Improvements in shaping of steels.

Priority: 11.03.82 GB 8207155

Date of publication of application: 21.09.83 Bulletin 83/38

Publication of the grant of the patent: 09.09.87 Bulletin 87/37

Designated Contracting States: AT BE CH DE FR IT LI LU NL SE

References cited:
BE-A-863 820
FR-A-1 074 119
GB-A-2 085 150

Proprietor: British Steel Corporation
9 Albert Embankment
London SE1 7SN (GB)

Inventor: Spenceley, Gene Donald
8, Croft Hills Tame Bridge
Stokesley Yorkshire (GB)
Inventor: Henderson, Steven
6, Pinewood Road Marton
Middlesbrough Cleveland (GB)

Representative: Heath, Peter William Murray
FRY HEATH & CO. Selduct House 16-18 Station Road
Redhill Surrey RH1 1NF (GB)

Note: Within nine months from the publication of the mention of the grant of the European patent, any person may give notice to the European Patent Office of opposition to the European patent granted. Notice of opposition shall be filed in a written reasoned statement. It shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European patent convention.)
This invention relates to a method of shaping steel having a final structure of substantially globular nature.

In casting operations of castable materials such as metals (including ingot casting and continuous casting), the metals are commonly cast with sufficient contained heat to ensure that the metal passes through any nozzle, runner or gating system or similar transfer system associated with the mould in a molten state without flow blockage and other refractory containment problems associated with metal skull build-up. To achieve this situation the molten metal is normally aimed to enter the ingot or mould above the liquidus temperature. In such arrangements it can be said that the metal is cast with “superheat”.

Solidification of the cast metal thereafter is essentially directional and can be likened to an advancing wall towards the centre of the casting. The rate of heat extraction and therefore plant throughput rate are determined and constrained by the rate of heat transfer through the solidified portion.

The characteristics of the cast structure are determined by the metallurgical characteristics of the metal cast, the degree of initial superheat and the rate of heat extraction from the system. Thus for example in chill cast steel the cast structures usually consist of a very thin chill zone at the periphery which comprises the portion of the steel solidified on contact with the mould, a prominent columnar dendritic zone and a central equiaxed zone. The directional nature of the solidification causes compositional inhomogeneity across the casting, i.e. macro-segregation. Thus the purer phases solidify first leaving a solute-enriched liquid to solidify in the later stages of the overall solidification process. The cast structure is therefore inhomogeneous physically and chemically, and may be inherently weak and commonly requires further mechanical working to break it down and develop the necessary potential strength of the material. As well as the above deficiencies, casting with superheat is accompanied by proportionate shrinkage which may manifest itself as porosity or shrinkage cavities. Attempts have been made to alleviate at least some of these difficulties, for example by electromagnetic stirring in continuous casting moulds, or by tandish or ladle casting with minimal superheat. However, significant problems remain. Thus with electro-magnetic stirring there are difficulties in achieving efficient stirring during the final stages of solidification, and with casting with minimal superheat difficulties arise with yield loss due to skull formation.

Reference is hereby made to “Handbook on Continuous Casting” by Herman 1980, pages 149/150. This discloses, under reference 636 the pouring of superheated metal melts into a mould, in which the molten metal is passed in turbulent flow through a teeming tube of relatively small cross-sectional area and during this passage the whole of the superheat and part of the heat of fusion is withdrawn from the melt. No mention is made of shear rate and its significance.

It is an object of the present invention to provide a method which enables the above mentioned problems to be overcome or at least substantially reduced.

According to the present invention there is provided a method of shaping steel having a final structure of substantially globular nature including the steps of transferring liquid steel from a containing vessel and/or delivery system to a shaping station through a hollow carrier; extracting heat from the steel as it passes through the hollow carrier; subjecting the steel to turbulent flow conditions as it passes through the hollow carrier and sustaining sufficient shear rate within the steel to maintain the fluidity and globular nature of the emergent material; and passing the liquid steel directly from the hollow carrier to the shaping station.

It is to be understood that the expression “below liquidus” used herein means a temperature within the solidus-liquidus temperature range, i.e. with at least part of the latent heat of solidification having been removed.

The invention is particularly applicable to the casting of steel but can also be used in connection with other techniques for treating steels in what can generally be described as “shaping” techniques. Thus, where the shaping technique is the casting of steel, the steel is transferred via the hollow carrier directly to a casting mould. Alternatively where the shaping technique is rolling, or extruding or forging, for example, the steel is transferred via the hollow carrier directly to a rolling station, an extruder or a forging station respectively.

By means of the invention it is possible to provide for the material emergent from the hollow carrier to be at or below liquidus in, for example, the casting of steel whilst still maintaining sufficient fluidity to enable casting to take place with no significant spooning problem of the kind mentioned above. Hence much less heat needs to be removed from the metal in casting mould, and the directional nature of solidification is significantly modified with corresponding metallurgical advantages. Alternatively it is possible to extract a portion only of the sensible superheat of the liquid material so that the liquid metal (or other material) can be cast at lower superheat.

Again, by means of the invention greater casting efficiency can be achieved since less solidification and cooling time of the metal in the casting mould is required.

A key feature provided by the invention is that the material is maintained in a turbulent condition by its passage through the hollow carrier. By this means the material can have fluidity below liquidus (i.e. even when a production of its latent heat has been removed) because of the shear produced, even with a high solids fraction. The turbulent regime also causes an enhancement of heat transfer across the fluid material. We believe that the turbulent flow in the system suppresses dendritic matrix formation.
The present invention is particularly, but by no means solely, applicable in connection with the production of high quality steel on a commercial scale in ingot casting, continuous casting or continuous forming plants.

The hollow carrier may be in the form of a pipe or an open-topped gutter or channel for example.

The hollow carrier may be horizontal, vertical or at some angle to the vertical.

The carrier may be constructed from metal, ceramic, cermet or composite material and heat may be extracted therefrom by natural convection in the atmosphere with or without cooling fins; by water cooling by jets, sprays, high-pressure mists or cooling coil or jackets; or by high pressure gas cooling systems; or by fluidised beds of solid materials.

The carrier may be disposable after a single cast or reusable depending upon its material and form of construction.

The carrier may, at least internally, be of any appropriate section such as round or square, and be of changing section, eg. tapered along its length.

The driving force for providing the turbulent flow through the hollow carrier may, for example, be gravity such as by a pressure head in an associated tundish, which may or may not be throttled, a vacuum in the receiving vessel, or a syphonic system.

We believe that preferred requirements for the method applied to the steel are:

1. Turbulent flow through the carrier.
2. Shear rates high enough to maintain fluidity at liquidus and sub-liquidus temperatures.
3. A controlled extraction of sensible and/or latent heat.
4. A carrier constructed from a material able to withstand the passage of liquid metal through it at the temperatures required, which temperatures depend on the heat transfer in the chosen system.

The required hydrodynamic characteristic with regard to any desired system or apparatus for carrying out the invention can be calculated in dependence on established theories of turbulent fluid flow. A typical calculation for a steel is outlined below.

It is to be noted that the following calculation (although theoretically only approximate because the fluids concerned may be non-Newtonian, flow is non-isothermal and the physical characteristics are not therefore constant throughout the section of the hollow carrier concerned) is adequate to provide a first estimate of physical parameters for achieving the invention.

We believe that to achieve full turbulent flow in a pipe the Reynolds' number for the system should exceed 10,000 and let it be taken that to maintain an apparent viscosity of the order of 1 poise or less for a given liquid steel a strain rate (γ) of the order 800 sec⁻¹ must be applied for temperatures and heat contents corresponding to a composition consisting of 20% solids fraction. Such values could be said to be typical of 1 Wt. % C plain carbon steel.

The minimum velocity (V_min) for turbulent flow can be expressed in terms of the Reynolds' number (Re):

\[ \text{Re} = \frac{V_{\text{min}} \cdot \rho \cdot d}{\eta} \]

where

- \( \rho \) is the density of the steel
- \( d \) is the diameter of the pipe
- \( \eta \) is the apparent viscosity of the steel

Thus

\[ V_{\text{min}} = \frac{1429}{d} \text{(c.g.s. units)} \]  \hspace{1cm} (1)

In order to fulfill condition (2) strain rates of the order 800 sec⁻¹ are required and which would maintain low viscosities of the order of 1 poise or less. If we assume that this is the minimum average strain rate (\( \dot{\gamma}_{AV}^{\text{Min}} \)) required, then the minimum average shear stress in the pipe (\( \tau_{AV}^{\text{Min}} \)) corresponding to this

\[ \dot{\gamma}_{AV}^{\text{Min}} = 800 = \frac{\tau_{AV}^{\text{Min}}}{\eta} \]  \hspace{1cm} (2)

and

\[ \tau_{AV}^{\text{Min}} = 800 \text{ dyne} \cdot \text{cm}^{-2} \]

Since turbulent conditions exist, the average minimum shear stress, \( \tau_{AV}^{\text{Min}} \), between the pipe axis and the pipe wall is half the minimum wall shear stress \( \tau_{W}^{\text{Min}} \) and therefore:

\[ \tau_{W}^{\text{Min}} = 1600 \text{ dynes} \cdot \text{cm}^{-2} \]  \hspace{1cm} (3)
The friction factor \( f \) for flow in pipes may be obtained from books on hydrodynamics. However it should be noted that the value of the friction factor \( f \) may be substantially charged by non-isothermal conditions of flow.

For the limiting case, we assume that the inner surface of the pipe is completely smooth and consequently the friction factor \( f \) for a Reynold’s number of \( 10^6 \) is 0.008, (as shown in “Transport Phenomena” by Bird R. B., Stewart W. E., and Lightfoot E. N., published in 1960 by Wiley and Sons of New York.) Using this value, the value of \( V_{\text{min}} \) can be determined since:

\[
\frac{f}{2} \cdot \frac{V_{\text{min}}^2}{\rho} = 1600
\]

\[\therefore V_{\text{min}} = 239 \text{ cm} \cdot \text{sec}^{-1}\]  

Substituting this value of \( V_{\text{min}} \) into equation (1) gives the effective pipe diameter:

\[
d = \frac{1429}{V_{\text{min}}} \]

\[d = 6.0 \text{ cm}\]  

Equations (4) and (5) therefore give a guide to the minimum rate of material throughout and pipe dimensions necessary to fulfill conditions (1) and (2). A solid skin may form within the pipe effecting changes in the internal diameter \( d \). It decreases initially and may reach an equilibrium value depending on the heat transfer and design of the individual system. The formation of a solid skin within the pipe does affect the heat transfer and hydrodynamics of the system. Conditions (3) and (4) are achieved by appropriate choice of pipe dimensions, pipe material, pipe wall thickness and the heat extraction system used.

The heat transfer characteristics of the pipe and the heat transfer and temperature profiles within the pipe are of importance.

The turbulence in the pipe may be enhanced by vibration, electromagnetic stirring, or gas injection for example. The turbulence may also be enhanced by suitable profiling of the pipe, for example by “rifling” or ribbing or by use of protrusions.

In order that the invention may be more readily understood two embodiments thereof will now be described by way of example with reference to the accompanying drawings in which:

Figure 1 is a diagrammatic representation of a steel slab continuous casting apparatus incorporating the invention;

Figure 2 is a diagrammatic representation of uphill teeming apparatus incorporating the invention; and

Figure 3 and 4 are representations of micro-structure of steel samples cast by means of the invention.

Referring to Figure 1 it will be seen that the continuous casting apparatus comprises a ladle 1 from which metal is poured into a tundish 2, via a shroud pipe 3. The tundish 2 has a two strand output from separate outlets 4 and 5.

Outlet 4, controlled by a stopper rod 6 feeds in a conventional manner via a shroud tube 7 to a slab mould 8 of a continuous casting machine (not shown) of conventional design.

Outlet 5 also feeds to a slab mould 9 of a conventional continuous casting machine (not shown). In this case however the outlet is connected via a refractory insert 10, to a water cooled transfer pipe 11 having an inner wall 12 of copper and an outer wall 13 of steel. Thereforer via a further refractory insert 14 the feed is through a shroud tube 15 to the slab mould 9. It will be seen that in order physically to accommodate the transfer pipe 11 between the tundish 2 and the mould 9, part of the base 16 of the tundish is at an elevated level. The dimensions of the transfer pipe are so chosen, using the calculation mentioned hereinafore, to ensure turbulent flow for the metal passing therethrough.

During operation heat is extracted from the metal flowing through the transfer pipe 11 so that on entry to the continuous casting mould it is at, near, or below, liquidus temperature. Heat extraction as illustrated is by water cooling.

Control of metal flow from outlet 5 is by means of a metering stopper rod 17 which can be adjusted to provide steady state flow through the pipe 11 despite any skull formation occurring therein. With apparatus of the kind illustrated metal flow rates of the order of 2/3 Tonnes per minute are anticipated.

In Figure 2 liquid steel is teemed into a trumpet 18 leading to a refractory down-runner 19 which has a restriction 20 near its base and a delay plate 21 of, for example, aluminium, steel or cardboard at or near the
0 089 196

base which allows the down-runner 19 to fill before the delay plate melts or breaks allowing the metal to flow through a seamless thick-walled steel tube 22 through a mould base 23 and into a casting mould 24. The height of the trumpet 18 and mould 24 are such that a minimum head of steel (H) above the casting mould 24 can be maintained throughout the casting period. The tube 22 is constructed so as to allow substantial heat extraction from the molten metal simply by means of exposure to ambient temperature.

In each of the embodiments illustrated, it may be desirable to include heating means for the metal contacting members such as the transfer pipes or tubes, to enable such members to be heated during initial starting of the apparatus, and so prevent or minimise undesirable skull formation.

Figures 3 and 4 show the microstructure of samples of steel emergent from air cooled steel pipe operated in accordance with the invention. The liquid steel temperature was in each case below liquidus at the pipe outlet. Further details of the test from which these samples were obtained are given in the Table below. Figure 3 is at ×20 magnification and shows that the microstructure is fine and degenerate compared with that obtained by conventional casting methods. Figure 4 is at ×50 magnification and shows the globular nature of the cast microstructure.

<table>
<thead>
<tr>
<th></th>
<th>Pipe inside diameter (mm)</th>
<th>Pipe outside diameter (mm)</th>
<th>Pipe length (mm)</th>
<th>Initial steel superheat (°C)</th>
<th>Initial steel velocity (M/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>63.5</td>
<td>114.3</td>
<td>2000</td>
<td>+5</td>
<td>1.9</td>
</tr>
</tbody>
</table>

Claims

1. A method of shaping steel having a final structure of substantially globular nature including the steps of transferring liquid steel from a containing vessel (2) and/or delivery system (18, 19) to a shaping station (9, 24) through a hollow carrier (11, 22); extracting heat from the steel as it passes through the hollow carrier (11, 22); subjecting the steel to turbulent flow conditions as it passes through the hollow carrier and sustaining sufficient shear rate within the steel to maintain the fluidity and globular nature of the steel emergent therefrom; and passing the fluid steel directly from the hollow carrier (11, 22) to the shaping station (9, 24).

2. A method as claimed in claim 1 wherein a shear rate of the order of 800 sec⁻¹ is sustained within the steel as it passes through the hollow carrier (11, 22).

3. A method as claimed in claim 1 or claim 2 wherein the steel is a carbon steel.

4. A method as claimed in claim 1, 2 or 3 wherein a portion only of the sensible superheat of the liquid steel is extracted during its passage through the hollow carrier (11, 22).

5. A method as claimed in any one of the preceding claims wherein the shaping station comprises a rolling stand.

6. A method as claimed in any one of claims 1 to 4 wherein the shaping station comprises a casting mould.

Patentansprüche

1. Verfahren zum Formen von Stahl mit einer Endstruktur von im wesentlichen globulä rer Art, umfassend daß man flüssigen Stahl aus einem Behälterkessel (2) und/oder Versorgungssystem (18, 19) zu einer Formstation (9, 24) durch einen hohen Träger (11, 22) überführt; daß man Wärme aus dem Stahl ableitet, wenn er durch den hohen Träger (11, 22) gelangt; daß man den Stahl turbulenten Fließbedingungen aussetzt, wenn er den hohen Träger passiert und daß man eine genügend hohe Schergeschwindigkeit innerhalb des Stahles anwendet, um die Fluidität und die globuläre Art des so erhaltenen Stahles aufrechtzuerhalten; und daß man den flüssigen Stahl direkt von dem hohen Träger (11, 22) zu der Formstation (9, 24) überleitet.

2. Verfahren nach Anspruch 1, bei dem eine Schergeschwindigkeit in der Größeordnung von 800 sec⁻¹ im Stahl aufrechterhalten wird, wenn dieser durch den hohen Träger (11, 22) fließt.

3. Verfahren nach Anspruch 1 oder 2, bei dem der Stahl ein Kohlenstoffstahl ist.

4. Verfahren nach einem der Ansprüche 1, 2 oder 3, wobei nur ein Teil der empfindlichen Überhitze des flüssigen Stahles während seiner Passage durch den hohen Leiter (11, 22) entzogen wird.

5. Verfahren nach einem der vorhergehenden Ansprüche, bei dem die Formstation eine Walzgerüst umfaßt.

6. Verfahren nach einem der Ansprüche 1 bis 4, bei dem die Formstation eine Gießform umfaßt.

Revendications

1. Procédé de conformation d’acier ayant une structure final sensiblement de, nature globulaire
comportant les étapes consistant à transférer l'acier liquide à partir d'un conteneur (2) et/ou d'un dispositif d'alimentation (18, 19) vers un poste de conformation (9, 24), à travers un organe de transport creux (11, 22), à soumettre l'acier à des conditions d'écoulement turbulent tandis qu'il passe à travers l'organe de transport creux (11, 22) et à maintenir une vitesse de cisaillement suffisante dans l'acier afin de conserver la fluidité et la nature globulaire de l'acier sortant de l'organe de transport creux (11, 22), et à faire passer l'acier fluide directement à partir de l'organe de transport creux (11, 22) au poste de conformation (9, 24).

2. Procédé suivant la revendication 1 caractérisé en ce qu'une vitesse de cisaillement de l'ordre de 800 s⁻¹ est maintenue dans l'acier tandis que celui-ci passe à travers l'organe de transport creux (11, 22).

3. Procédé suivant l'une quelconque des revendications 1 ou 2 caractérisé en ce que l'acier est un acier au carbone.

4. Procédé suivant l'une quelconque des revendications 1, 2 ou 3 caractérisé en ce que seule une partie de la surchauffe sensible de l'acier liquide est extraite pendant son passage à travers l'organe de transport creux (11, 22).

5. Procédé suivant l'une quelconque des revendications précédentes caractérisé en ce que le poste de conformation est constitué par une cage de laminage.

6. Procédé suivant l'une quelconque des revendications 1 à 4 caractérisé en ce que le poste de conformation est constitué par un moule de coulée.
FIG. 1.