ELECTROMAGNETIC EQUIPMENT FOR NON-CONTACTING TREATMENT OF LIQUID METAL IN METALLURGICAL PROCESSES

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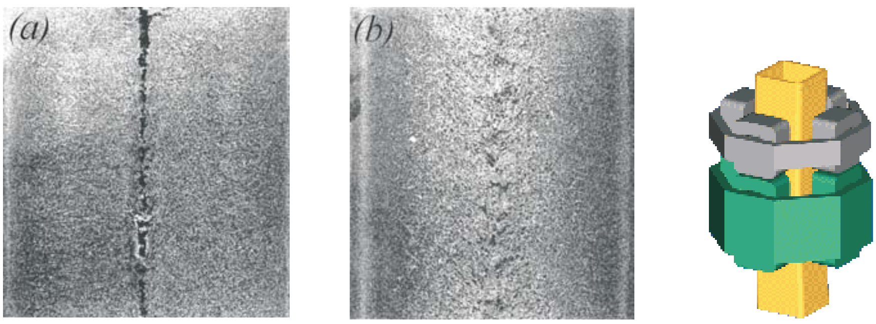
Introduction. Electromagnetic stirrers (EMS) and electromagnetic brake (EMBR) units are widely used in continuous casting and ladle metallurgy. The application of electromagnetic stirring improves strand quality, increases metallic yield and continuous caster (CC) productivity, and raises production flexibility. The EMBR reduces turbulent metal flow and standing waves in the CC mould, improves slab quality and increases casting speed. ASEA-SKF ladle furnaces provide optimum conditions for the manufacture of high-grade steels. Electromagnetic stirring is used in all treatment stages of liquid steel in ASEA-SKF ladles.

1. The effect of electromagnetic stirring on billet and bloom quality. The chemical composition, solidification conditions and nature of the liquid metal flow in the mould essentially affect the surface quality and the inner structure of the strand. The process of strand formation includes solidification of the liquid metal in the mould and in the secondary cooling zone (SCZ). Rotating or travelling magnetic fields affect the nature of flows in the melt and intensify the heat-mass transfer processes. The degree of influence of electromagnetic stirring on strand quality depends on the technical characteristics of the EMS and on its arrangement along the CC bending axis. EMS can successfully be installed in the mould, in the SCZ and in the final solidification zone (FCZ).

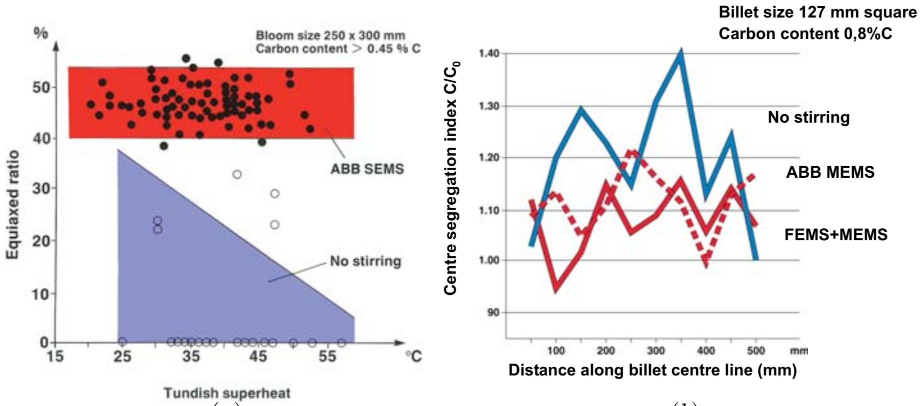
ABB supplies EMS for the mould (MEMS) with one EMS and two independent EMS (dual-coil MEMS), for the SCZ in the form of a strand EMS (SEMS) and for the FSZ as a final EMS (FEMS) [1].

To improve surface, subsurface and inner strand quality, the liquid metal stirring has to take place in the mould. MEMS are either of round or square design and it can be installed internally or externally. Fig. 1*a*, *b* shows longitudinal samples from a stirred mould and an unstirred square billet with a 150×150 mm section, containing 0,29% C, 0,28% Si and 0,54% Mn. The result of applying MEMS is a reduction in centre porosity and segregation in the billet [1]. To provide



(*a*) (*b*) (*c*)

Fig. 1. Longitudinal billet samples: (*a*) without stirring, (*b*) with MEMS. (*c*) Dual-coil MEMS.



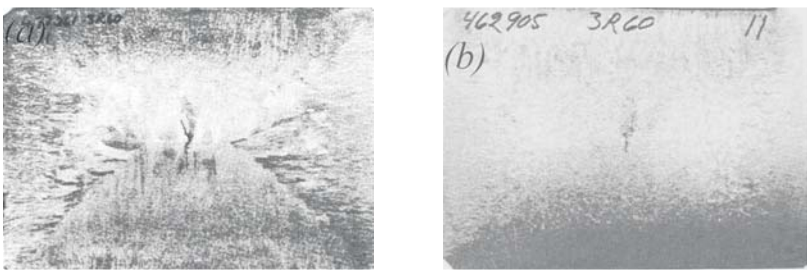
(*a*) (*b*)

Fig. 2. (*a*) Equiaxed crystallic zone formation in steel with high overheating. (*b*) Distribution of carbon segregation along the centre line of a billet.

flexible control of stirring speed in the mould meniscus, the dual-coil MEMS was developed. A schematic of the dual-coil MEMS is shown in Fig. 1*c*. It consists of two independent EMS. The upper EMS is intended for flow control in the meniscus. The lower EMS performs the main metal stirring in the mould. The reduction in metal speed in the meniscus is achieved by rotating the upper EMS magnetic field in the opposite direction to that of the lower EMS. Such a MEMS design widens the opportunities for using the technique under various conditions of continuous steel casting [2].

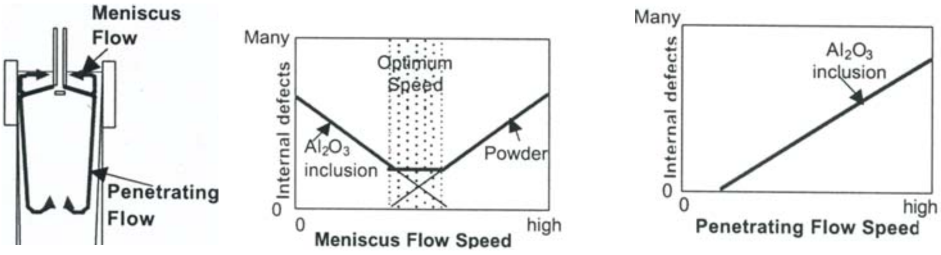
The application of electromagnetic stirring of metals promotes the formation of an equiaxed crystallic zone in the strand. The effect of steel overheating in the CC tundish on the size of the equiaxed crystallic zone in blooms with a 250×300 mm section, with and without stirring by SEMS, is shown in Fig. 2*a*. As can be seen, stirring improves strand quality, even in steel casting with overheating.

To further reduce and cut peaks in centre segregation, FEMS, in combination with MEMS or SEMS, has to be used. FEMS is particularly efficient when casting high carbon or high alloy steel grades. A distribution of carbon segregation along the centre line of a wire rod billet is shown in Fig. 2*b*. FEMS and MEMS combinations reduce the areas with the highest carbon content, where cementite and martensite otherwise might form. It was found that stainless steels, solidifying with primary ferrite, have a sound centre at a reduction ratio of 3.6 when using SEMS and FEMS. This corresponds to AISI 304 grades with 18% Cr and 10% Ni. For steel, solidifying to primary austenite, AISI 316, centre cracks and porosities are reduced by EMS. Fig. 3 shows a cross-section of AISI 316 with 16.8% Cr, 12.1% Ni and 2.6% Mo with and without stirring by travelling magnetic fields.



(*a*) (*b*)

Fig. 3. Cross section of AISI 316 samples: (*a*) without stirring, (*b*) with SEMS.



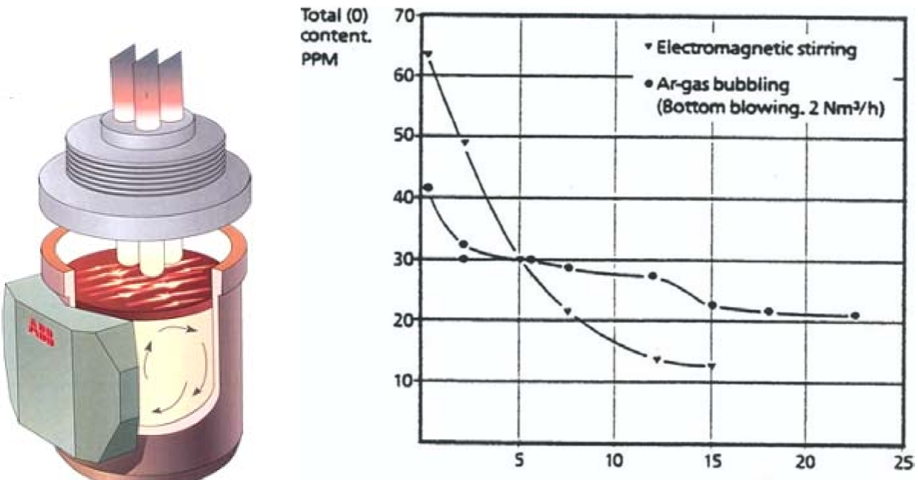
(*a*) (*b*) (*c*)

Fig. 4. The effect of metal flow rate on the distribution of inclusions.

The application of SEMS increases the equiaxed crystallic zone instead of columnar structure and reduces cracks in the steel strand. This is evident from Figs. 3*a* and 3*b* [3].

2. Using electromagnetic brakes in slab casters. A static magnetic field from an EMBR unit slows down the steel flow from the submerged entry nozzle to the mould (Fig. 4*a*). The reduction in flow rate and turbulence in the meniscus area offers advantages such as higher steel purity, fewer rejects and higher casting speed. For optimum control of the metal flow in the mould, a new version of the FC Mould system has been developed, generating two static magnetic fields. The upper field operates by metal speed in the meniscus, and the lower field slows down the metal flow in the direction of slab casting. The relationship between the aluminium oxide distribution in the meniscus area and in the slab – and metal flow rate is shown in Fig 4. The optimum meniscus metal flow rate is presented in Fig. 4*b* [4].

3. Application of electromagnetic stirring in ladle metallurgy. The performance of the ASEA-SKF ladle is determined by the electric arc heating, the vacuum system and the electromagnetic stirring system (Fig. 5*a*). Stirring by travelling magnetic fields results in homogenisation of temperature and chemical composition of the liquid steel and in an intact slag layer. Good protection of the melt from the atmosphere minimizes the risk of unexpected aluminium re-oxidation and nitrogen pick up during the ladle treatment. The stirring is co-ordinated with the needs of the technological process at each stage by controlling



(*a*) (*b*)

Fig. 5. (*a*) An ASEA-SKF ladle furnace. (*b*) Dependence of oxygen content on stirring time.

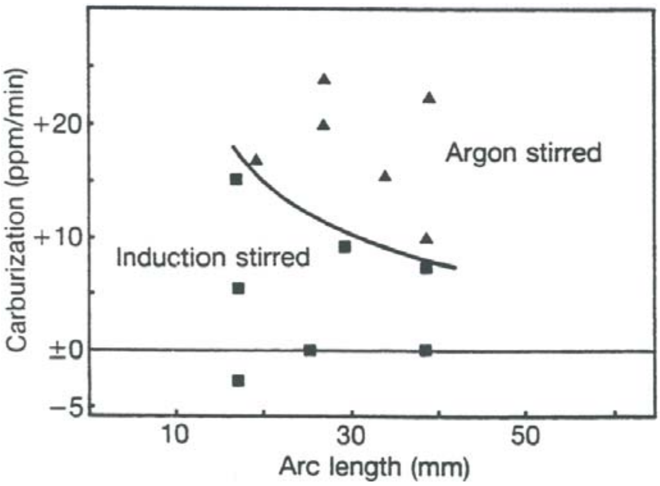


Fig. 6. Stirring influence on carbon pick up of steel from electrodes.

the power and the stirring direction. Electromagnetic stirring is more effective than gas stirring when it comes to removing metal inclusions and oxygen thanks to a uniform distribution of stirring energy in the steel volume. For example, electromagnetic stirring of steel for 15 mines reduces the oxygen content by 5 ppm, while gas stirring only reduces oxygen by 2 ppm. (Fig. 5*b*). Gas stirring works well in steel desulphurization. Electromagnetic stirring and gas stirring are used in vacuum degassing to reduce hydrogen and sulphur content [5, 6].

Electromagnetic stirring with a calm surface of slag creates good conditions for electric arc heating with high electrical efficiency and insignificant carbon pick-up from the electrodes, compared with gas stirring, which operates with a "boiling" surface around the electrodes (Fig. 6). This is particularly important in the production of carbon-sensitive steel grades and steel with a low carbon content [5].

4. Conclusion. Rotating, travelling and static magnetic fields, generated by MEMS, SEMS, FC Mould are used in casters and in ASEA-SKF ladles to improve metal quality, productivity and production flexibility.

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