

[54] APPARATUS AND METHOD FOR ELECTROSLAG REMELTING

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249/82

[51] Int. Cl. **B22d 27/02**

[58] Field of Search 164/52, 252, 348; 249/60,
249/82

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Primary Examiner—Francis S. Husar

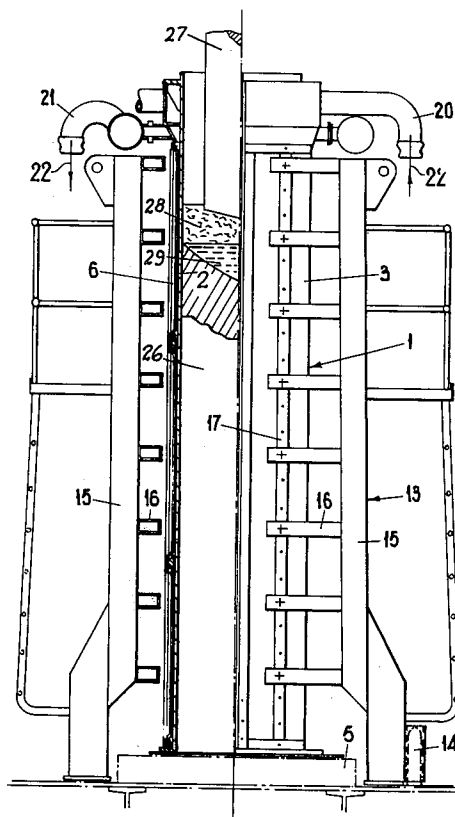
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[57] ABSTRACT

An electroslag mould suitable for forming an ingot having a cross-section bounded by substantially straight sides or large circular ingots, comprises mould walls reinforced by vertically extending ribs secured to the outer surfaces of the wall at spaced positions, the mould wall thickness and the rigidity afforded by the ribs being such that thermal expansion of the walls is constrained to take place in local bowing of the walls between adjacent vertically extending ribs.

28 Claims, 8 Drawing Figures



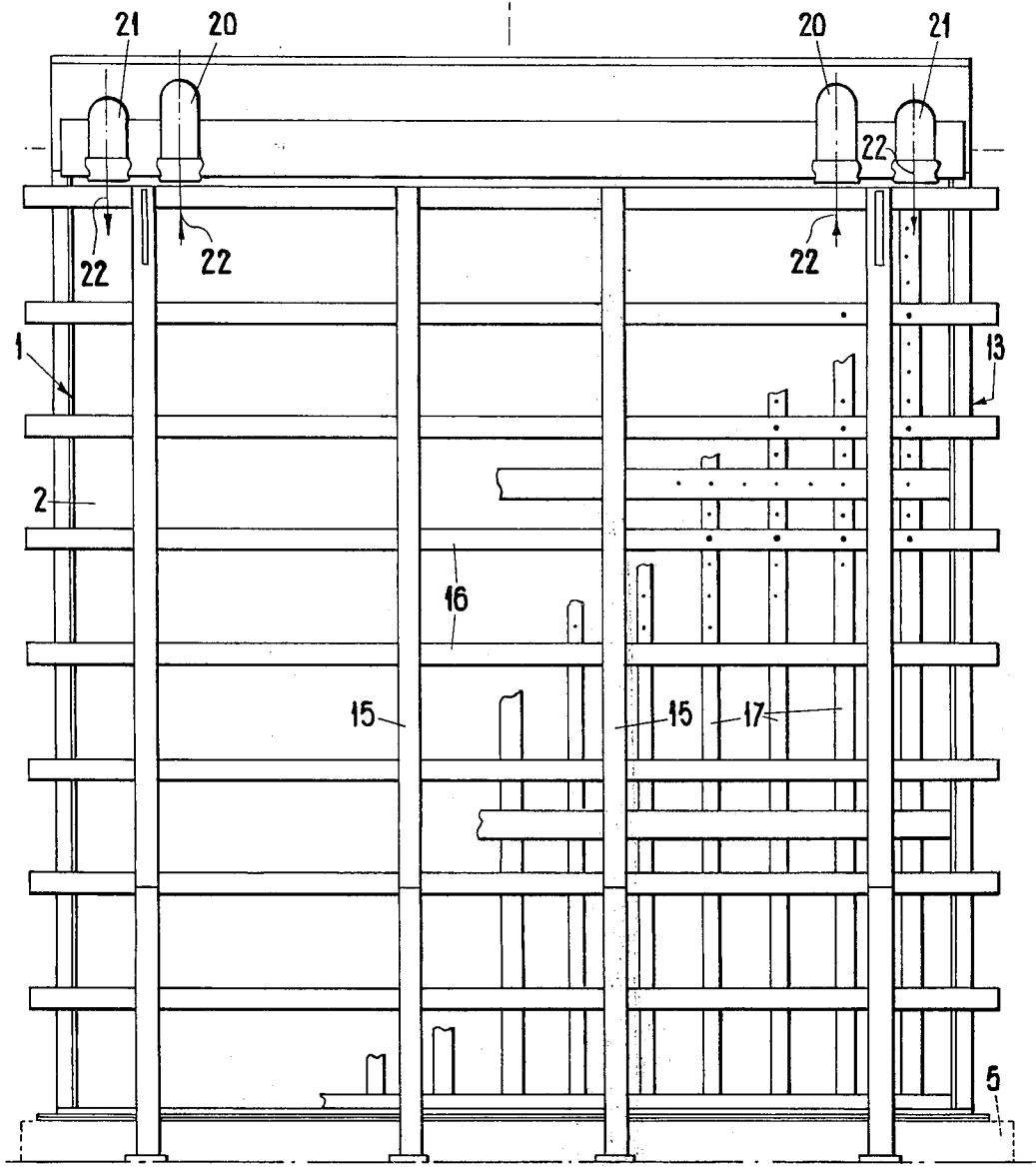


Fig.1

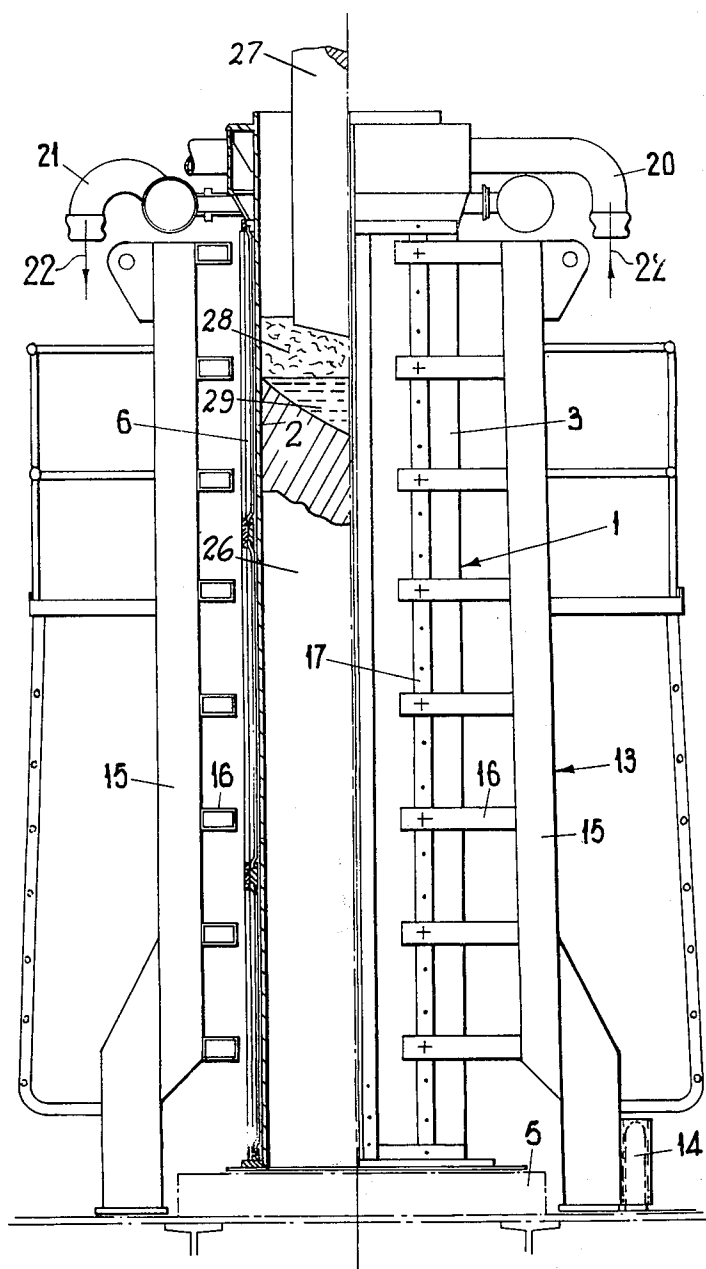
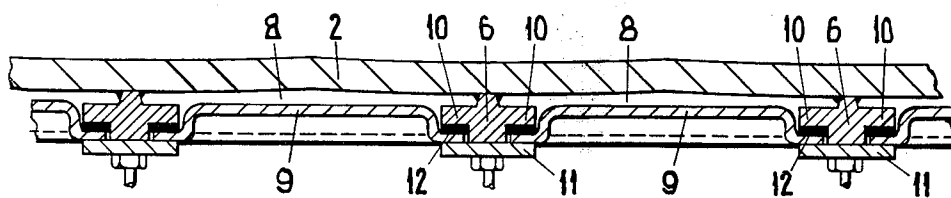
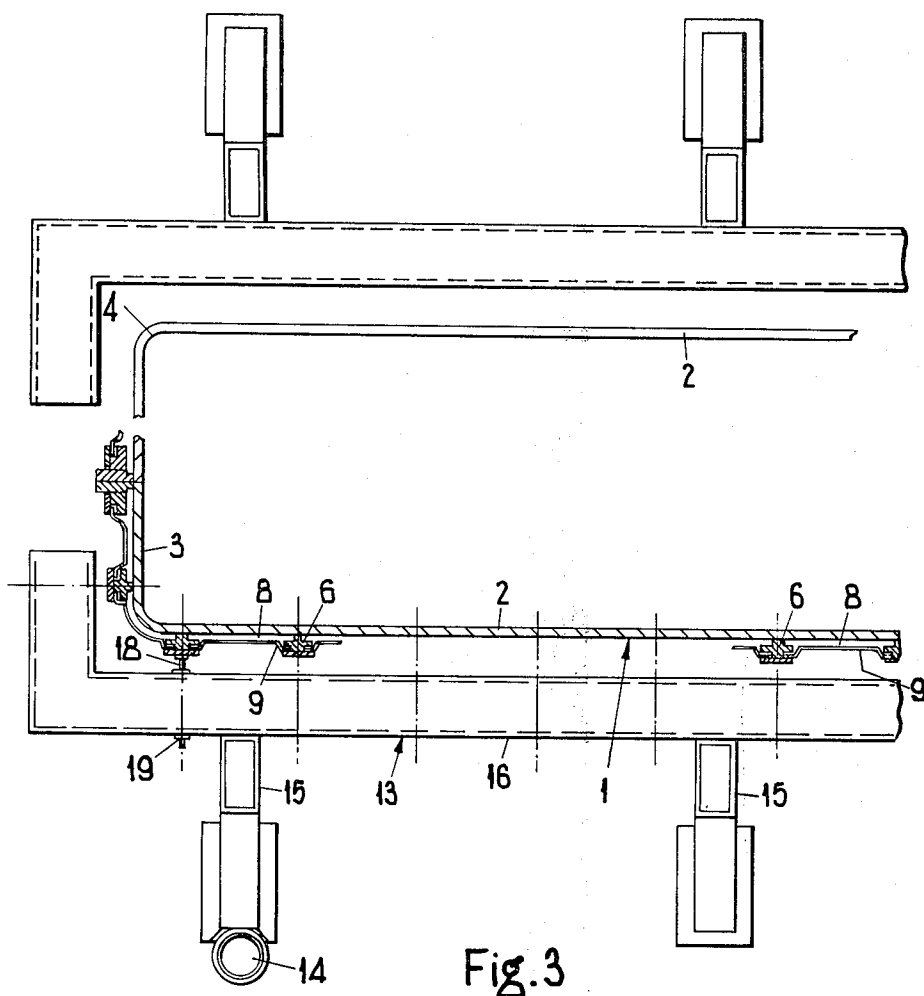


Fig.2



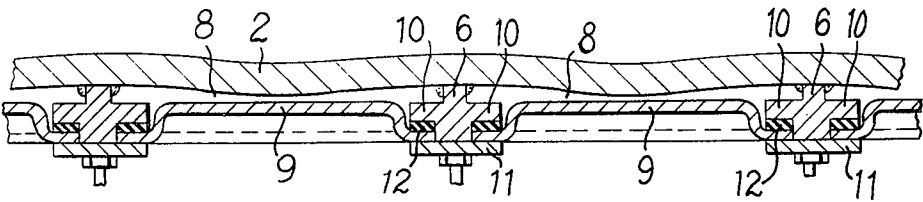


Fig. 9

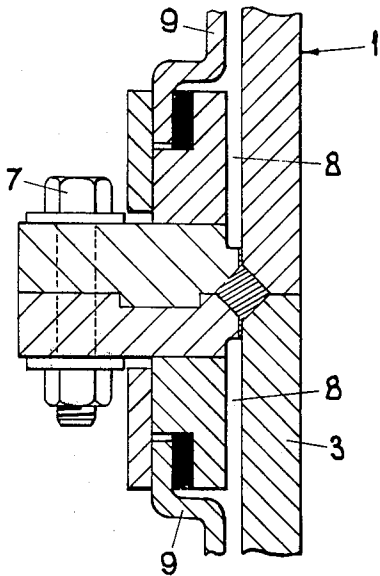


Fig. 5

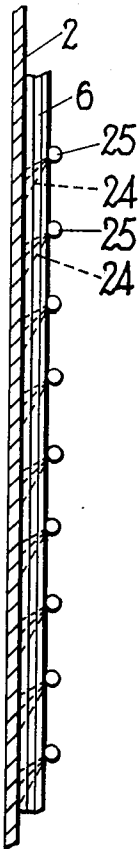


Fig. 8

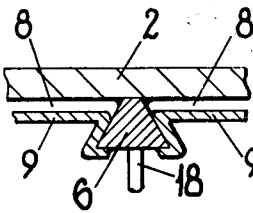


Fig. 6

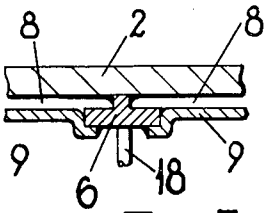


Fig. 7

APPARATUS AND METHOD FOR ELECTROSLAG REMELTING

This invention relates to electroslag moulds suitable for forming an ingot having a cross-section bounded by substantially straight sides or sides curved to a radius of not less than 600 mm., for example ingots of generally triangular, rectangular or other polygonal cross-section, or for forming ingots of circular cross-section having a diameter of at least 1200 mm.

The walls of such electroslag moulds are usually water cooled so that the heat passing into the walls from the slag pool and the forming ingot is dissipated with the minimum rise in the temperature of the mould walls. Nevertheless, the rise in temperature of the mould walls in the region of the slag pool and the top of the forming ingot, in relation to the comparatively cooler metal above and below this region produces differential thermal expansion which can cause pronounced distortion of the mould walls and difficulty in stripping the ingot.

In order to alleviate this problem it has been proposed to form the mould walls of very thick material so that the rigidity of the mould walls forces the thermal expansion to be taken up in compressive stress and strain in the material. However, the thickness of the material results in a greater temperature difference between the inner surface and outer surface of the mould walls than would normally occur and an increased tendency to bow towards the hotter (inner) surface.

An object of this invention is to provide an electroslag mould suitable for forming an ingot having a cross-section bounded by substantially straight sides or sides curved to a radius of not less than 600 mm., for example ingots of generally triangular, rectangular or other polygonal cross-section, or for forming ingots of circular cross-section having a diameter of at least 1200 mm.

According to the present invention a liquid cooled electroslag mould suitable for forming an ingot having a cross-section bounded by substantially straight sides or sides curved to a radius of not less than 600 mm., for example ingots of generally triangular, rectangular or other polygonal cross-section, or for forming ingots of circular cross-section having a diameter of at least 1200 mm., comprises mould walls reinforced by vertically extending ribs secured to the outer surfaces of the walls at spaced positions, the mould wall thickness and the rigidity afforded by the ribs being such that thermal expansion of the mould walls is constrained to take place in local bowing of the walls between adjacent vertically extending ribs.

The spacing of the ribs and the rigidity afforded thereby are preferably such as to ensure that the local bowing of the walls is of an amplitude such as to be substantially restored on cooling so that there is no significant cumulative increase in the amplitude during use.

The portions of the mould walls between two adjacent ribs may be slightly bowed when the mould is in a cold state and the bows on these portions may be either inwards towards the ingot or outwards away from the ingot.

The relatively thin mould walls may be cooled by circulating a cooling liquid (e.g., water), through passages defined between the outer surface of the walls and panels secured to the ribs. Conveniently the ribs may be of cruciform or T-shaped cross-section and the panels, which may be of steel, may be clamped to the cross

arms of the ribs to form the passages. Moreover, such rib sections give lateral stiffness assisting in restricting the bowing of the wall to the portion between two adjacent ribs.

Alternatively, the mould walls may be cooled by jets of cooling liquid (e.g., water) which impinge on the outer surfaces of the walls between the ribs.

The ribs may be secured to a support structure by a plurality of tie means having one of their ends secured to the ribs at spaced positions along the length of the ribs and their other ends anchored on the support structure.

The support structure may conveniently comprise a plurality of upright members to which are secured a plurality of horizontally extending girders.

The invention is particularly advantageous when applied to electroslag moulds for forming ingots of rectangular cross-section having a width which is considerably greater than their thickness, for example, moulds for forming rectangular ingots in which the width exceeds the thickness by a ratio of more than 2:1.

The invention also resides in a method of producing electroslag ingots using an electroslag mould as defined above and in ingots produced by this method and by using the defined electroslag mould.

The invention will now be described, by way of example with reference to the accompanying drawings, in which:

FIG. 1 is a front elevation of an electroslag mould embodying the invention;

FIG. 2 is a side elevation, partly in section, of the electroslag mould shown in FIG. 1;

FIG. 3 is a fragmentary plan view of the electroslag mould shown in FIG. 1, partly in section and drawn to a larger scale than that Figure;

FIG. 4 is a fragmentary horizontal section of a side wall of the mould shown in FIG. 3 but drawn to a larger scale than that Figure;

FIG. 5 is a fragmentary section of a joint in an end wall of the mould shown in FIG. 3 but drawn to a larger scale than that Figure;

FIGS. 6 and 7 are fragmentary horizontal sections of a side wall similar to FIG. 4 but showing alternative forms of the ribs;

FIG. 8 is a fragmentary vertical section of a side wall of another electroslag mould embodying the invention and having an alternative form of cooling system; and

FIG. 9 is a fragmentary horizontal section of a side wall of a further electroslag mould embodying the invention.

Referring to FIGS. 1 to 5 of the drawings, the electroslag mould 1, which is of a kind suitable for forming a rectangular ingot having a width considerably greater than its thickness, has two side walls 2 each having a width which is substantially five times the width of each of its two end walls 3. The two side walls 2 are substantially parallel to each other as are the two end walls 3 and the corners 4 are radiused. Typically, the mould 1 has side walls 2 which are 10 feet in width and end walls 3 which are 2 feet in width, the corners 4 having a radius of 2 inches and the vertical height of the walls 2 and 3 being 12 feet. The lower end of the mould 1 is sealed by a base plate 5 which is of copper and is suitably water-cooled. The base plate 5 may be movable relative to the mould to allow the solidified lower end of a forming ingot to emerge from the lower end of the mould, in which case the vertical height of the mould

wall would be less than the typical dimensions given above. A suitable arrangement would be provided for moving the mould base relative to the walls.

The side walls 2 and end walls 3 are formed of relatively thin copper plate and are reinforced against bending by a plurality of vertically extending metal ribs 6 which are brazed or welded to the outer surface of the copper plate at spaced positions around the perimeter of the walls 2 and 3. The mould is formed in two parts, each comprising one side wall 2 and half one end wall 3, the two parts being secured together with clamping bolts 7 as shown in FIG. 5. Typically, with a mould 1 having walls 2 and 3 with the dimensions given above, the copper plate has a thickness of three-fourth inch and the ribs 6, which are of cruciform cross-section, are spaced 9 inches apart, the end of one arm of the cruciform cross-section of each rib 6 being brazed or welded to a wall 2 or 3. The ribs 6 are formed from a metal having a thermal expansion coefficient which is similar to that of the walls 2 and 3 and is capable of being brazed or welded thereto, and for the copper plate mentioned may be brass, bronze, cupronickel or stainless steel. The walls 2 and 3 are cooled by water circulating through passages 8 defined between the outer surfaces of the walls 2 and 3 and steel panels 9 which are clamped or otherwise fixed to the cross arms 10 of the ribs 6 between clamping plates 11 and sealing members 12. Typically, the overall length of the horizontally extending cross arms may be 3 inches, the overall length of the vertically extending cross arms may be 1½ inches, the thickness of the horizontal arms and the vertical arm secured to the mould wall being ½", the thickness of the other vertical arm being 1". The cruciform cross-section of ribs 6 ensures that a maximum area of the wall 2 and 3 is in contact with the cooling water.

Surrounding and spaced from the mould 1 is a rigid support structure 13 located on location posts 14 and comprising a plurality of upright box-section members 15 arranged along each side wall 2 and to which are secured a plurality of horizontally extending box-section girders 16. Further, vertically extending members 17 are secured to the girders 16 which extend parallel to each side wall 2 and partway along each end wall 3. The mould is attached to the support structure 13 by a plurality of threaded tie rods 18 each having one end secured in one of a plurality of tapped holes in the ribs 6 at spaced positions along the lengths of the ribs 6 and its other end anchored to one of the girders 16 or one of the members 17 at correspondingly spaced positions. Threaded nuts 19 screwed on to the outer ends of the tie rods 18 enable the tension on the tie rods 18 to be adjusted.

The support structure 13 also carries a plurality of inlet ducts 20 through which water can be supplied to the passages 8 and a plurality of outlet ducts 21 through which water can be discharged from the passages 8. The water is supplied through an inlet duct 20 at the upper end of one passage 8 and is discharged through an outlet duct 21 at the upper end of an adjacent passage 8, the direction of the flow of water down one passage 8 and up the adjacent passage being indicated by the arrows 22.

In use of the electroslag mould 1 to form an ingot 26, a plurality of consumable electrodes 27 are arranged to depend into a pool of molten slag 28 contained in the mould 1 and molten metal from the tips of the elec-

trodes 27 falls through the slag 28 to form the ingot 26 in the bottom of the mould. The mould 1 is cooled by water caused to flow through the passages 8 and through the water cooled base plate 5. As the ingot 26 grows in the mould 1, any differential expansion in the mould wall in the region of the slag pool and the molten metal 29 at the top of the ingot 26, is accommodated by bowing of the copper plate between the ribs 6 which resist bending due to their inherent rigidity and the support afforded by the tie rods 18 spaced along their lengths. The support structure 13 is sufficiently rigid to carry the loads imposed along the tie rods 18 without significant deflection, and the tie rods 18 are sufficiently strong to permit adjustment of the nuts 19 to correct any distortion of the mould 1 that may occur. Moreover, in the event of an ingot 26 being trapped in the mould 1 the nuts 19 can be tightened to pull the whole wall away from the ingot so that the ingot can be removed from the mould 1. The local bowing of the walls 2 and 3 between the ribs 6 is largely restored on cooling and any bowing that is permanent is tolerable with an economic life of the mould.

In some circumstances it may be advantageous to arrange for the portions of the walls 2 and 3 between two adjacent ribs 6 to be slightly bowed in their initial, cold state. As shown in FIG. 4 this initial bowing may be towards the forming ingot and may amount to a bow of one-fourth inch in the 9 inch spacing between two adjacent ribs of a mould 1 of the dimensions described above.

An inward bow of this kind, on being slightly increased by thermal expansion will result in an ingot of slightly reduced dimensions, thus facilitating removal of the ingot from the mould. It has been found that with a mould having the dimensions and rib spacing exemplified above the bowing between two adjacent ribs will be increased by approximately 0.050 of an inch on heating but that this increase will largely be restored on cooling so that there is no significant cumulative increase in the bowing. Alternatively as shown in FIG. 9, the initial bow between two adjacent ribs 6 may be away from the forming ingot so that any increase in the bow due to thermal expansion will be opposed by the pressure of the water in the passages 8.

The ribs 6 need not be of cruciform cross-section and as illustrated in FIG. 6 the ribs 6 may have a cross-section in the form of a truncated triangle with the apex of the triangle brazed or welded as shown, or otherwise fixed to a wall of the mould such as a side wall 2 and the panels 9 brazed or welded to the base of the cone to form the passages 8. The threaded tie rods 18 are secured in tapped holes in the base of the triangle at spaced positions along the lengths of the ribs 6. In another arrangement illustrated in FIG. 7 the ribs 6 are T-shaped in cross-section and have the end of the stem of the T brazed or welded to a wall 2 of the mould and have the panels 9 brazed or welded to the cross arms of the T to form the passages 8. The tie rods 18 are secured in tapped holes in the cross arms of the T at spaced positions along the lengths of the ribs 6.

In another embodiment of the invention illustrated in FIG. 8 the walls of the mould such as wall 2 are cooled by jets of water 24 which are sprayed by pipes 25 extending transversely of the ribs 6 and impinge on the outer surface of the walls 2.

Although the invention has been described with reference to a mould for forming a rectangular ingot

whose width exceeds its thickness by a ratio of 5:1, so that rolling in a slabbing mill can be minimised or even eliminated, in that the ingots produced are suitable for direct rolling to plate, it is envisaged that the invention will be applicable to moulds for forming rectangular ingots whose width exceeds their thickness by a ratio of 10:1 or greater, so that having regard also to the homogeneity of the ingot material the need for rolling is yet further reduced.

The invention is also applicable to a mould for forming a rectangular ingot whose width is substantially equal to its thickness, or to moulds for forming ingots of other polygonal cross-sections having substantially straight sides or curved sides with a radius greater than 600 mm., or substantially circular ingots having a diameter greater than 1200 mm.

I claim:

1. A method of producing an ingot comprising the steps of:

- a. providing an electroslag mould having a horizontal cross-section bounded by substantially straight side walls or side walls curved to a radius of not less than 600 mm., the said walls being relatively thin and reinforced by a multiplicity of vertically extending ribs disposed at spaced positions around the mould walls, each rib being secured to the outer surface of a mould wall throughout the length of the rib, and the mould walls being surrounded by a rigid support structure which is spaced from the mould walls and secured to the ribs at spaced positions along their lengths such that thermal expansion of the mould walls is constrained to take place in local bowing between adjacent ribs;
- b. forming the ingot in the mould by the electroslag melting of at least one consumable electrode depending into a slag pool contained in the mould;
- c. cooling the outer surfaces of the mould walls while the ingot is being formed; and
- d. thereafter removing the ingot from the mould.

2. A method as claimed in claim 1, wherein the mould walls are cooled by circulating a cooling liquid through passages defined between the outer surfaces of the mould walls and panels secured to the ribs.

3. A method as claimed in claim 1, wherein the mould walls are cooled by jets arranged to cause a cooling liquid to impinge on the outer surfaces of the mould walls.

4. A method as claimed in claim 1, including the step of moving a base plate arranged to seal the lower end of the mould walls relative to the mould walls to allow the solidified lower end of the forming ingot to emerge from the lower end of the mould walls.

5. An electroslag mould comprising:

- a. relatively thin mould walls defining a vertically extending mould space having a cross-section bounded by substantially straight sides or sides curved to a radius of not less than 600 mm;
- b. a multiplicity of vertically extending ribs disposed at mutually spaced positions around the mould walls, each rib being secured to the outer surface of a mould wall throughout the length of the rib;
- c. a rigid support structure surrounding and spaced from the mould walls; and
- d. means for securing the ribs at mutually spaced positions along their lengths to the support structure such that thermal expansion of the mould walls is constrained to take place in local bowing of the

mould walls between adjacent vertically extending ribs.

6. An electroslag mould as claimed in claim 5, wherein the wall thickness of the mould, the mutual spacing of the ribs, and the rigidity afforded thereby are such that local bowing of the walls is of an amplitude such as to be substantially restored on cooling so that there is no significant cumulative increase in the amplitude during use of the mould.

7. An electroslag mould as claimed in claim 5, wherein the portions of the mould walls between two adjacent ribs are slightly bowed when the mould is in a cold state.

8. An electroslag mould as claimed in claim 5, wherein the portions of the mould walls between two adjacent ribs are slightly bowed inwards when the mould is in a cold state.

9. An electroslag mould as claimed in claim 5, wherein the portions of the mould walls between two adjacent ribs are slightly bowed outwards when the mould is in a cold state.

10. An electroslag mould as claimed in claim 5, wherein the ribs are of cruciform cross-section with the end of one arm of the cruciform cross-section brazed to the outer surface of the mould wall.

11. An electroslag mould as claimed in claim 5, wherein the ribs are of T-shaped cross-section with the end of the stem of the T brazed to the outer surface of the mould wall.

12. An electroslag mould as claimed in claim 5, wherein the ribs have a cross-section in the form of a truncated triangle with an apex end of the triangle brazed to the outer surface of the mould wall.

13. An electroslag mould as claimed in claim 5, having means for cooling the mould walls including passages for the circulation of a cooling liquid defined between the outer surfaces of the mould walls and panels secured to the ribs.

14. An electroslag mould as claimed in claim 13, wherein the ribs are of cruciform cross-section and the panels are secured to cross arms of the cruciform cross-section.

15. An electroslag mould as claimed in claim 13, wherein the ribs are of T-shaped cross-section and the panels are secured to the cross arms of the ribs.

16. An electroslag mould as claimed in claim 5, wherein the means for securing the ribs to the support structure includes tie means extending between the ribs and the support structure.

17. An electroslag mould as claimed in claim 5, wherein the means for securing the ribs to the support structure includes a plurality of tie rods having one of their ends secured to the ribs at spaced positions along the length of the ribs and their other ends anchored to the support structure.

18. An electroslag mould as claimed in claim 17, including means for adjusting the lengths of the tie rods.

19. An electroslag mould as claimed in claim 5, having means for cooling the mould walls including jets for causing a cooling liquid to impinge on the outer surfaces of the mould walls.

20. An electroslag mould as claimed in claim 5, wherein the support structure comprises a plurality of upright members to which are secured a plurality of horizontally extending girders.

21. An electroslog mould as claimed in claim 5, including a base plate arranged to seal the lower end of the mould walls.

22. An electroslog mould as claimed in claim 21, wherein the base plate is movable relative to the mould walls to allow the solidified end of a forming ingot to emerge from the lower end of the mould.

23. An electroslog mould as claimed in claim 5, having three or more walls disposed to form an ingot of polygonal cross-section.

24. An electroslog mould as claimed in claim 5, having four walls each disposed at right angles to the two adjacent walls so as to produce an ingot of rectangular cross-section.

25. An electroslog mould as claimed in claim 24, wherein two parallel walls have horizontal dimensions

which exceed the horizontal dimensions of the other two parallel walls so as to produce a rectangular ingot having a width greater than its thickness.

26. An electroslog mould as claimed in claim 5, wherein the horizontal dimensions of the pairs of parallel walls are such as to produce a rectangular ingot in which the width exceeds the thickness by a ratio of more than 2:1.

27. An electroslog mould as claimed in claim 5, wherein the mould walls are of copper and the ribs are of a metal selected from the group brass, cupro-nickel and stainless steel.

28. An ingot produced in an electroslog mould in accordance with claim 5.

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