(54) Title: SUPERHEATING AND MICROALLOYING OF MOLTEN METAL BY CONTACT WITH A PLASMA ARC

(57) Abstract

A method of treating high melting point metals in the form of a moving stream with a plasma arc is disclosed. The method has particular application to the superheating and/or microalloying of molten steel at the tertiary stage i.e., during teeming from the ladle (12) into a tundish (16), prior to its entry into a continuous casting machine. The transferred plasma arc (23) is struck between the cathode (28) [and microalloy (40, 42, 44)] and the teeming stream (22), thus superheating the molten steel. If added, the microalloy is dispersed as a fog, by melting, partial vapourisation and condensation and drawn down by the teeming stream (22) into the bath of molten steel in the tundish (16), where it is alloyed by the intense mixing that occurs. Microalloying with a transferred plasma arc and microalloy (52, 56, 58) submerged below the surface of the turbulent molten steel is also disclosed as an alternative. Apparatus for carrying out the method consists of a tundish (16), a ladle nozzle (13) which defines the teeming stream (22), a cathode (28) mounted adjacent to the teeming stream (22)/bath and associated electrical circuitry, as shown in Figure 3. A protective refractory hood (50, 56) for the cathode is required for a submerged plasma arc. A return electrode is positioned in the tundish, (so as to dip into the molten steel), downstream from the cathode.

- 1 -

SUPERHEATING AND MICROALLOYING OF MOLTEN
METAL BY CONTACT WITH A PLASMA ARC.

FIELD OF THE INVENTION

This invention relates to the treatment of molten
metal and has particular but certainly not exclusive
application to the treatment of molten steel held in a
tundish, for example for feeding a continuous caster. In
particular preferred aspects, the invention is concerned
with superheating molten metal and with making alloy
additions to such metal.

BACKGROUND ART

With continuous casting, efforts by steelmakers to
ensure accurate temperature, composition and inclusion
shape control are easily negated by the long standing time
in the ladle. Problems include ladle temperature
stratification, aluminium fade, decreased recovery of
alloys, and inclusion formation due to interaction with
refractories and slag.

An additional requirement of continuous casting is
the need for higher tap temperatures, up to 70°C above
that required for ingot steel, made necessary to ensure
sufficient thermal reserve for ladle treatment, losses to
the tundish and possible longer standing times. The

- 2 -

higher tap temperatures cause a marked increase in converter refractory wear and also increase the flux requirements for phosphorus control.

A further difficulty with continuous casting is the initial tundish temperature dip, and temperature sag during the cast. Ideally, metal superheat should be about $2-10^{\circ}C$ at the submerged entry nozzle (SEN). Lower temperatures can cause SEN blocking and skull formation, whilst higher temperatures increase the cooling load on the mould and require slower casting speeds.

Although part of the temperature problem can be offset by use of a ladle furnace, this equipment is capital intensive, creates large shifts in the base power requirements of the plant (30-40MW), greatly reduces ladle life, and does not overcome the problem of temperature sag during casting.

The most satisfactory solution to these problems to date has been to provide facilities for heating ($5-20^{\circ}C$ temperature increase) and tertiary alloying at the tundish, the intermediate receptacle to which the steel is delivered from the ladle, and from which it passes to the continuous caster via the SEN. Tundish heating achieves closer temperature control than a ladle furnace due to its proximity to the mould, and may lessen the impact of some of the disadvantages of a ladle furnace.

Two methods of in-cast tundish heating have been cited in recent literature - by radiofrequency (RF) heating and by transferred plasma-arc to the top of the tundish.

RF heating, described in Mabuchi et al, 5th International Iron and Steel Congress, Steelmaking Proc. 69 (1986), 737, is capital intensive, requiring a non-suscepting stainless steel tundish or tundish modifications. Heating efficiency ranges from 50-85%

- 3 -

depending on configuration.

Plasma heating by transferred arc to the exposed surface of the metal is disclosed in Tolve et al, 5th International Iron and Steel Congress, Steelmaking Proc. 69 (1986), 689, and is apparently 30-50% efficient. Temperature stratification and contamination by H, N (from atmospheric moisture and N_2) and entrainment of slag are envisaged due to high plasma temperatures, arc impaction and an exposed metal surface. Another system relying on plasma heating of the exposed metal surface is disclosed in Kubabara et al, "Development of Tundish Plasma Heater", Nippon Steel Company, presented at ISPC Tokyo 1987. Efficiency is apparently about 80%. Although contamination is prevented by the use of a hood over the plasma torch, to provide steel temperature homogeneity, and to prevent superheating of the tundish slag layer and rapid refractory wear, this system has been used only in small shallow tundishs, apparently less than 15 tonne, and inert gas stirring of the metal below the zone of arc impingment is recommended by the manufacturers.

The Tolve et al paper also describes a method of alloying by aluminium wire through a hollow stopper rod, and by cored CaSiBa wire spiralled directly into the liquid metal. Although the paper suggests the use of these techniques for other alloys, the problem of obtaining uniform distribution of high melting point alloys is not discussed.

Other possible approaches to tundish preheating include resistance heating, and submerged or enclosed combustion. Electrical resistance heaters, such as Mo ribbon, carbon or MoSi rods, are costly and operate most efficiently by radiative heat transfer directly to the exposed metal. Splash must be avoided. Mo ribbon and carbon must also operate in a protective argon

- 4 -

atmosphere. Temperature stratification will also occur.
Submerged combustion would cause excessive hydrogen pickup
from the combustion gases and is inefficient due to only
partial combustion to CO. Combustion in a submerged
combustion tube is inefficient and limited by convective
heat transfer.

SUMMARY OF THE INVENTION

It is therefore an object of the invention to
provide a treatment of molten metal which may be utilised
for improved heating and/or tertiary alloying of molten
steel as or before it is fed to a continuous caster.

The invention provides a method of treating, for
example heating, molten metal comprising contacting a
moving stream of the metal with plasma-arc.

The moving stream is preferably a falling stream of
the metal. In one advantageous application, the molten
metal is steel, for example a stream of molten steel being
teemed from a ladle into a tundish for a continuous caster.

The treatment may advantageously comprise
superheating the molten metal by means of the arc plasma.
The plasma is preferably a transferred-arc plasma whereby
the return electrode is disposed in contact with the
molten metal downstream of the contact of the plasma with
the stream.

Alloying elements may be incorporated into the
plasma and thereby added to the stream of molten metal.
Incorporation of the alloying elements is preferably
achieved by injecting alloying material containing the
elements through the centre of a hollow cathode which
generates the arc plasma, or by providing the alloying
material as a progressively consumed anode with respect to
the plasma generating cathode.

- 5 -

The invention also provides apparatus for treating molten metal comprising a receptacle for molten metal, means defining a path for a stream of the molten metal being directed to the receptacle, and means for generating and contacting the stream with a plasma-arc.

The invention further provides apparatus for treating molten metal comprising means defining an enclosure for a moving stream of the molten metal, and means for generating and contacting the stream with a plasma-arc.

BRIEF DESCRIPTION OF THE DRAWINGS

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

Figure 1 is a sectioned isometric and somewhat diagrammatic view of a ladle and tundish assembly fitted with apparatus according to the invention, for superheating molten steel before it is fed to a continuous caster;

Figure 2 is a fragmentary cross-section of a modification of the assembly of Figure 1, suitable where headroom at the site is limited;

Figure 3 is a simple block diagram of the power supply for the plasma-arc heating unit in Figure 1;

Figure 4 is a graph of tundish operating conditions and the corresponding metal superheat and power requirement profiles for a superheat of about 30°C;

Figures 5A-5C are respective fragmentary cross-sections depicting alternative arrangements for incorporating alloying elements in the molten steel; and

Figures 6A-6C are respective fragmentary cross-sections depicting alternative arrangements for

- 6 -

incorporating alloying elements in the molten steel as it enters the submerged entry nozzle from the tundish.

BEST MODES OF CARRYING OUT THE INVENTION

The assembly 10 illustrated in Figure 1 includes a ladle 12 for molten steel with a lower nozzle 13 and associated slide gate 14, and a tundish 16 from which the molten metal is fed as a strand through a submerged entry nozzle (SEN) to a continuous caster (not shown). Fitted between outlet 14 and tundish 16, to the side of the tundish, is a transferred-arc plasma unit or furnace 20 with an electrode 28 for contacting the falling stream of molten metal (depicted for illustrative purposes at 22) with a plasma-arc 23 and thereby heating stream 22 as it falls from outlet 14 into the tundish 16, where it is temporarily retained as a pool feeding nozzle 18.

Furnace 20 consists of a refractory lined cylinder 26 forming an enclosure about a plasma chamber 27 about 600mm across. Cylinder 26 may be 12mm stainless steel and the refractory lining a 125mm thick high alumina castable. Cooling may be provided but is usually unnecessary. The cylinder 26 is of sufficient length for the minimum free length (shroud-path height) of stream 22 to be about 250mm to reduce the tendency for stream breakup at low metal flowrates.

A sliding cover (not shown) on plate furnace 20 forms a gastight seal with the housing 15 of ladle slide gate 14. The cover is necessary to prevent contamination of the argon atmosphere in the furnace, and to protect the ladle slide gate mechanism from radiant heat from the arc and hot plasma gases. The bottom rim of cylinder 26 is similarly gas-tight sealed with the tundish housing and

- 7 -

with a baffle 17 in the tundish. Each gas-tight seal may
include a suitable gasket. In an alternate arrangement,
sealing of the bottom of the furnace 20 could be
eliminated by immersing the lower end of the furnace into
the metal pool in the tundish.

Figure 2 illustrates modified structure, suitable
where headroom is limited, in which the electrode is
incorporated into a lid 20' for the tundish, but is still
directed at the metal stream.

Cathode 28 is a graphite rod, for example of 100mm
diameter and 1200 mm long. The cathode is conveniently
hollow, e.g. a 10mm axial bore, to allow entry of argon
plasma gas and, if required, an ignition device. Argon
flow should be kept to the minimum to control arc plasma
shape. Excessive argon flow may cause undesirable
turbulence in the main body of the tundish, and also
increase toxic gas or fume emissions (O_3, NO_x, Pb etc
from the steel or impurities in the argon). The cathodes
may be cooled, e.g. by water or compressed air if desired.

Electrode 28 is moveable pneumatically or
electromechanically (e.g. using a rack and pinion
mechanism not detailed) along a support mast 19 to three
positions - fully retracted for electrode replacement or
tundish exchange, standby position with the electrode
advanced just inside the furnace wall, and ignition
position and heating positions 0-200mm back from the
stream. The electrode is therefore slideable through a
sealed port 21 in the wall 20a of furnace 20. To prevent
damage and to facilitate electrode entry into the furnace
chamber, positive location of the electrode support mast
19 with respect to the port 21 is provided by a mounting
bracket 19a for the mast secured to the outside of furnace
20.

The electrode is directed downward (e.g. $10-40^\circ$)

- 8 -

at an acute ange to the direction of flow of stream 22, to
help deflect steel splash and to allow arc contact with
the bath during periods of unstable stream conditions.

Initial arc length can be estimated from the
electrode length (determined by mast position at electrode
entry point) and the estimated slide gate position, or, by
advancing the electrode until the arc voltage drops to
below 30V (assumed zero arc length) and then retracting
150mm.

As the arc length will vary with slide gate position
and electrode wear (about 100mm/h at maximum output)
periodic resetting of the electrode position may be
necessary.

Electrical insulation betwen the electrode 28 and
the furnace 20 is provided by the refractory lining of the
furnace chamber. A clearance at port 21 of 24-40mm is
provided to prevent arcing between the electrode and hot
interior refractory surfaces near the port. Additional
gas sealing is provided by 25mm thick flanges of kaowool
insulation board. External insulation and protection of
the electrode may be provided by a vented enclosure or
grill (not shown): this would also prevent operator
exposure to arc light in the event of an electrode
breaking outside the heater.

Quick connect electrical and water supplies are
provided to enable removal of the heater during tundish
changes, typically after 5-8 heats, or for grade changes.
This allows any necessary patching of refractories and
servicing of electrodes (resetting or replacement), and
replacement of the sealing gaskets.

The return current path is provided by an in situ
immersed anode 36 of J-configuration slung on the wall of
the tundish 16 at each end of the tundish. Each anode 36
is a mild steel plate sandwiched between the existing

- 9 -

tundish refractories 35 and an insulating board 38. The
lower end of the anode is bent up at 37 to reduce erosion
and the tip encased in castable 39. Alternative return
electrode arrangements, not illustrated, include insitu
electrodes in the wall of the tundish, a separate arcing
return electrode, a dipped pipe protected by skulling, a
mould return (i.e through the continuous cast mould
lubricant and strand - mould contacts, with earth straps
if necessary to protect load cell structures from stray
currents), a mould return with a separate return roll or
slide to share the current load, and an in situ ladle
return electrode seated in the floor of the ladle.

Heat is transferred to the metal stream by direct
arc impingement and radiation, this ratio varying mainly
with arc length. In furnace 20, about 60-70% of the
energy is thought to be transferred by direct impingement,
with only 30-40% transferred by direct radiation from the
plasma and multiple reflection from the refractories to
the stream and the metal pool in the tundish.

The electrodes may be powered by an AC or a DC
system but a DC system is presently favoured as it offers
improved control, longer electrode life, and higher
efficiency over that for an AC system. Figure 3 is a
schematic diagram for the power supply.

The preferred method of power control is by varying
the current. The arc voltage should remain relatively
constant and independent of current, at around 120-150V
for argon support gas. The flat voltage characteristic is
due to the increase in arc area and temperature (i.e
reduced arc resistance) with increased current.
Therefore, stream temperature increase should be
approximately linear to the furnace current. Operation
and current control would be determined by a combination
of slide gate opening, ladle and tundish load cells, and

- 10 -

tundish thermocouples.

A typical operating sequence for the assembly 10 of Figure 1 will now be described. The ladle 12 is lowered over the tundish and nozzle 13 located through the furnace cover plate. The slide gates are opened to commence teeming and the electrode 28 advanced on its mast 19 tothe standby position. If temperature measurements indicate low steel temperature, the electrode is slowly advanced toward the stream 22 up to the estimated stream centre line until ingnition occurs. The starting power is set at, e.g. about 150KW, with an open circuit voltage limit of about 200V. Current control may alternately be used for starting.

After ignition of the arc, the electrode is retracted to give an estimated arc length of, say, about 150mm. Power is increased to give the required temperature rise in the steel. Monitoring and control is continued through the duration of ladle run out.

Figure 4 shows typical tundish operating conditions (curves C and D), and the corresponding power profile (curve A) required to maintain an ideal metal superheat (curve B) of about $30^{\circ}C$.

In a modified assembly (not illustrated), plural electrodes are provided, equi-angularly spaced about the metal stream. The furnace may be conveniently annular and there may be, for example, three electrodes offset at different vertical heights relative to the direction of metal flow. Such a configuration may be advantageous by maximising the area of the stream under arc impact and to reduce refractory stress from arc radiation.

The absence of air and slag, and the high plasma temperatures and intense mixing in the tundish make the stream furnace 20 an ideal location for microalloying e.g with Al, B, Cr, Mn, Mo, Nb, Ni, Pb, Ti, and V. Accurate

- 11 -

carbon trimming could also be achieved under these conditions.

In this context, the plasma-arc heating so far described can:-

- provide rapid melting of large alloy material, e.g sheathed wires, therefore preventing the formation of a skull around the wire,

- offset the chilling effect of adding cold alloys, and

- create a metal fog from the alloy - which is important for slow dissolving lead or for high melting point additions such as ferroniobium (Tm 1530°C), ferrovanadium (Tm 1770°C) and ferromolybdenum (Tm 1900°C).

Alloy additions vary from 0.2kg/t for microalloys such as Nb to 10kg/t for Mn. The vaporisation power required is highest for metallic molybdenum, about 1.5MW. However, complete vaporisation in the plasma is only required for extremely rapid dissolution, such as required for the strand additions discussed below. Melting and some degree of atomisation should be sufficient to ensure rapid dissolution of most alloys.

The alloying mechanism is envisaged to be as follows:

(a.) Melting and partial vaporisation by plasma heating.

(b.) Condensation of vapours and coalescence to form submicron alloy fog.

(c.) Entrainment of droplets, fog, vapour and any larger particles by the teem steam.

(d.) Rapid dissolution and dispersion by the intense mixing in the tundish pouring box.

(e.) Float or sink-out of any remaining large particles (floats Ti; sinks Ni, Cr, Mo, Pb) followed by slower dissolution.

- 12 -

Three alternative arrangements for introducing
alloying materials are depicted in Figures 5A to 5C.
Figure 5A shows a hollow cathode, e.g a hollow carbon
cathode, for which the simplest arrangement would involve
injecting the alloys through the centre of the electrode.
If wire feeding is used, as is illustrated, the wire 40
would be maintained at electrode potential. As an arc
will be present at all times (from the electrode carbon),
good control and stability is ensured. The wire spool
should be maintained at an elevated potential (about 50V),
although this could be avoided by maintaining the wire at
earth potential and forming the arc directly between the
cathode and the wire: however, this would require a more
complex electrode involving an insulated central wire
guide.

Figure 5B depicts a plasma powder torch 42. For
non-transferred arc plasmas, specific metal vaporisation
rates range from 50-100g/MJ, with efficiencies of 70-85%.
The main loss of efficiency is due to the high argon flows
required for non-transferred arc plasmas and water cooling
of the torch. Although this torch has a lower efficiency,
it provides a modular/self contained device and does not
require a return electrode. The main limitation with this
device is the shorter residence time of the solids in the
plasma, which would probably restrict its use to either
fine wires or powders.

The use of a consumable wire electrode 44 is shown
in Figure 5C. Heavy wires may be added by making the wire
the anode, and feeding directly into the metal pool in the
tundish. As relatively large droplets are formed by wire
melting, this technique may not be suitable for alloys
with high melting points (e.g. ferromolybdenum) or low
solubility (e.g. lead). The main engineering problem with
this technique is the requirement to have the wire feeder

and spool at about 50V above ground potential.

From the available information, the presently preferred option is to use the hollow carbon cathode or the consumable wire-electrode method. These enable higher injection rates and the use of larger wires than possible with non-transferred arc torches, as the residence time of particles in the transferred arc is about three orders of magnitude greater than that in a powder torch (1-5s versus ⁻1ms), and with wire feeding, direct arc impingement gives much higher heat fluxes.

The ability to produce metal fog from alloys, including the high melting point elements, may allow individual strand alloying at the submerged entry nozzle 18. This operation would be particularly beneficial for the production of small tonnage, value-added grades, and leaded steels, where direct strand injection would obviate the environmental precautions required for refurbishing tundishes and eliminate the problems of lead segregation to the floor of the tundish.

Successful strand alloying, especially for the more refractory elements, requires introducing the alloy in a finely divided form, say ⁻100μm. This requires atomisation of the liquid alloy, or the formation of metal fog by the vaporisation-condensation mechanism. Because of the short residence time in the injector, both require high heat transfer rates.

It is proposed to introduce the molten alloying material as a fog or mist via a vertical lance located above the strand outgate from tundish 16 at nozzle 18, using a "strand injector". Three possible arrangements are shown in Figures 6A-6C, using both transferred arc and plasma torch heating.

Figure 6A depicts a submerged arc injector 50. This simple arrangement uses a consumable wire electrode 52.

The alloy wire 52 is melted by a transferred arc with the liquid steel in the recess beneath the injector. A steeply drooping power supply would be used to maintain a low current arc with the carbon wire guide during low wire feed rates (i.e current decreases rapidly with increasing voltage). The main problem with this arrangement is the need to maintain the wire and spool at about 20-50V above ground.

A plasma torch injector is shown in Figure 6B. In this arrangement, a small (about 100kW) plasma torch 54 is located in the top of a large bore refractory injection lance 56. The alloy material is introduced into the hot plasma gases as either fine wire or powders. The molten, partially vaporised material then travels down the injector under gravity in the plasma gases. The power input would be varied to maintain the inside of the probe at about $1600^{\circ}C$ to prevent skulling - internally and at the outlet. A higher argon flow is required, and the method is not suited for rapidly melting large diameter wires.

Figure 6C shows an arc-ultrasonic atomising injector. This arrangement involves arc melting of a rapidly vibrating alloy wire 58. The purpose is to utilise the rapid heating of a transferred arc, with the droplet size controlled by ultrasonic atomisation. Droplets are torn from the liquid film formed by arc heating, rather than dripping from the wire under gravity. Radio frequency heating could also be used.

It is expected that strand injection according to the invention would overcome the problems of lead addition in particular by providing extremely fine lead droplets and an even dispersion in the steel entering the strand, and so avoiding the formation of lead stringers in the end product. The sealed environment at the point of addition

- 15 -

also minimises environmental problems, a special concern
with lead.

The most suitable device for strand leading may be a
piezoelectric or magnetostrictive atomiser which can
produce a fine, narrow droplet size distribution. The
simplest method is to provide liquid lead to the
atomiser. However, if steel sheathed lead wire is to be
used, the arc-ultrasonic atomiser of Figure 6C could be
used. Powdered lead or lead compounds may be introduced
either by direct addition or by plasma torch. The
advantage of the plasma torch is that larger sized powders
may be used and improved dispersion would be obtained.
Powders may include lead concentrates, sulphides,
carbonates or metallic lead.

By way of conclusion, it is proposed to summarize
the principal advantages of the inventive method as
applies to the treatment of molten steel as it is fed from
a ladle to a tundish of a continuous caster. Foremost,
the method is capable of readily providing a temperature
increase of up to $20^{\circ}C$, even 30°, in the metal
entering the tundish. It permits accurate addition of
refractory and toxic alloys by wire, shot or powder
feeding, yet contamination of the teeming stream is
prevented. The equipment is non-intrusive to the already
busy tundish area, may be removed and serviced with normal
tundish changes, and is non capital-intensive and economic
to operate.

Strand injection uses external heating involving arc
or radio frequency means to produce finely divided alloy
particles capable of rapid dissolution and uniform mixing
into the steel entering the SEN. Further dispersion of
the alloying material is obtained by ultrasonic vibrations
or in the case of lead injection, high pressure liquid
lead from an external dispenser.

- 16 -

CLAIMS

1.   A method of treating molten metal comprising
contacting a moving stream of the metal with a plasma-arc.

2.   A method according to claim 1 comprising heating
said molten metal stream with the plasma-arc.

3.   A method according to claim 1 or 2 wherein said
moving stream is a falling stream of the metal.

4.   A method according to claim 1, 2 or 3 wherein said
molten metal is steel.

5.   A method according to claim 1 for superheating
molten steel in a tundish, comprising plasma-arc heating
the stream of molten steel as it is teemed from a ladle
into the tundish.

6.   A method according to any preceding claim wherein
said plasma is a transferred-arc plasma whereby a return
electrode is disposed in contact with the molten metal
downstream of the contact of the plasma with the stream.

7.   A method according to any preceding claim wherein
said plasma-arc is directed into contact with said stream
at an acute angle to the direction of flow of said steel.

8.   A method according to any preceding claim further
comprising adding alloying elements to the plasma-arc and
thereby to the stream of molten metal.

9.   A method according to claim 8 wherein said alloying
elements are added by injecting alloying material

- 17 -

containing said elements through the centre of a hollow
cathode which generates the plasma-arc.

10.   A method according to claim 8 wherein said alloying
elements are added by providing alloying material
containing said elements as a progressively consumed
electrode.

11.   Apparatus for treating molten metal comprising a
receptacle for molten metal, means defining a path for a
stream of the molten metal being directed to said
receptacle and means for generating and contacting said
falling stream with a plasma-arc.

12.   Apparatus according to claim 11 further comprising a
ladle from which said molten metal may be teemed as said
stream, and wherein said receptacle is a tundish for
temporary retention of said metal.

13.   Apparatus according to claim 11 or 12 wherein said
path defining means comprises an enclosure for said
stream, mounted to said receptacle.

14.   Apparatus according to claim 11 or 12 wherein said
path defining means comprises lid means for the receptacle
having an opening for said stream.

15.   Apparatus according to any one of claims 11 to 14
wherein said plasma-arc generating means comprises a first
electrode for directing said plasma-arc into contact with
said stream as a transferred-arc plasma, and a second
electrode disposed in contact with said molten metal in
said tundish.

- 18 -

16.   Apparatus according to claim 15 wherein said first
electrode is arranged to direct said plasma-arc into
contact with said falling stream at an acute angle to the
direction of flow of the stream.

17.   Apparatus according to claim 15 or 16 wherein said
first electrode is an elongate electrode moveable to and
from an operative position with respect to said falling
stream.

18.   Apparatus according to any one of claims 15 to 17
wherein said first electrode is a cylindrical carbon
electrode having an axial bore for admission of plasma gas.

19.   Apparatus according to any one of claims 11 to 18
further comprising means to add alloying elements to the
plasma-arc and thereby to the stream of molten metal.

20.   Apparatus according to claim 19 wherein said adding
means comprises a progressively consumed electrode of
alloying material containing said alloying elements.

21.   Apparatus for treating molten metal comprising means
defining an enclosure for a moving stream of the molten
metal, and means for generating and contacting said stream
with a plasma-arc.

22.   Apparatus according to claim 11 wherein said
plasma-arc generating means is arranged to generate a
plasma-arc effective to heat said molten metal.

23.   A method of adding an alloying element to molten
steel, comprising entraining particles of the alloying
element in an arc plasma and contacting the plasma with

the molten steel.

24.   A method according to claim 23 wherein the plasma
contacts themolten steel at the top of a strand of the
steel being directed into a continuous caster.

FIG 1
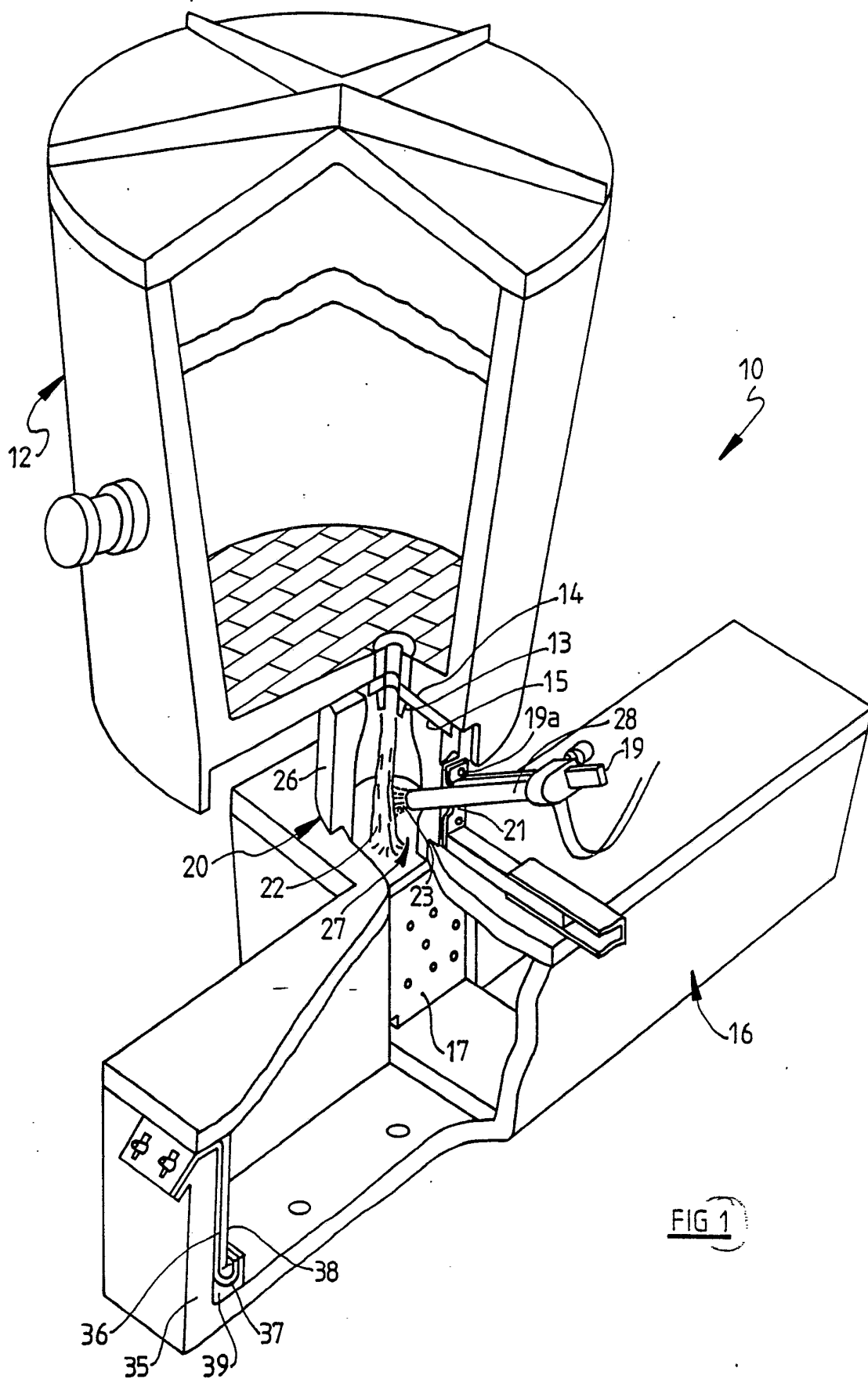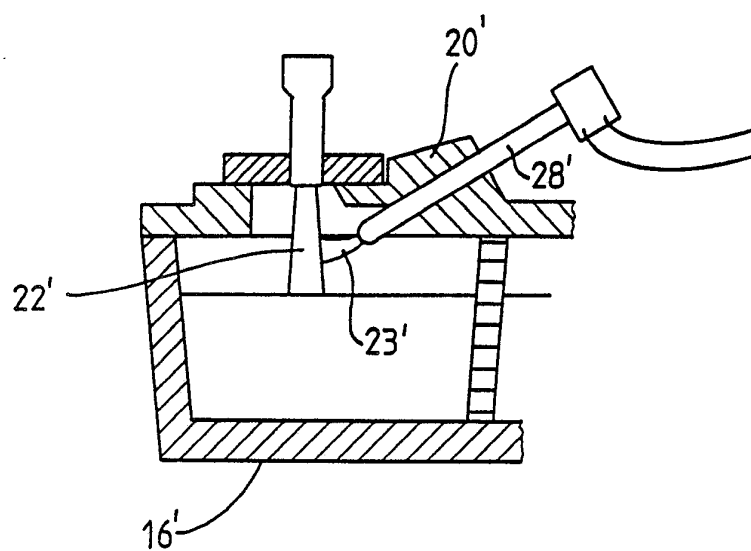
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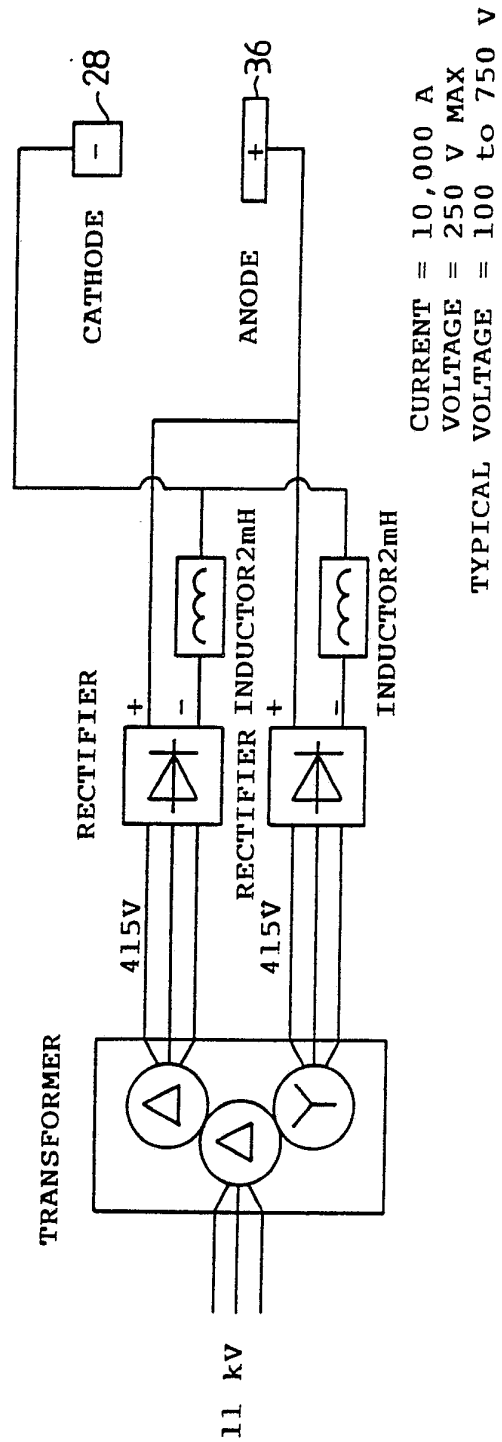
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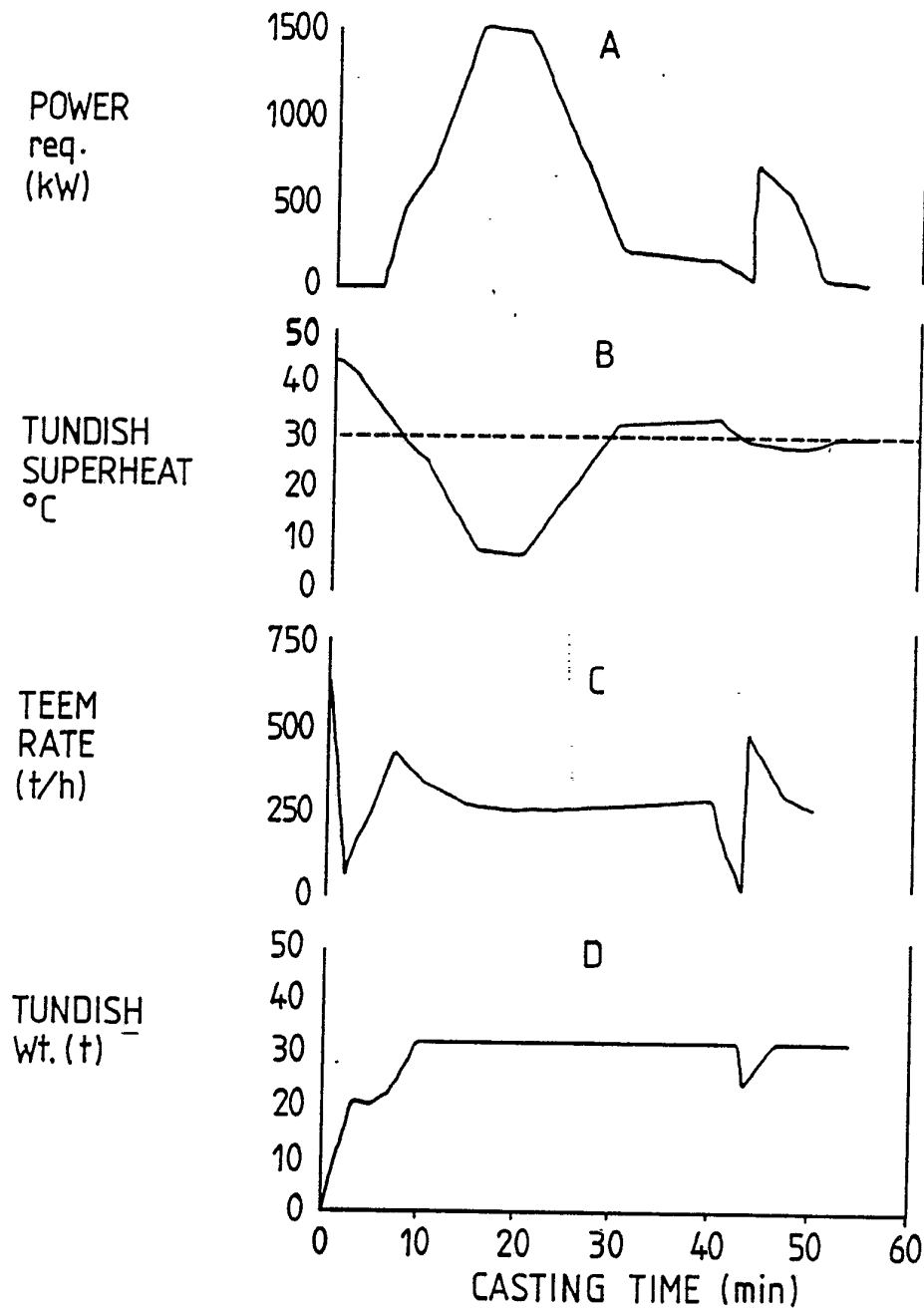
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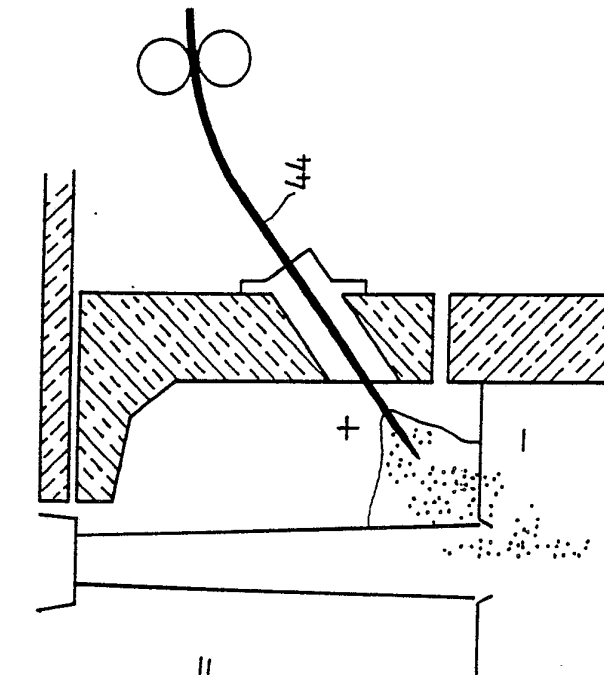
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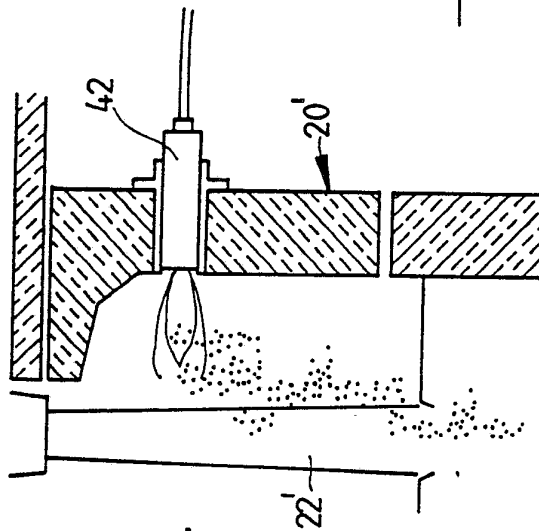
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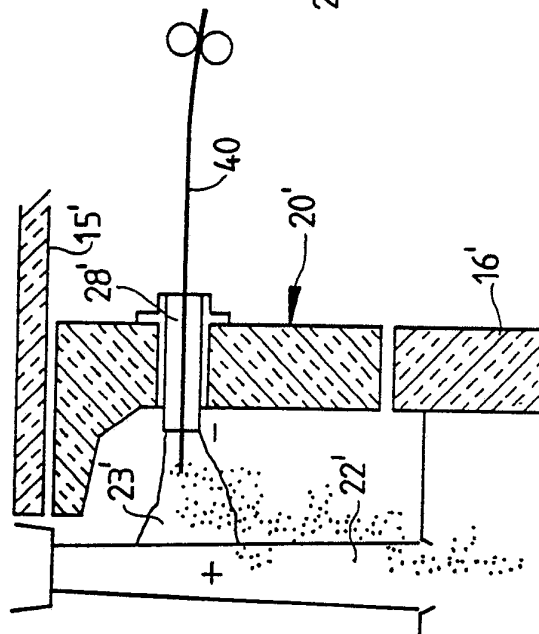
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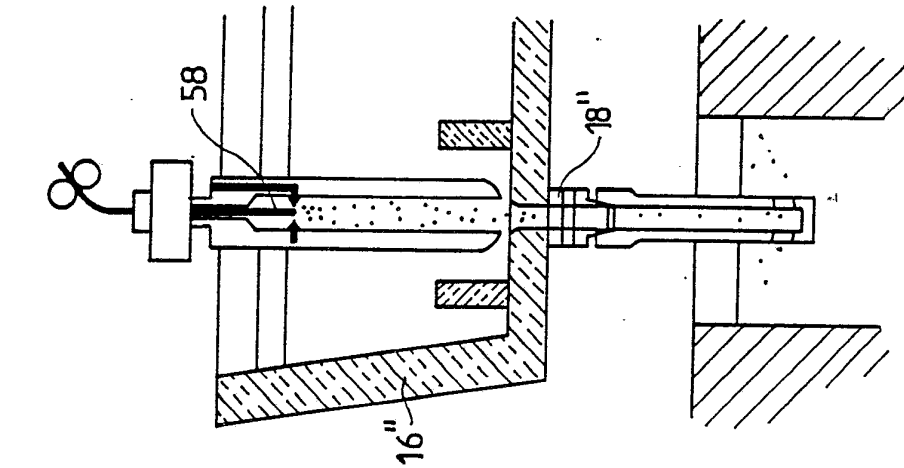
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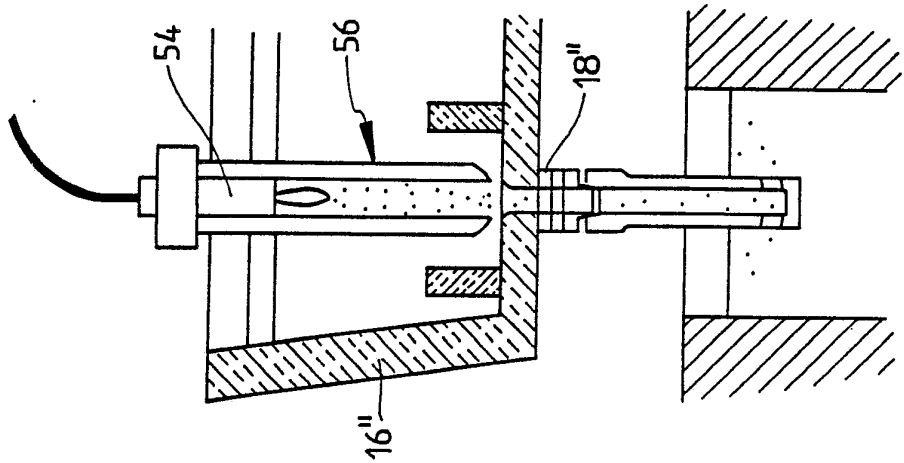
FIG 6B
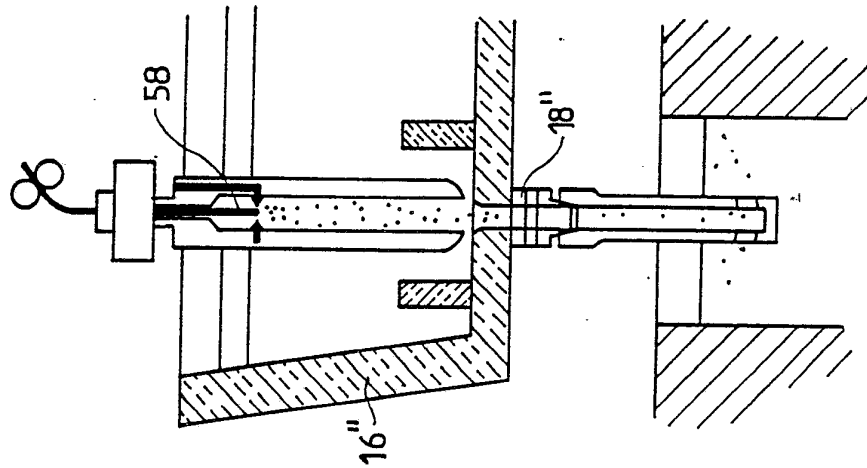
FIG 6C

INTERNATIONAL SEARCH REPORT

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁶

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl.⁴ B22D 11/10, C21C 7/00, C22C 33/04, 33/06,
H05H 1/42 // B22D 11/16, C22B 9/16, C21C 7/06.

II. FIELDS SEARCHED

Minimum Documentation Searched ⁷	
Classification System	Classification Symbols
IPC	B22D 1/00, 7/12, 11/10, H05H 1/42.
US Cl.	75/10.22, 373/22.

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are included in the Fields Searched ⁸

III. DOCUMENTS CONSIDERED TO BE RELEVANT⁹

Category*	Citation of Document,¹¹ with Indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
X	AU B1 514181 (WESTINGHOUSE ELECTRIC CORPORATION) 29 January 1981(29.01.81) (see page 4 lines 7-9, page 5 lines 13-15 and Figures 1, 2 and 3 of the drawings).	1,2,21,22.
A	AU B2 534839 (COUNCIL FOR MINERAL TECHNOLOGY AND MIDDLEBURG STEEL AND ALLOYS (PTY.) LTD.) 16 February 1984 (16.02.84)(see page 2 lines 19-21, page page 3 lines 1,2,11-18, page 4 lines 14-24, page 5, page 6 lines 1-7 and the furnaces of GB A 1390351/2/3 and GB A 1529526).	1-3,6,11,13, 15,17,18,21.
A	AU A1 67090/86 (VOEST-ALPINE AKTIENGESELL-SCHAFT) 6 August 1987(06.08.87)(see Claims 1,2, page 4 lines 26,27, page 5 lines 1-3 and the drawing).	1-4,11,21,22.
X	EP A1 232961 (PLASMA ENERGY CORPORATION) 19 August 1987(19.08.87)(see pages 5,6, 7 and Figures 1,2 and 3 of the drawings).	1,2,4,6,7,11 13,17,21,22.

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* Special categories of cited documents: ¹⁰

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
26 May 1989 (26.05.89)	15 June 1989 (15.06.89)
International Searching Authority	Signature of Authorized Officer
Australian Patent Office.	B. Bourke (B. BOURKE)

III. DOCUMENTS CONSIDERED TO BE RELEVANT   (CONTINUED FROM THE SECOND SHEET) (1)

Category*	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
X	GB A1 2184377 (CENTRO SPERIMENTALE METALLURGICO) 24 June 1987(24.06.87)(see page 2 lines 50-120 and Figures 1,2 of the drawings).	1-5, 8, 9, 11-14,17,19, 21,22.
X	PATENT ABSTRACTS OF JAPAN, UNEXAMINED APPLI- CATIONS, Volume 7, Number 203 (M-241) [1348], issued 8 September 1983 (THE PATENT OFFICE, JAPANESE GOVERNMENT) ' JP A2 58-100951 (SHIN NIPPON SEITETSU K.K.) ' 15 June 1983(15.06.83)(page 1 M 241, see the whole abstract).	1-2,4-6,11- 15,21-24.
X	PATENT ABSTRACTS OF JAPAN, UNEXAMINED APPLI- CATIONS, Volume 8, Number 227 (M-332) [1664], issued 18 October 1984 (THE PATENT OFFICE, JAPANESE GOVERNMENT) ' JP A2 59-107755 (SHIN NIPPON SEITETSU K.K.) ' 22 June 1984(22.06.84)(page 8 M 332, see the whole abstract).	1,2,4,5,11- 15,21,22.
X	PATENT ABSTRACTS OF JAPAN, UNEXAMINED APPLI- CATIONS, Volume 8, Number 240 (M-336) [1677], issued 6 November 1984 (THE PATENT OFFICE, JAPANESE GOVERNMENT) ' JP A2 59-120353 (SHIN NIPPON SEITETSU K.K.) ' 11 July 1984(11.07.84)(page 98 M 336, see the whole abstract).	1,2,4,5,11- 15,21,22.
X	PATENT ABSTRACTS OF JAPAN, UNEXAMINED APPLI- CATIONS, Volume 9, Number 14 (M-352) [1737], issued 22 January 1985 (THE PATENT OFFICE, JAPANESE GOVERNMENT) ' JP A2 59-163062 (SHIN NIPPON SEITETSU K.K.) ' 14 September 1984(14.09.84)(page 120 M 352, see the whole abstract).	1,2,4,5,11- 15,21,22.
X	PATENT ABSTRACTS OF JAPAN, UNEXAMINED APPLI- CATIONS, Volume 9, Number 70 (M-367), [1793], issued 30 March 1985 (THE PATENT OFFICE, JAPANESE GOVERNMENT) ' JP A2 59-202142 & JP A2 59-202144 (SHIN NIPPON SEITETSU K.K.) ' 15 November 1984(15.11.84)(page 100 M 367, see the whole abstract in each case).	1-6,11-14,21, 22. AND 1-5,11-13,21, 22.
X	PATENT ABSTRACTS OF JAPAN, UNEXAMINED APPLI- CATIONS, Volume 12, Number 27 (M-662) [2874], issued 27 January 1988 (THE PATENT OFFICE, JAPANESE GOVERNMENT) ' JP A2 62-183946 (NIPPON KOKAN KABUSHIKI KAISHA) ' 12 August 1987 (12.08.87)(page 163 M 662, see the whole abstract).	1,2,4,5,11- 14,17,20,21.

(continued......

III. DOCUMENTS CONSIDERED TO BE RELEVANT   (CONTINUED FROM THE SECOND SHEET) (2)

Category*	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
X	PATENT ABSTRACTS OF JAPAN, UNEXAMINED APPLICATIONS, Volume 12, Number 404 (M-757) [3251], issued 26 October 1988 (THE PATENT OFFICE, JAPANESE GOVERNMENT) ' JP A2 63-149055 (NIPPON STEEL CORPORATION) ' 21 June 1988(21.06.88)(page 159 M 757, see the whole abstract).	1,2,5,11-14, 17,21,22.
X	SOVIET INVENTIONS ILLUSTRATED, Section Ch: Chemical, WEEK D41, issued 18 November 1981 (DERWENT PUBLICATIONS LTD.LONDON, ENGLAND) ' SU 797840 A1 (TULACHERMET) ' 23 January 1981(23.01.81)(METALLURGY - page 12, see the whole abstract).	1-5,7,11-14, 16,17,21,22.
A	US A 3479022 (W.COUPETTE) 18 November 1969 (18.11.69)(see page 2 lines 19-45,59-72, page 3 lines 3-13 and the drawing).	1-4,7,11,13, 21,22.
X	US A 3547622 (H.R.HUTCHINSON) 15 December 1970(15.12.70)(see page lines 10-75, page 4, page 5 lines 1-73 and the drawing).	1-4,11,13,14, 17,21,22.
X	US A 4150248 (M.G.FEY,F.G.ARCELLA) 17 April 1979(17.04.79)(see pages 2,3 page 4 lines 1-48 and Figures 1,2 and 3 of the drawings).	1,2.
X	US A 4645534 (R.D'ANGELO,A.RAMACIOTTI, E.REPETTO,P.TOLVE) 24 February 1987 (21.02.87)(see page 2 lines 30-67,page lines 23-55,page 4 lines1-28,the claims the drawing and the tundish of GB A1 2159741.	1,2,4-6,11- 13,15,21,22.
X	US A 4686687 (H.MURE,R.MIZOGUCHI,S.YOKOI, S.FUJIHARA,K.ICHIKAWA) 11 August 1987 (11.08.87)(see page 2 lines 9-69,page 3, page 4 lines 1-24 and Figure 1 of the drawings).	1-6,11-15,17, 21,22.
X	US A 4632700 & US A 4713826 (H.J.BEBBER, D.NEUSCHUTZ,H-O ROSSER) 30 December 1986 & 15 December 1987(30.12.86 & 15.12.87) (see page 4 lines 45-68,pages 5,6,7,8 and Figures 1-6 of the drawings).	1,2,4,11,13, 17,21,22.