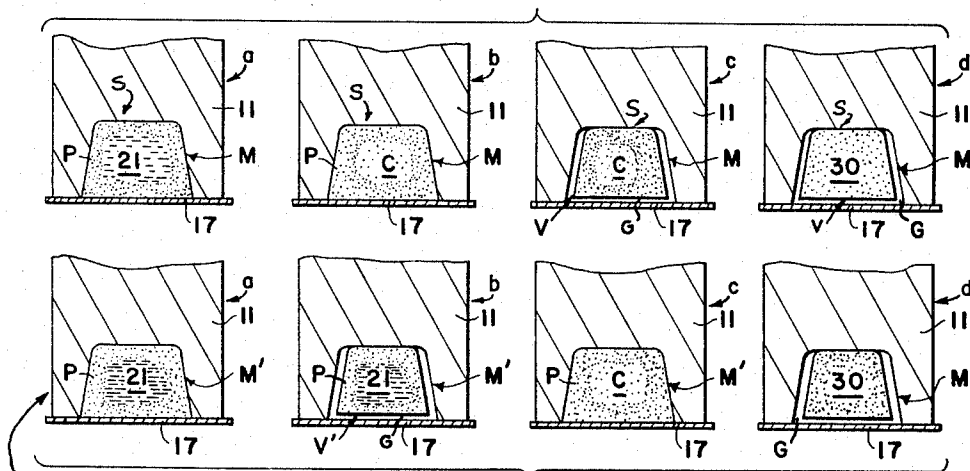


Fig. 2

Fig. 3



PRIOR ART

Fig. 4

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Fig. 5

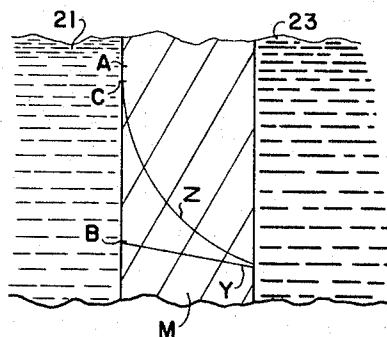
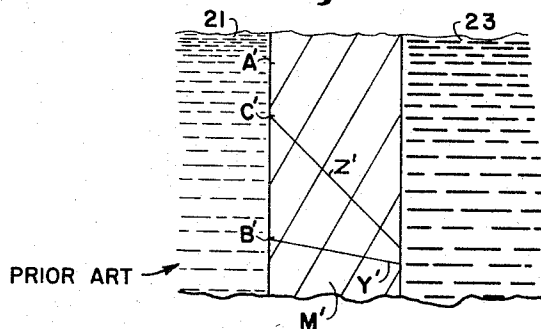


Fig. 6



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METHOD OF COOLING CONTINUOUS CAST METAL IN THE MOLD

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This invention relates to the casting of molten metals and more particularly, to the continuous casting of a molten metal in a shape which provides a small surface area relative to the mass of molten metal to be cooled during casting and where the continuous casting mold is exposed to cyclic temperature conditions.

In the continuous casting of molten metals, it is customary to use a continuous casting mold which is substantially closed and in which molten metal is solidified to obtain cast metal as the molten metal passes through or travels with the mold. The continuous casting mold may be formed by continuously travelling walls, by a combination of continuously travelling and stationary elements, or simply by a stationary tube from which cast metal passes after solidification of the molten metal. However, regardless of the particular arrangement used to form the continuous casting mold, the solidification of molten metal to obtain cast metal is accomplished by the transfer of heat from the molten metal to or through the mold which is itself frequently cooled by the subsequent transfer of heat to a fluid medium such as water or air.

Moreover, regardless of the particular arrangement used to form the continuous casting mold, it is a requirement of a continuous casting mold that the solidification of the molten metal be achieved within a reasonably short length of time. This requirement exists because desirable high casting rates can be obtained only with reasonably rapid solidification of the molten metal. Such reasonably rapid solidification of the molten metal is particularly difficult to achieve in the continuous casting of a cast metal such as a cast bar having a shape which provides only a small surface relative to the mass of molten metal which must be cooled. This is because a large amount of heat must be transferred through a relatively small surface in a relatively short time. It is for this reason that various elaborate cooling arrangements have been proposed and used in the prior art with continuous casting molds for cast bars and similar shapes of cast metal.

It is also for this reason that continuous casting molds for cast bars and similar shapes of cast metal have characteristically been constructed of materials having a high rate of heat transfer. In the prior art, it was felt that such materials would quickly and efficiently transfer heat from the molten metal to the particular cooling arrangement selected and would provide the most efficient cooling of the molten metal in spite of only a relatively small surface being available for cooling.

A difficulty with using a material having a high rate of heat transfer for a continuous casting mold is that such materials frequently have relatively poor structural strength. In addition, many continuous casting molds such as casting wheels are exposed to cyclic temperature conditions as molten metal is repeatedly received and cooled, and the relatively large temperature fluctuations which generally occur throughout most materials having a high rate of heat transfer with exposure to these cyclic temperature conditions cause excessive thermal fatigue in such molds. Thus, the useful life of a continuous casting mold constructed of a material having a high rate of heat transfer has characteristically been relatively short because of the formation of large thermal cracks in the mold and often because of the complete structural fail-

ure of the mold. Further, in casting wheels, the poor structural strength and thermal fatigue encountered in the prior art have frequently resulted in thermal ratcheting and the partial closing of the casting groove.

Moreover, the use of a material having a high rate of heat transfer in a continuous casting mold for cast bars and similar shapes of cast metal has often adversely affected the properties of the cast metal. This is because the continuous rapid transfer of heat through the mold from the molten metal to a cooling arrangement selected to provide efficient and rapid cooling of the mold as taught in the prior art causes the mold to be simply a heat transfer device to which the peripheral portions of the molten metal continuously transfer heat at a rate which is substantially greater than the rate at which heat is transferred from the central portion of the molten metal to these peripheral portions.

As a result, there is a non-uniform cooling of the molten metal and sometimes a chilling of the peripheral portions of the molten metal. The non-uniform cooling of a molten metal or the chilling of any portion of a molten metal will often adversely affect the properties of many cast metals.

The non-uniform cooling of the molten metal which is characteristic of prior art continuous casting molds constructed of materials having a high rate of heat transfer also results in the early forming of only partially solidified molten metal while substantial heat remains in the central portion of the molten metal. Since the partially solidified molten metal occupies less space in the mold than that occupied by the molten metal initially, a gap is formed between the mold and some of the peripheral portions of the partially solidified molten which retards the continued cooling of the molten metal by contact between the molten metal and the mold.

The heat transferred across this gap generally does not effectively offset the retarding of heat transfer by contact between the molten metal and the mold which occurs because of this gap. Thus, the rapid initial solidification of the peripheral portions of the molten metal which is characteristic of prior art continuous casting molds constructed of materials having a high rate of heat transfer not only results in a non-uniform cooling of the molten metal, but also results in a reduction in the cooling efficiency with which the molten metal is cooled while there is still substantial heat in the central portion of the molten metal.

In some prior art continuous casting molds, this reduction in the cooling efficiency of the mold while there is still substantial heat in the central portion of the molten metal causes a reheating of the previously solidified peripheral portions of the molten metal by heat transferred from the central portion to these peripheral portions. This, in turn, causes a partial melting of the peripheral portions of the partially solidified molten metal and the previously formed gap to be in whole or in part eliminated. When this occurs, there is a second rapid cooling of the peripheral portions of the molten metal which further contributes to the non-uniform cooling of the molten metal and may even cause a second chilling of the peripheral portions of the molten metal.

The invention disclosed herein overcomes these and other difficulties encountered in the prior art in that it provides for the continuous casting of metal under cyclic temperature conditions at efficient casting rates with substantially uniform cooling of all portions of the molten metal and without significant chilling of any portion of the molten metal even though the surface of the molten metal is small relative to the mass of molten metal to be cooled. Thus, the invention provides cast metal which has little tendency to crack or fail mechanically. Further, the invention provides a continuous casting mold

which has a relatively long useful life because of its initial structural strength and because of the small amount of thermal fatigue and the lack of thermal ratcheting in the mold even though the mold is exposed to cyclic temperature conditions.

These improvements in the continuous casting of molten metal are provided by initially retaining sufficient heat from the molten metal in the casting mold adjacent the molten metal to cause an increase in the temperature of the mold which prevents too rapid cooling of the peripheral portions of the molten metal and by restricting this increase in the temperature of the mold and other extreme temperature changes to only a portion of the mold. More specifically, these improvements are provided by using a mold construction or material which results in a mold having a particular rate of heat transfer and a particular rate of temperature propagation or transfer. The rate of heat transfer is such that that portion of the mold adjacent the molten metal increases rapidly in temperature to a temperature which substantially slows the initial cooling of the molten metal by the mold and is such that the mold nevertheless transfers heat from the molten metal to a cooling medium. The rate of temperature transfer of the mold is such that the increase in temperature when the mold initially receives the molten metal and other extreme temperature changes are restricted to that portion of the mold adjacent the molten metal.

The slowing of the initial solidification of the peripheral portions of the molten metal. Thus, the invention provides for substantially uniform cooling of all portions of the molten metal.

Moreover, when the solidification of the molten metal does reach that point at which a gap is formed between the partially solidified molten metal and the mold, the substantially uniform cooling of the molten metal has reduced the heat in the central portion of the molten metal to a degree which avoids that substantial reheating of the peripheral portions of the molten metal which is frequently encountered in the prior art. However, the rate at which heat is nevertheless transferred from the molten metal to a coolant by the mold results in the complete solidification of the molten metal at casting rates equivalent to those achieved in the prior art.

Where the mold is a casting wheel or other mold arrangement which is exposed to the cyclic temperature conditions of repeatedly receiving and cooling molten metal, the restricting of extreme temperature changes to that portion of the mold adjacent the molten metal prevents those extreme fluctuations in temperature throughout the mold which cause substantial thermal fatigue. This and the fact that a mold construction or material having these rates of heat transfer and temperature transfer need not have the poor structural strength characteristic of prior art mold materials having a high rate of heat transfer result in the invention providing a casting mold which is structurally strong and which has a relatively long useful life.

These and other features and advantages of the invention will be more clearly understood from the following detailed description and the accompanying drawings in which like characters of reference designate corresponding parts throughout and in which:

FIG. 1 is a side elevational view of a continuous casting machine of a type in which the invention disclosed herein may be readily embodied;

FIG. 2 is a partial sectional view of the continuous casting machine shown in FIG. 1 taken substantially in line 2—2 in FIG. 1;

FIG. 3 is a schematic presentation of solidification of molten metal in the casting machine of FIG. 1 in accordance with the invention showing the solidifying molten metal at the four points indicated in FIG. 1;

FIG. 4 is a schematic presentation of the solidification of molten metal in a casting machine similar to that of FIG. 1 in accordance with the prior art showing the solidifying molten metal at the four points indicated in FIG. 1;

FIG. 5 is a schematic presentation of temperature gradients between the casting cavity and the coolant in the casting machine of FIG. 1 when molten metal is solidified in accordance with the invention and shows a temperature gradient before molten metal is received in the mold and a temperature gradient substantially immediately after molten metal is received in the mold;

FIG. 6 is a schematic presentation of temperature gradients between the casting cavity and the coolant in a casting machine similar to that shown in FIG. 1 when molten metal is solidified in accordance with the prior art and shows a temperature gradient before molten metal is received in the mold and a temperature gradient substantially immediately after molten metal is received in the mold.

These figures and the following detailed description disclose a specific embodiment of the invention but the invention is not limited to the details disclosed since it may be embodied in other equivalent forms.

The invention in the continuous casting of metals disclosed herein may be most easily understood in terms of a continuous casting machine 10 such as that shown in FIG. 1. However, it should be understood that the continuous casting machine 10 shown in FIG. 1 is representative of many mold arrangements which substantially enclose molten metal as it is solidified to obtain cast metal and with which efficient casting rates can be obtained only by relatively rapid solidification of the molten metal. Moreover, it should also be understood that the continuous casting machine 10 is representative of those casting machines which have been used in the prior art for casting of a bar 30 or other shape having a small surface relative to the mass of molten metal to be cooled during casting and which are exposed to cyclic temperature conditions as it continuously receives molten metal to be cooled and removed as cast metal.

The continuous casting machine 10 selected to illustrate an embodiment of the invention comprises a casting wheel 11 rotatably mounted on a support member (not shown) for rotation by a motor (not shown) or other power source. Rotatably carried by the support member (not shown) on opposite sides of and adjacent the casting wheel 11 are two idler pulleys 14 and 15. These idler pulleys 14 and 15 cooperate with an idler pulley 16 carried by the support member (not shown) below the casting wheel 11 to support a continuous belt 17 which engages the lower periphery of the casting wheel 11 between the idler pulley 14 and the idler pulley 15.

The casting wheel 11 has a peripheral groove 18 which is closed by the belt 17 and provides mold members or walls 20 which cooperate with the belt 17 to define a continuous casting mold M with a casting cavity V into one end of which molten metal 21 is poured from a crucible 22 and from the other end of which completely solidified molten metal passes as a bar 30. The mold M is cooled by the passage of coolant 23 in three channels 24 adjacent the walls 20 and by the spraying of coolant 23 on the belt 17 with nozzles 27 extending from an arcuate duct 28. It will be understood that the coolant 23 is fed to the three channels 24 and to the arcuate duct 28 from a coolant supply (not shown) and that after passing through the channels 24 and over the belt 17, the coolant 23 is either discharged from the system or recirculated.

It will also be understood by those skilled in the art that the cooling arrangement described provides an effective means for removing heat from the mold M by the transfer of heat from the mold M to the coolant 23. More importantly, it will be understood by those skilled in the art that in a continuous casting mold such as the mold M having an effective cooling arrangement, the removal of

heat from the molten metal 21 for solidification of the molten metal 21 is primarily determined by the transfer of heat between the molten metal 21 and the mold M and by the transfer of heat between the mold M and the coolant 23.

Thus, the continuous casting machine 10 used herein for the purpose of illustrating the invention is a conventional casting machine to the extent that the solidifying of the molten metal 21 is a function of the heat transferred between the molten metal 21 and the mold M and of the heat transferred between the mold M and the coolant 23. It is for this reason and because the structural arrangement of the continuous casting machine 10 in general resembles prior art casting machines that the structural arrangement of the continuous casting machine 10 is not described in greater detail.

However, unlike continuous casting machines used in the prior art, in the casting machine 10 described above, both the belt 17 and that portion of the casting wheel 11 forming the mold M between the coolant 23 and the molten metal 21 are formed of a material having a rate of heat transfer which results in that portion of the mold M adjacent the molten metal rapidly increasing in temperature to a temperature which substantially retards the cooling of the molten metal immediately after the molten metal 21 is poured from the crucible 22 into the casting cavity V while at the same time providing for the transfer of heat from the molten metal 21 to the coolant 23 and having a rate of temperature transfer which prevents the rapid transfer of this temperature increase throughout the mold M. Those skilled in the art will understand that similar heat transfer and temperature transfer rates can be provided by various mold constructions such as those using several materials to form a composite mold M. Thus, the mold M formed of a single material is only representative of apparatus for practicing the invention disclosed herein.

The significance of using a material for the mold M having the rate of heat transfer described above is best understood by comparing the casting of molten metal 21 in the mold M and in a mold M' formed of a prior art material having a rate of heat transfer which results in the continuous rapid transfer of heat from the molten metal 21 to the coolant 23 as molten metal 21 is received in the cavity V'. FIG. 3 schematically shows the progressive solidification of a segment of molten metal 21 in the mold M at various arbitrarily selected points a, b, c, and d during the rotation of the casting wheel 11. Similarly, FIG. 4 schematically shows the progressive solidification of the molten metal 21 in the mold M' at the same arbitrarily selected points during the rotation of the casting wheel 11.

Thus, FIGS. 3 and 4 schematically show the solidification of molten metal 21 at corresponding points in its passage through a mold M and a mold M' with rotation of the casting wheel 11. However, it should be understood that FIGS. 3 and 4 are merely representative of the solidification of the molten metal 21 and that they are not intended to show the actual state or degree of solidification of molten metal 21 at any specific point in its passage through a mold M or M'.

From both FIGS. 3a and 4a, it will be seen that the initial cooling of molten metal 21 in the mold M or M' occurs as a result of contact between the molten metal 21 and the mold M or M'. This is because the molten metal 21 completely fills the mold M or M' as it is poured into the mold M or M' from the crucible 22 and because this places the peripheral portions P of the molten metal 21 in direct contact with the mold M or M'. Thus, in both the mold M and the mold M' there is an initial contact transfer of heat between the molten metal 21 and the mold M or M' at an initial rate determined largely by the initial difference in temperature between the molten metal 21 and the mold M or M'.

However, since the prior art mold M' is constructed of a material having a high rate of heat transfer, the initial heat transferred to the mold M' from the molten metal 21 passes almost as rapidly through the mold M' to the coolant 23 as it is received from the molten metal 21 and the transfer of heat from the molten metal 21 to the mold M' continues at a rate of heat transfer which causes the peripheral portions P of the molten metal 21 to solidify rapidly.

As a result, the peripheral portions P of the molten metal 21 are quickly cooled by the mold M' and before there has been a significant transfer of heat from the central portion C of the molten metal 21 to these peripheral portions P. Thus, there is a substantially non-uniform cooling of the molten metal 21 which adversely affects the properties of the cast bar 30. In many prior art molds such as the mold M', the cooling of the peripheral portions P is so excessive as to cause chilling of the peripheral portions P of the molten metal 21 which further adversely affects the properties of the bar 30.

Further, even when the non-uniform cooling does not chill the peripheral portions P of the molten metal 21 the continuous rapid cooling of the molten metal 21 by the mold M' causes a substantial shrinking of the partially solidified molten metal 21 and the early forming of a gap G between the mold M' and the molten metal 21 as indicated in FIG. 4b. This gap G retards the continued transfer of heat from the solidifying molten metal 21 to the mold M' since it reduces contact between the molten metal 21 and the mold M'. As a result, there is retarded cooling of the molten metal 21 by the mold M' while there is still substantial heat in the central portion C of the partially solidified molten metal 21. This substantial heat remaining in the central portion C of the partially solidified molten metal 21 is frequently adequate to cause a partial remelting of the previously solidified peripheral portions P of the molten metal 21 and an expansion of the partially solidified molten metal 21 which substantially eliminates the gap G as indicated in FIG. 4c.

When this occurs, there is a second rapid cooling of the peripheral portions P of the molten metal 21 before the molten metal 21 finally solidifies completely into the bar 30 as indicated in FIG. 4d. This second rapid cooling serves to further augment the non-uniform cooling of the molten metal 21 by the mold M; and may even result in a second chilling of the peripheral portions P of the molten metal 21. However, even in the absence of any second chilling of the partially solidified molten metal 21, it will be understood that the mold M' has solidified the portions C and P of the molten metal 21 in a substantially non-uniform manner.

In contrast to the mold M', the mold M retards the rapid cooling of the peripheral portion P of the molten metal 21 before there is excessive cooling of the peripheral portions P of the molten metal 21 and the gap G is formed. This is because the relatively low rate of heat transfer of the material from which the mold M is formed causes a substantial amount of the heat initially transferred from the molten metal 21 to the mold M to be retained by the portion S of the mold M adjacent the molten metal 21 so as to cause a rapid and substantial increase in the temperature of the portion S of the mold M to a temperature which substantially reduces the temperature difference between the molten metal 21 and the mold M. Thus, the transfer of heat from the molten metal 21 to the mold M is retarded before excessive cooling of the peripheral portions P of the molten metal 21 and sufficient solidification of the molten metal 21 to form the gap G occur. However, the material from which the mold M is constructed has a rate of heat transfer which provides for the heat from the molten metal 21 to be continuously transferred through the mold M to the coolant 23 at a rate which results in the heat transferred to the coolant 23 alone or the heat transferred to the coolant

23 and the heat retained in the portion S of the mold M together being equal to that amount of heat which must be removed from the molten metal 21 in order to completely solidify the molten metal 21 in a predetermined interval of time.

Thus, the invention provides controlled cooling of the molten metal 21 in a manner which causes the heat transferred from the peripheral portions P of the molten metal 21 to the mold M subsequent to the initial heat transferred to the portion S to not substantially exceed the heat transferred from the central portion C of the molten metal 21 to the peripheral portions P. As a result, substantially uniform cooling of the molten metal 21 occurs until that point in the solidification of the molten metal 21 indicated in FIG. 3c is reached at which the gap G is formed between the molten metal 21 and the mold M because of the solidification of the molten metal 21.

The forming of the gap G in the mold M further retards the transfer of heat from the molten metal 21 to the mold M because it reduces the contact between the molten metal 21 and the mold M. However, unlike the mold M', in the mold M, the gap G is formed later and after a longer period of substantially uniform cooling. Thus, there is less heat in the central portion C of the molten metal 21 when the gap G is formed in the mold M and less tendency than with the mold M' for the heat of the central portion C to reheat the peripheral portions P of the molten metal 21. As a result, the cooling and solidification of the molten metal 21 continues in a substantially uniform manner without that non-uniform cooling or chilling of the peripheral portions P of the molten metal 21 which is frequently encountered in the prior art because of the heat remaining in the central portion C of the molten metal 21 when the gap G is formed.

It will now be understood that the mold M is both a means for retaining heat adjacent the molten metal 21 to provide an initial temperature increase which prevents too rapid initial cooling of the molten metal 21 and a means for transferring heat from the molten metal 21 to a coolant 23. It will also be understood that the solidification of the molten metal 21 to obtain the cast bar 30 between the points a and d in FIG. 1 requires the transfer from the molten metal 21 to the mold M of a particular amount of heat between the points a and d and that the casting rate is dependent upon the length of time required to transfer this particular amount of heat from the molten metal 21 to the mold M.

In both the mold M and the mold M', the length of time required to transfer this particular amount of heat from the molten metal 21 to the mold M or M' is dependent not only upon the rate at which heat is transferred by the material of the mold M or the mold M' and the degree of cooling provided by the coolant 23 but also upon the distance through the mold M or M' between the molten metal 21 and the coolant 23. It is because of this and because many materials having a relatively low rate of heat transfer also have great structural strength that the mold M provides casting rates equivalent to those achieved in the prior art by simply reducing the distance through the mold M between the molten metal 21 and the coolant 23 to a degree not possible with prior art materials without seriously impairing the strength of the mold M'.

Moreover, since the mold M, unlike the mold M', initially retains a substantial amount of heat to provide a temperature of the portion S of the mold M which retards the cooling of the molten metal 21, the total amount of heat transferred to the mold M from the molten metal 21 between the points a and d in FIG. 1 is the sum of the amount of heat initially retained in the portion S of the mold M which remains in the mold M at point d and of the heat transferred by the mold M to the coolant 23 between the points a and d in FIG. 1. Thus, the mold M will also provide casting rates equivalent to those of

prior art mold M' even if the distance between the molten metal 21 and the coolant 23 is the same in the mold M and the mold M' by allowing some or most of the amount of heat initially retained in the portion S of the mold to remain in the mold M at point d in FIG. 1 and by removing this heat from the mold between points d and a with the coolant 23 in the channels 24 while the mold M is empty.

It is also because the cooling of the molten metal 21 by the mold M is a function both of the cooling between the points a and d in FIG. 1 by the coolant 23 and of the amount of heat retained by the portion S of the mold M at point d in FIG. 1 that the mold M provides convenient control of casting rates. This is because the cooling of molten metal 21 between the points a and d in FIG. 1 in a particular length of time can be varied by varying the cooling of the mold M between points a and d, by varying the temperature of the mold M just prior to point a in FIG. 1 so as to vary the amount of heat initially transferred to and retained by the portion S of the mold M, or by varying the amount of the heat retained by the portion S of the mold M at the point d in FIG. 1 and which is removed between points d and a.

That the use of a material for the mold M which not only has the rate of heat transfer described above but also a rate of temperature transfer which prevents temperature changes of the portion S of the mold M from being rapidly transferred throughout the mold M provides a mold M which resists thermal fatigue is best shown in FIG. 5. In FIG. 5 it will be seen that in a mold M having a relatively low rate of temperature transfer, the substantial change in the temperature of the portion S of the mold M which retards the cooling of the molten metal 21 and which occurs because of the relatively low rate of heat transfer does not pass through the mold M because of the relatively low rate of temperature transfer.

This is particularly important in a mold M, such as that provided by the casting wheel 11, which is exposed to cyclic temperature conditions as the molten metal 21 is alternately received in the mold M, cooled, and removed as a cast bar 30. The substantial restricting of the resulting temperature fluctuations in the mold M to the portion S of the mold M prevents that thermal fatigue throughout the mold M which would impair its structural strength even though the mold M were formed of material having great initial structural strength. It is because of this and because many materials having both a rate of heat transfer and a rate of temperature transfer suitable to the invention also have great structural strength that the invention disclosed herein provides a mold M which has a relatively long useful life and which resists the thermal ratcheting and the closing of the casting groove V frequently encountered with prior art casting wheels similar to the casting wheel 11.

Operation

A description of the operation of a casting wheel 11 having a mold M formed of low carbon steel will further clarify the invention when compared with the operation of a casting wheel 11 having a mold M' formed of copper as in the prior art. This is because the copper of the mold M' is typical of prior art materials having a high rate of heat transfer, a high rate of temperature transfer, and relatively low structural strength and because low carbon steel provides a material for the mold M which has a relatively low rate of heat transfer, a relatively low rate of temperature transfer, and relatively great structural strength.

In describing the operation of the mold M and M' it will be assumed that both the mold M and M' are used to cast molten copper at the same temperature A as shown in FIGS. 5 and 6 and that both the mold M and the mold M' are at approximately the same temperature B as shown in FIGS. 5 and 6 just prior to point a in FIG.

1. This is because regardless of the particular temperature of the mold M or M' or of the molten metal 21, it will be understood by those skilled in the art that the temperature gradient in the mold M just prior to point a in FIG. 1 is generally represented by the line Y in FIG. 5 and that because of the relatively low rate of temperature prior to point a in FIG. 1 is generally represented by the line Y' in FIG. 6.

It will also be understood by those skilled in the art that because of the relatively low rate of heat transfer in low carbon steel, the pouring of the molten metal 21 into the mold M causes the temperature of the mold M adjacent the molten metal 21 to increase by approximately nine-tenths of the difference between the temperature B of the mold M and the temperature A of molten metal 21 to a temperature C generally indicated in FIG. 5 and that because of the relatively low rate of temperature transfer in low carbon steel, this increase to the temperature C of the mold M causes the temperature gradient in the mold M to be generally represented by the line Z in FIG. 5. Similarly, it will be understood by those skilled in the art that because of the relatively high rate of heat transfer in copper, the pouring of the molten metal 21 into the mold M' causes the temperature of the mold M' adjacent the molten metal 21 to increase only by approximately two-thirds of the difference between the temperature B of the mold M' and the temperature A of the molten metal 21 to a temperature C' generally indicated in FIG. 6 and that because of the relatively high rate of temperature transfer in copper, this relatively small increase to the temperature C' of the mold M' nevertheless causes the temperature gradient in the mold M' to be generally represented by the line Z' in FIG. 6.

Thus, by retaining substantial heat in the portion S adjacent the molten metal 21, the mold M provides a temperature difference between the temperature C of the mold M and the temperature A of the molten metal 21 which is substantially less than the temperature difference between the temperature C' of the mold M' and the temperature A of the molten metal 21 but which nevertheless is sufficiently large for the cooling of the molten metal 21 to be achieved. It is this relatively small temperature difference between the temperature C of the mold M and the temperature A of the molten metal 21 which retards the cooling of the peripheral portions P of the molten metal 21 in the mold M and it is the relatively large temperature difference between the temperature C' of the mold M' and the temperature A of the molten metal 21 which causes the excessive and non-uniform cooling of the molten metal 21 in the mold M'.

It is by preventing large temperature changes throughout the mold M as indicated by the line Z in FIG. 5 that the mold M reduces the thermal fatigue which the large temperature changes throughout the mold M' as indicated by the line Z' in FIG. 6 characteristically cause in a mold M'. This lack of thermal fatigue in the mold M and the great structural strength of steel results in the mold M having a useful life substantially longer and a resistance to thermal ratcheting substantially greater than that of a mold M' of copper.

It will be obvious to those skilled in the art that many variations may be made in the embodiments chosen for the purpose of illustrating the present invention without departing from the scope thereof as defined by the appended claims.

What is claimed as invention is:

1. In a method of continuously casting a molten metal in a mold defined by the peripheral groove of a casting

wheel, the steps of pouring molten metal at a first temperature into a mold having a second temperature substantially less than said first temperature, initially cooling said molten metal by a transfer of heat from said molten metal to said mold while substantially simultaneously increasing the temperature of said mold to a third temperature which is greater than said second temperature but less than said first temperature by retaining in said mold adjacent said molten metal substantially all of the heat transferred from said molten metal to said mold during initial cooling of said molten metal and so as to retard initial cooling of said molten metal, subsequently cooling said molten metal until it is substantially solidified into a cast metal, removing said cast metal from said mold, and cooling said mold to said second temperature, all of said steps being cyclic and being repeated a plurality of times during the continuous casting of a molten metal.

2. The method of claim 1 including the step of substantially restricting said third temperature to a portion of said mold adjacent said molten metal.

3. The method of claim 1 wherein the steps of initially cooling said molten metal and increasing the temperature of said mold to a third temperature are substantially simultaneous with the step of pouring molten metal.

4. The method of claim 1 wherein the steps of initially cooling said molten metal and subsequently cooling said molten metal are within a predetermined interval of time and the step of increasing the temperature of said mold is at the beginning of said interval of time.

5. The method of claim 1 wherein said molten metal is non-ferrous and said mold is of ferrous alloy.

6. The method of claim 1 in which the step of cooling said mold includes cooling said mold during the steps of initially cooling said molten metal and subsequently cooling said molten metal.

7. The method of claim 6 wherein the step of cooling said mold during the steps of initially cooling said molten metal and subsequently cooling said molten metal removes an amount of heat from said mold which is equivalent to all heat transferred from said molten metal to said mold less any of said all heat retained in said mold.

8. The method of claim 7 in which the step of cooling said mold removes from said mold said any of said all heat retained in said mold.

9. The method of claim 1 in which the step of increasing the temperature of said mold increases the temperature of said mold by substantially nine-tenths of the difference between said first temperature and said second temperature.

10. The method of claim 1 in which said step of increasing the temperature of said mold includes transferring heat from said mold adjacent said molten metal to a coolant at that rate of heat transfer which is provided by low carbon steel.

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2,983,972	5/1961	Moritz	22—57.2

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