Process improvement with EMS

In the electric arc furnace (EAF) process, there are a number of factors that can impact negatively on productivity and cost-efficiency, many of which can be reduced or completely eliminated with the application of electromagnetic stirring (EMS) to deliver improved productivity, reduced costs and a safer, more reliable and energy-efficient operation. By **Lidong Teng[1]**, **Pär Ljungqvist[2]**, **Helmut Hackl[1]**, **Joakim Andersson[2]**

FINDING ways to maximise process output and minimise costs is more important than ever in this competitive and financially challenging landscape. New technologies that provide process improvements can help steel producers make the most of what they already have and contribute to improved profitability. However, with limited investment budgets come higher expectations as well as technology that solves problems and delivers tangible process improvements.

The latest EMS technology for EAF, known as ArcSave, has been applied on a 90-tonne spout tapping furnace for stainless steel production at Outokumpu Stainless Steel AB (OSAB) in Avesta, Sweden, with the aim of delivering improved productivity, lower costs and elimination of furnace bottom skulls, all of which have been successfully achieved.

ArcSave electromagnetic stirring for EAF operation

ABB has delivered electromagnetic stirring for EAF operation since 1947, enhancing process performance at 150 customer sites worldwide. ArcSave, was developed in response to demand for stronger stirring power that goes further to optimise the EAF process for both plain carbon and high alloyed steel production.

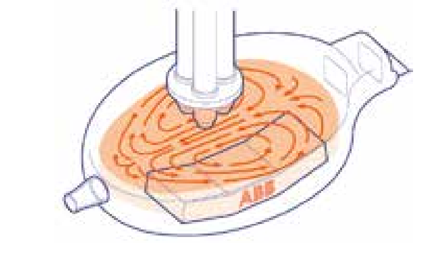

Fig 1. Flow pattern in the melt in a spout tapping furnace fitted with an ArcSave stirrer

Fig. 1 illustrates the flow pattern occurring in a spout tapping arc furnace mounted with an ArcSave stirrer underneath the furnace bottom shell. The stirrer is placed under a non-magnetic (austenitic stainless steel) steel plate bottom or window. ArcSave has no physical contact with the steel melt; therefore the system requires very little maintenance. The low frequency electric current passes through the stirrer windings to form a traveling magnetic field which penetrates the furnace bottom, thereby generating forces in the molten steel[1]. When the traveling field is reversed, the melt will flow in the opposite direction. The melt flow rate is proportionate to the current of the stirrer. Since the stirrer is extended over the entire diameter of the furnace, effective stirring forces are obtained over the whole bath and the entire melt is stirred.

The melt flow pattern at the steel/slag

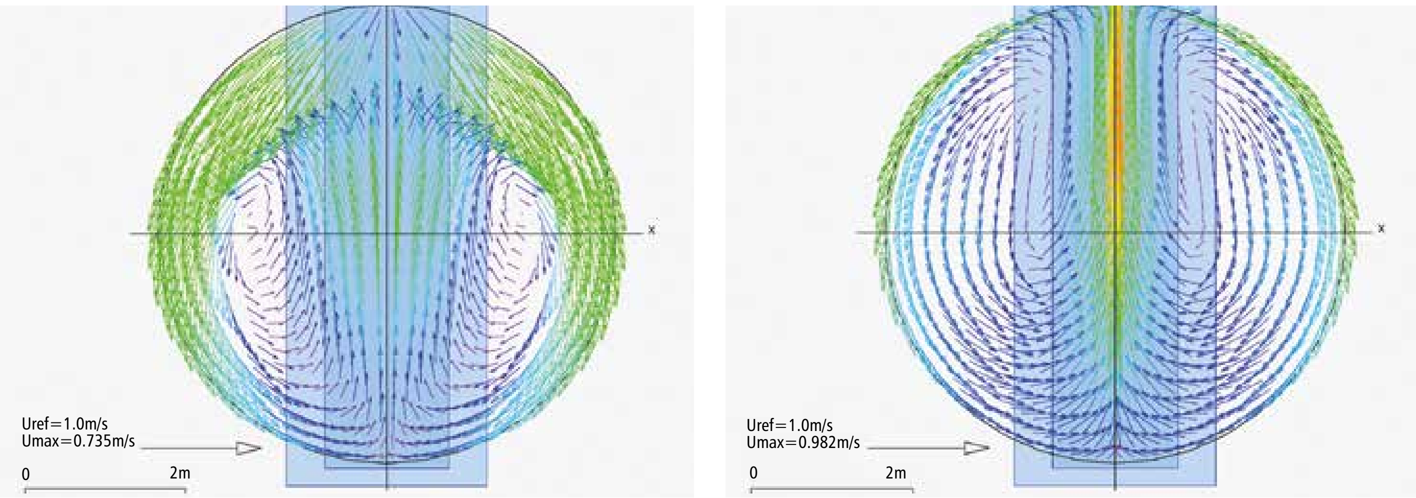

Fig 2. Melt flow velocity vectors simulated in a 100 ton spout tap EAF [2]

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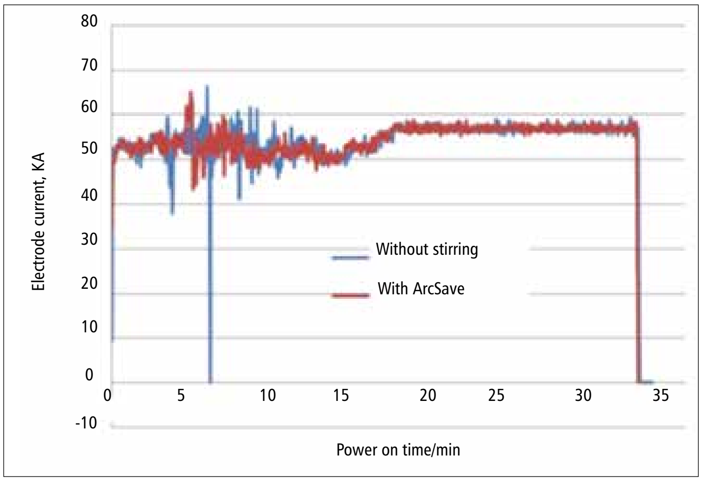

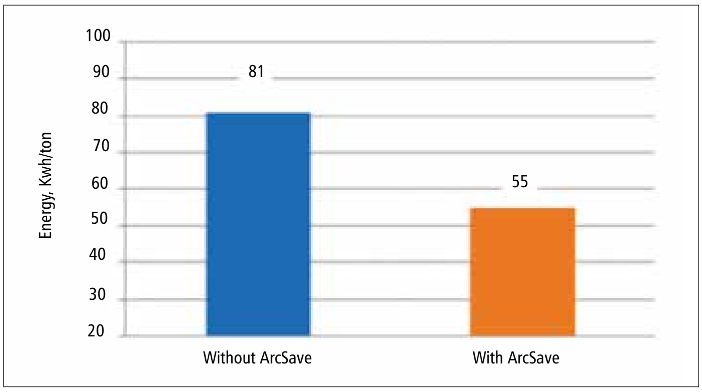

Fig 3. (left) Effect of ArcSave® on electrode current swings

Fig 4. (above) Effect of ArcSave on energy loss to furnace water cooling panels

interface and bottom in a 100-tonne spout tapping stainless steel furnace is presented in **Fig. 2**[2]. The designed average volume melt velocity induced by the ArcSave is around 0.2~0.5 m/s. It can be seen from **Fig. 2** that ArcSave creates a global circulation in the melt and thereby provides efficient mixing of the complete bath. This is one of the major advantages of ArcSave compared to the bottom gas stirring by porous plugs. Mixing the entire melt accelerates homogenisation of the temperature and chemical composition of the steel, as well as the chemical reactions between steel and slag.

ArcSave stirring is automatically controlled by a designed stirring profile which is customised to match the needs of different EAF process steps, such as scrap heating, homogenisation, melting of alloys, decarburisation, de-slagging and tapping. Operation is characterised by low stirring cost, reliable and safe operation and creates optimum conditions for reproducible production of high quality steel and precise logistics.

ArcSave project objective at OSAB

The OSAB melt shop consists of an EAF, AOD, ladle furnace, continuous casting and grinding. The EAF has a 110 MVA transformer and a 90-tonne capacity. The EAF is equipped with a lance-manipulator consisting of four lances to inject O_2, N_2, FeSi and Carbon. In combination with electric power, three oxy-fuel burners are used. Special steel grades, containing a high amount of chromium, are produced at OSAB. For these steel grades a high amount of FeCr alloys are added in the furnace. Due to the FeCr alloys' high melting point, problems with skulls in the bottom of the furnace appear. This leads to variations in tapping weight, high electric power consumption and problems when charging the scrap baskets. The objective of the ArcSave installation is to solve the FeCr melting problem, reduce costs and increase productivity. The process benefits due to improved kinetic conditions for heat and mass transfer obtained with ArcSave are discussed in this article. The hot test results at OSAB are based on three months without and three months with ArcSave.

Test results

Improved scrap melting and arc stability

The main difference between the EAF with and without ArcSave is the intensity of convection in the melt bath. Forced convection induced by electromagnetic stirring enhances the melting of larger scrap pieces and bundles, and makes scrap stratification less significant. CFD simulation results show that melt velocity is increased by a factor of 10 by ArcSave compared with only natural convection in the melt bath[2]. The stronger convection inside the melt contributes to a homogenous temperature distribution and a higher scrap melting rate. ArcSave has also stabilised the arc due to faster melting of big scrap bundles and reduced scrap cave-ins. **Fig. 3** shows that current swings were reduced with ArcSave. The standard deviation of current swings is 9.3 without stirring and 3.7 with ArcSave, resulting in a higher power input and, therefore, reduced power-on time. The reduction of electrode current swings with ArcSave has also been observed in the EBT type furnace for carbon steel production[3].

Arc heating efficiency and energy savings

Temperature gradients in the flat bath during scrap melting in conventional AC arc furnaces without stirring have been reported to be in the range of 50-70°C[4] and the temperature gradient with EMS is about 25% of that without EMS during the power-on period[1]. This means that stirring reduces the melt surface superheat and the heat from the arc zone is quickly transmitted to the bulk melt[5]. The decreased surface superheat temperature reduces heat losses to the furnace wall and roof during the power-on period, thereby reducing electricity consumption. **Fig. 4** shows that at the OSAB furnace, energy loss to the water-cooling panels is reduced by 26 kWh/tonne with ArcSave, corresponding to more than 5% energy saving. Simultaneously, stirring increases the scrap and/or ferrochromium melting rate and/or decarburisation rate and, therefore, saving time and further contributing to lowering energy losses in the furnace process. The more stable arcing, reduction in superheat, oxidised slag and electrical power consumption results in 9% lower electrode consumption.

Bath homogenisation and tapping temperature reduction

The bulk turbulent flow induced by ArcSave stirring brings a thorough mixing of the whole melt, resulting in superior temperature and composition homogenisation. **Fig. 5** shows ArcSave temperature distribution when measured in two positions with a 1-2 minute time interval for the same heat after power-off. The corresponding temperature difference at two positions is less than 2°C on average.

Good homogeneity is important for a number of reasons. It implies a reliable measurement and prediction of bath composition and temperature. Bath

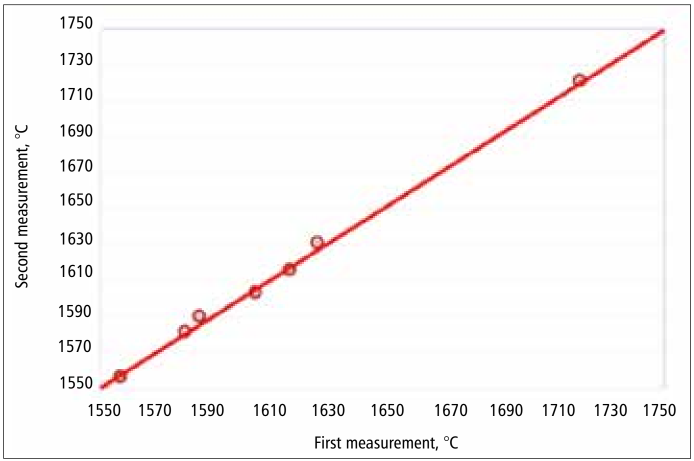

Fig 5. (left) Comparison of two temperature measurements in different positions in the bath after power-off

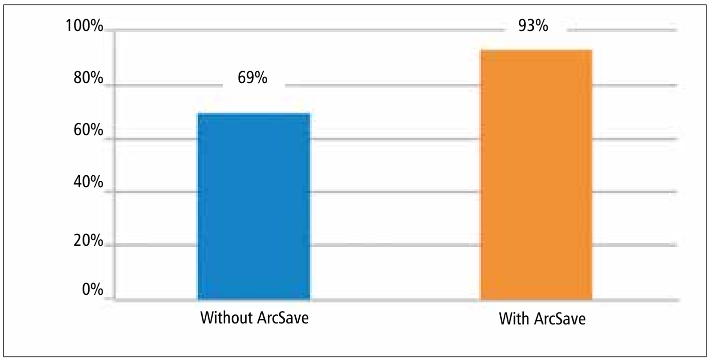

Fig 6. (above) Tap weight hit ratio without stirring and with ArcSave

homogenisation with ArcSave makes it possible to obtain an exact tapping temperature for different steel grades, which is very important for a smooth downstream AOD operation. Tapping temperature is reduced by an average of 20-30°C without any change to the AOD arrival temperature.

Improved slag-metal reaction and reduced Cr_2O_3 content in slag

ArcSave delivers a stirring effect on the slag due to the steel/slag interface friction bringing different parts of the slag and melt to the reaction zone all the time. In the absence of stirring, transportation of all parts of the melt to and from the reaction zone has to take place by diffusion only. With induction stirring, the bath and slag movements take care of most of this transportation. Diffusion distances are thus reduced considerably and this is an important factor for desulphurisation and Cr_2O_3 reduction. It is very important when chromium, which has been oxidised during the oxidising period and has entered the slag, is reduced back into the steel. By optimising the stirring profile the slag/metal reaction can be enhanced and efficient slag reduction obtained. It is found that the Cr_2O_3 content in the slag is reduced by an average of 3.1% with ArcSave together with O_2 injection practice optimisation. Consumption of N_2, traditionally injected from the slag door manipulator to improve mixing in the melt, was reduced by around 70%. In fact, there is no need to use N_2 at all with ArcSave.

Reduced consumption of FeSi and slag builders

During the reference test FeSi consumption in the OSAB EAF was higher than normal

Items	Improvements
Total energy consumption	-3~4 %
Electrode consumption	-8~10 %
Power on time	-4~5 %
Tap temperature hit ratio	100 %
Tapping temperature reduction	-20~30 oC
Tap weight hit ratio	+24% (reached 93%)
N_2	-70%

Table 1 Process improvements after ArcSave® at OSAB

for stainless steel arc furnace operation, since O_2 was used to create extra energy to help melt FeCr skulls. After ArcSave the addition of FeSi has been tentatively reduced. Of course, reduction of FeSi will increase electrical energy consumption accordingly. With ArcSave overall energy consumption is, however, reduced by 3-4%. Si reduction reduces SiO_2 content in the slag, thereby cutting lime consumption since slag basicity is kept constant. ArcSave's positive influence on arc stability makes it possible to reduce slag thickness.

Enhanced ferrochromium melting and tapping weight control

High FeCr addition and short tap-to-tap time (less than 60 minutes) has its drawbacks, including the formation of un-melted FeCr skulls on the furnace bottom. The resulting furnace bottom build-up reduces the effective volume of the bath, making bucket charging difficult. FeCr, with its higher melting temperature and density, tends to rest on the bottom of the furnace, where the melt is cooler. In the absence of stirring, dissolving can be problematic. Following ArcSave installation the temperature is equalised throughout the entire bath and the melting of FeCr and even heavy scrap pieces is enhanced. Both temperature homogenisation and forced convection of melt help with FeCr dissolution. The furnace bottom is also shown to be cleaner with ArcSave than without stirring and the problem with furnace bottom skulls has been eliminated. **Fig. 6** shows that the tap weight hit ratio is increased by roughly 24% thanks to improved FeCr melting.

Greater process reliability and safety

The positive effect of ArcSave on the EAF process discussed in the sections above will have a significant impact on improving process reliability. The fast melt-down of big scrap and ferrochromium provides efficient homogenisation of the melt bath on both chemical composition and temperature, which delivers the targeted steel tapping weight and temperature. Stirring in the melt bath reduces scrap cave-ins, stabilises electrodes, and reduces electrode breakage risk. Homogeneous temperature in the whole bath provides smooth tapping and reduces tapping delays. Elimination of thermal stratification in the melt bath apparently reduces tapping temperature. ArcSave eliminates hot and cold spots in the bath and didn't create any negative effects on the bottom hearth refractory lining, but clearly reduced refractory wearing in hot spot and slag-line areas.

AOD operation benefits

Improved accuracy in tapping weight and tapping temperature from EAF makes it possible to obtain consistent AOD initial operation conditions. The correct tapping weight will eliminate extra alloying additions in the AOD converter, which would otherwise lead to increased FeSi, lime and O_2 consumption in AOD. An initial AOD tapping temperature, which is lower than necessary, also increases FeSi consumption in order to create the chemical energy to

increase the bath temperature. A consistent AOD operation can also mean increased productivity and reduced operating costs.

Conclusion

Electromagnetic stirring enhances the kinetics of heat and mass transfer in the arc furnace process and gives a more homogenous melt bath.

The test results at OSAB show that ArcSave enhances scrap and ferrochromium melting and reduces energy consumption. The bath temperature is more homogeneous and tapping temperature is controlled more correctly, providing for smoother AOD operations. With stirring, the ferroalloy is melted efficiently, thus giving better steel yield and more accuracy in tapping weight. Slag reduction is also enhanced by stirring, resulting in lower FeSi consumption and higher Cr yield.

The reduction in surface superheat temperature and efficient heat transfer under stirring reduces heat losses to the furnace wall and roof and result in lower electricity and electrode consumption. Shorter tap-to-tap time and consistent furnace operation also greatly increase productivity.

At OSAB ArcSave successfully achieved the customer's objectives including elimination of furnace bottom skulls, improved productivity and lower operating costs.

ABB's ArcSave technology is proven to improve EAF process performance. Helping steel producers overcome many of the challenges facing them today, it delivers benefits that simultaneously reduce costs, increase productivity and allow for a safer, more reliable and energy-efficient operation. ■

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