MHD-equipment and technologies of semi-continuous billet casting of high-strength Al-alloys

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Abstract
In this study, there are presented design and conceptual approaches developments for 2 (two) kinds of the original complex technological foundry equipment for the melting, holding and managed electromagnetic magneto-hydrodynamic high-strength aluminum alloys pouring at continuous billet casting processes.
First kind performed as MHD-complex device created on base of the magneto-dynamic installation (MDI MDN-6A-0.63-WMD-M), that has applied as mixer-batcher with 630 kg capacity by Al-alloys with electromagnetic pump (up to 0.35 bar pressure). An experimental approbation for workability of the developed technologies for MHD-semi continuous billet casting, by means open stream melt feeding into 7 inch crystallizer and by progressive hot-top closed process, at the producing 1.0 meter of 7' billet from Al-Zn-Mg-Cu wrought alloy has been executed.
As second kind, there are developed conceptual design of 500 kg capacity by Al-Alloy pilot plant of the foundry equipment for the melting, holding and managed electromagnetic continuous billet casting, comprised upgraded tilting reverberator melting furnace combined with multifunctional horizontal magneto-hydrodynamic units (MHDU), as a W-shaped induction channel with 2 inductors (2x20kW) and external C-type electromagnet (0.01~0.3T). MHDU provide homogenization melt temperature (650~850°C) and it chemical compositions (at circulation melt intermixing 0.5~3.0kg/s) and at the switching electromagnet of electromagnetic melt pouring with managed flow rate 0.05kg/s ~ 15kg/s to tundish of the 3~10 inches billet continuous casting machine (CCM).

Keywords : High-strength aluminum alloys, continuous billet casting, electromagnetic stirring, electromagnetic pump.

Introduction

At the developing of rational equipment for the semi or continuous billet casting technologies from high-strength aluminum alloys 6xxx and 7xxx series, the main trend are accented on the creation multifunctional and multitask equipment, combined several metallurgical and casting operations in one electro-technological device.

These thing are concerned for the serious decreasing of the energy using, simplification exploitation modes and creation of new possibilities of high-effective melt processing methods for rising alloys properties, prevention casting defects due to the absence or insufficiency chemical, temperatures and structural inhomogeneity in the liquid state of alloy. Second reason in the decreasing of the quantity melting and foundry equipment's using are concluded, and accenting using only one electric energy for all operation from melting, holding, refining up to the pouring are consisted. Especially for the continuous castings technologies as usual applying induction crucible melting furnaces, induction channels furnaces or crucible electric resistance furnaces [1]. As more advantage oven for the melt melting can be suggested an reverberate melting furnace with upper location heaters, when the main steel case of furnace lined inside and have a widely by capacity of aluminum alloys range. However as a disadvantage have an insufficient melt stirring into main capacity and cannot guaranteed melt homogeneity and require application of the artificial melt stirring means. As a next melt processing stage continuous casting technologies require melt holding, degassing, refining at the providing melt temperature and chemical homogeneity. For these by the usual approaches using the mixer-batcher or intermediate heated vessel with maintaining melt temperature range in the holding mode.

As a most like for this case, have a perfect possibilities an induction channels furnaces [1, 2], that to perform artificial melt stirring and inductions contactless heating before pouring melt to the molds or crystallizers. As a finishing device at the continuous casting processes are used the rows means for the liquid alloys transportation with high accuracy operating parameters by speed, mass flow-rate, temperature and with prevention for the second oxidation or involving gases or hydrogen methods [2, 3]. Usual there are tilting mixer-batcher, pneumatic pressure dosing devises or electromagnetic magneto-dynamic pump (EMP) with contactless action on the melt. As well magneto dynamic pumps (MDP) as a most progressive equipment can be selected for the continuous casting technologies [2~4]. Assuming dedicated the usual equipment are consist as minimum 3 divided devices, that are required own electrical energy rates and as minimum two times melt overfilling from each devices as following step by step.

MHD-complex device for semi-continuous billet casting of the high strength Al-alloys (7xxx series)

For reasons creating a full-closed technological cycle of production of high-strength aluminum alloy at development for special technology of continuous casting has been accepted, where are the one foundry unit, for melting and further

controllable contactless electromagnetic pouring directly into the crystallizer of continuous casting machine are using.
MHD-complex device and comprised methods for manufacturing, preparing, processing and controllable contactless electromagnetic pouring melt directly to the crystallizer by the MHD-tundish means can be succeed applied. As main unit in this case applied the magneto dynamic installation (MDI) as a mixer-batcher [2, 3~5], electromagnetic pump (EMP) and induction-melting furnace. The classic solution of MDI for aluminum alloys MDN-6A (630 kg capacity by Al-alloy), designed with dual combined W-shaped channel, with two independently controlled inductors for each channel, and additional electromagnet for creation of external alternating magnetic field (B) [1].
The main working principle MHD-equipment based on the interaction of AC-current (I) (5~20kA) with external AC-magnetic field (B) in the working area (WA) (fig. 1). As result by the Fleming's Left Hand Rule in WA are creating the unidirectional pulsating (120Hz) pulse electromagnetic force, - Fem (70~285N). It is produce pumping of molten metal from EMP WA through central channel (fig. 1), follow or into crucible by circulation mode or to casting molds/tundish, by EM-pump with managed pressure 7~35kPa and flow rate 0.1~5kg/sec by low electromagnetic pressure principle.
MDI allows providing the number technologies for electromagnetic stirring of liquid aluminum alloy in the crucible and induction channels with controlled melt flow rate 1~5 m/sec, using this electromagnetic pump. In addition, for melt processing the MDI can use the high-density of AC-electric current (up to 60 A/mm^2) and pulsing electromagnetic forces PEMF (120 Hz) for purpose homogenization, dispersion of micro-segregation in melt, dissolve ligatures and modifiers dispersing of intermetallic compounds [5]. On these means MHD-equipment for continuous billet casting, named as MHD-tundish (fig. 1, 2) has assembled and tested. It is consisted the MDI combined with special metal-duct/tundish for controlled electromagnetic pouring Al-alloy from mixer-batcher to the crystallizer of the CCM.

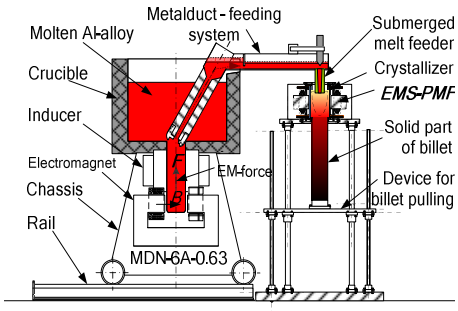


Fig. 1: Scheme of 7075-alloy casting from magneto-dynamic installation to the semi-continuous 3~10" billet casting machine

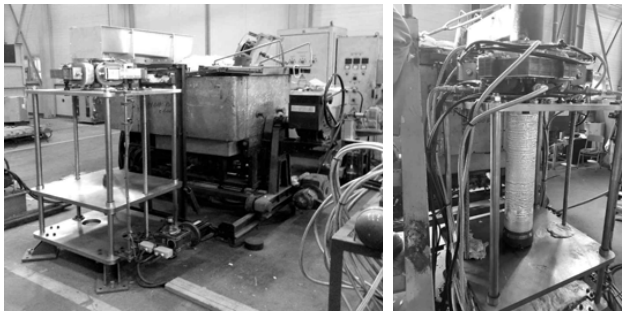


Fig. 2: Photos pilot-plant installation for high-strength alloy casting from magneto-dynamic installation semi-continuously billet casting and 7" billet casting process, (analog 7075 alloy)

For practical verification workability of MHD-technologies of continuous/semi-continuous billet casting, there are of 2 types for MHD-tundish, EMS, Cu-water-cooled crystallizer and billet puling stand has been developed and installed.
On first stage for feeding melt from MDI to 7" EMS-crystallizer has been used metal-duct/tundish with stream melt feeding system by opened meniscus mode, and further - original closed melt feeding process at the using hot-top system.
For opened meniscus casting mode as tundish has been used modified metal-duct, consisted primary ceramic tube with graphite tip, installed to the central mouth of the W-shaped induction channel into crucible MDI, from where are the melt are pumping inside (fig. 2). On the upper end metal duct was installed metallic cap as an tundish, that has horizontal channel with height 250 mm and length 500 mm. On the opposite end of tundish was connected the cylindrical vessel with diameter 200 mm. In this bottom place was manufactured hole with diameter 70 mm, and outside in the vertical plane to this hole was attached removable crater with output hole with diameter 8 mm.
Selection gating hole for 8 mm diameter to provide create mass flow-rate aluminum alloys from tundish, at the conditions hydrostatic pressure 0.2~0.25 meter in ranges 0.05~0.1 kg/sec. Crater was need for the stabilization melt flows lines and focusing melt stream to the center of crystallizer. Height of crater selected as 100 mm, from viewpoints possibilities on 10~30mm submerging it end under melt level into crystallizer for the prevention occurs melt foam and it involving to the billet body or catching in mushy zone.
Casting process has realized by switching MDI to the electromagnetic pumping mode and starting controllable melt filling to the cavity of tundish with speed in range 0.5~0.6 kg/sec, 690~710°C. Visual slowly filling melt to the crystallizer cavity, for formation full filling it chamber up to the touching hot-top insertion during no less than 30~40 second. After filling crystallizer cavity – delaying no more than 10~20 second to switching billet pulling device for 60~100mm/min and starting semi-continuous billet casting process. At the maintaining electromagnetic melt feeding into tundish in range 0.5~0.8 kg/sec - continuing filling tundish cavity up to the level 150~160 mm from it bottom side and after reducing voltage on electromagnet for value, when melt level in tundish maintaining on set level. After reaching required lengths billet, MDI switching to holding mode.

Study of the MHD-Physical modification effect on microstructure refinement of the Al-Zn-Mg-Cu (Zr-Free) high-strength wrought aluminum alloy in 7" billet at semi-continuous casting

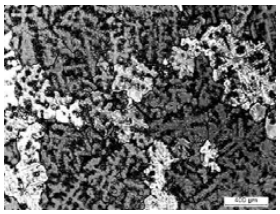
As an alloy for the continuous billet casting was selected experimental Al-5.5Zn-2.2Mg-0.6Cu-0.1Mn-0.23Cr-0.1Fe-0.1Si-0.1Ti wrought alloy composition without admissions Zr.

For manufacturing alloy used unique methods, when MDI furnace started by pure aluminum in quantity 50 kg, and all necessary component was added step by step into MDI crucible in the master alloy state.

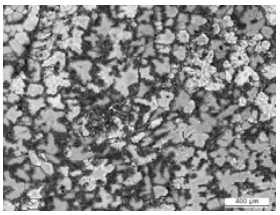
The final capacity melted alloy reached for 300 kg as for test mode. By the original way, the argon gas degassing melt has performed during 20 minutes for 300 kg, at the Ar-gas rate 5l/min at using lateral static tuyere in the special lateral stirring mode [5]. Final content of hydrogen had no more than 0.1 ppm.

For homogenization alloy state the 2 main working modes used, as permanent holding mode at slowly (2~3 kg/sec) melt circular electromagnetic stirring and intake reverse mode intensively stirring by pulsing (100~120Hz) electromagnetic force with 15~20kPa pressure, (70~143.5N), during 10 minutes. After that has been performed continuous billet casting from the magneto-dynamic installation for two main conditions without EMS and with application electromagnetic melt stirring into Cu-water-cooling crystallizer for recognizing effect processing melt into MDI by the MHD means and combined effect MHD-melt processing into MDI and it EMS-processing into crystallized during billet solidification.

For compare efficiency applying MHD-processing 7xxx-series Al-alloy has produced 2 experimental casting at using melt from conventional melting furnace with/without EMS (fig. 3), and pouring from MDI, with/without EMS (fig. 4).

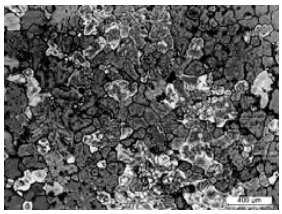


a) DC casting, non-treated

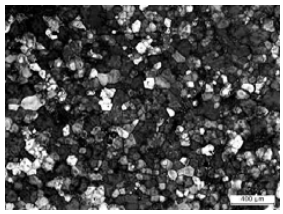


b) EMS, conventinoal furnace

Fig. 3. Microstructure for central part 7" billet from Al-Zn-Mg-Cu alloy melted in conventional melting furnace: a) DC casting; b) EMS-processing into crystallizer.



a) DC casting, MHD-processed



b) EMS, MHD-processed

Fig. 4. Microstructure for central part 7" billet from Al-Zn-Mg-Cu alloy melted and poured from magneto-dynamic installation:: a) DC casting from MDI; b) EMS-processing into crystallizer.

At MHD processing (fig. 4a), by the means of unidirectional 120Hz pulse electromagnetic force (70~143.5Newton), created in working area (WA) electromagnetic pump are provide the fine distribution intermetallic particles, as emulsion state in liquid melt. Indicated microstructure state reached during 10 minute intensively processing and keeping at holding mode permanently as ready to the cast mold pouring conditions.

It is allow forming advantageous conditions for further non-dendrite microstructure formation in EMS-mold (fig. 4b), with resulted grain size no more 50~80μm for quantity melt from 50~600 kg as for one capacity of MDI crucible.

Analysis of the 7" billet at casting to the water-cooled crystallizer of continuous casting machine shown that MHD-processed melt have not hot cracks (fig. 4), porosity or any tensions into billet. However non-treated alloy (Fig. 3a), poured from conventional melting furnace, have prone to the hot crack appearance in the central part of billet, and large dendrite microstructure with 450~650μm for DC casting state (fig. 3a), and 150~250μm dendrite's for EMS (fig. 3b). As well, MHD-process can by presented as in-time melt processing into magneto-hydrodynamic tundish, for creation high-effective technology manufacturing 3"~10"billets with improved properties and solving problem hot-cracks occurs into wide billets at it manufacturing.

Development of MHD-technological foundry equipment for semi-continuous billet casting high strength Al-alloys

For creation specialized for continuous casting processes equipment there are focusing attention for concepts creation combined as one device the 3 main aggregates, - melting furnace, mixing-batching device and confirmed early means about electromagnetic pump, for managed melt pouring in the continuous casting mode (fig. 5, 6). At first developing device could be have a melt capacity no less than 500 kg or more (up to 10 tons), provide independent alloys melting from ingots state and overheating to required temperature. From this viewpoint and according to required semi-continuous working mode, as a main melting device was selected the reverberator-melting furnace with minimal capacity 500 kg. Existed reverberate furnace have a wide range by capacity from 500 kg up to 50 tons by aluminum alloys, using simple melt heating method, safety at the exploitation and not require expensive changeable ceramic crucible and can realize melting process without harmful effect for inductions channels as well.

The main bath of furnace have a steel string case (fig. 5), linen inside by the fireproof mass, have a tilting mechanism for pouring melt and use the upper radiation heating melt methods from the electric resistance heating elements. Case of furnace fully closed and heat insulated inside, have a long time servicing.

On the front side installed loading door, for removing slag, flux processing and loading ingots or melt scrap. On opposite side located the pouring nozzle, for outfling melt by the gravity methods at the furnace case tilting by the hydraulic cylinders. As well, this construction can be use also for continuous casting technologies, but take into account that pouring speed in this case controlling only by the tilting angle, and cannot provide the maintaining the melt flow rate in stable value ranges. Additionally by using the upper melt heating way also to difficult are provide the homogeneity melt temperature in the on surface and in the down part.
Especially appointed to the continuous casting technologies was decided improve reverberator melting furnace by the attaching multifunctional horizontal magneto-hydrodynamic units MHDU, as a W-shaped induction channel with 2 inductors and electromagnet fig. 4, 5.

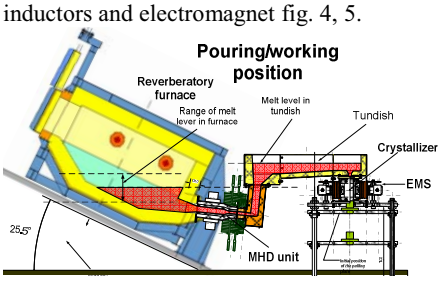


Fig. 5. Device and technological scheme for pilot plant reverberator-melting furnace with MHD unit and tundish for continuous billet casting.

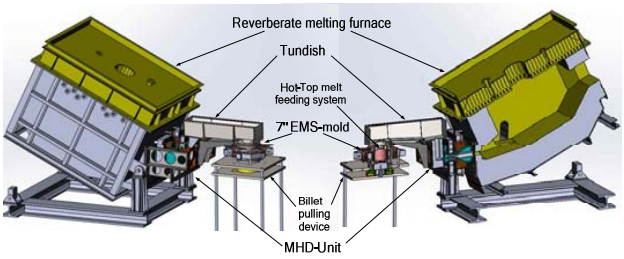


Fig. 6. 3D-model of the reverberator melting furnace 500 kg capacity by Al alloy, adopted for the assembling with MHD Unit.

In this case magneto hydro-dynamic unit (MDU) to provide the continuous contactless high effective induction heating with artificial continuous melt stirring into channels and into all volume of the reverberator melting furnace during melting, refining, holding and controlled electromagnetics pouring to crystallizer of continuous billet casting machine. The prototype of foundry melting, processing and pouring device presented on fig. 4, 5. Magneto-hydrodynamic unit are provide additional controllable induction melt heating with power 2~50kW, continuous melt stirring into channel and into furnace crucible by the electromagnetic force means – named as electromagnetic pump. There are provide the homogenization of melt temperature and chemical compositions and at switching electromagnet, also provide electromagnetic melt pouring from the pouring nozzle with managed flow rate 0.5 kg/s ~ 15 kg/s to the mold, tundish of the continuous casting machine (CCM), as presented on fig. 4 – working position.
The main construction of reverberator furnace, as was described early, executed as an base case, that have tilting possibilities in one direction to MHD-unit side on 24~26 degree. For tilting furnace the case installed on the frame, which have the 2 tilting support points knots, and on opposite directions knots for attaching of two hydraulic cylinders.

Conclusion

In this study presented design and conceptual approaches for 2 (two) kinds of the original technological foundry equipment for the melting hydrodynamic high-strength aluminum alloys pouring at continuous billet casting processes., holding and managed electromagnetic magneto-
First kind performed on base of the magneto-dynamic installation (MDI MDN-6A-0.63-WMD-M), that has applied as mixer-batcher with 630 kg capacity by Al-alloys with electromagnetic pump (up to 0.35 bar pressure). An experimental approbation developed technologies for MHD-semi continuous billet casting, by means open stream feeding into 7“crystallizer and by progressive hot-top closed process, at the producing 1.0 meter of 7” billet from Al-Zn-Mg-Cu wrought alloy has been execute. There are show efficiency of MHD melt processing – providing non-dendrite microstructure state and full elimination crack-ability as fore DC and for EMS billet casting modes.
As second, developed an conceptual design of 500 kg capacity by Al-alloy pilot-plant foundry equipment, comprised upgraded tilting reverberator melting furnace combined with multifunctional horizontal magneto-hydrodynamic units (MHDU), as a W-shaped induction channel with 2 inductors (2x20kW) and external C-type electromagnet (0.01~0.3T). MHDU provide homogenization melt temperature (650~850°C) and chemical compositions, at circulation melt intermixing 0.5~3.0kg/s, and electromagnetic melt pouring with managed flow rate 0.05kg/s ~ 15kg/s to tundish of the 3”~10” billet casting for continuous casting machine.

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