Section - II

ULTRASONICS

Ultrasonic Immersion C-Scan Imaging Technique: A Novel Tool to Evaluate and Optimize EMS Parameters for Continuously Cast Steel Billet Quality

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ABSTRACT

With increasing demand for clean steels, the quality, in terms of internal defects and macro structural features (central porosity, equiaxed zone, etc.), of billets has become of utmost importance. By optimizing the Electro Magnetic Stirrer (EMS) parameters viz., EMS current and frequency the severity of defects, area of columnar zone as well as central porosity, in continuously cast billet can be effectively minimized. The result would be an increase in equiaxed zone area and improved internal soundness. In the present work attempts have been made to determine the best combination of EMS current as well as frequency to ensure good internal soundness of billets. The EMS current and frequency were changed to different values in the range of 240A to 300A and 3Hz to 4Hz respectively. Corresponding billet samples were collected for macro structural evaluation. The samples were scanned using an automatic computerized multi-scan immersion ultrasonic immersion ultrasonic C-scanner to get images of samples. C-scan images obtained through system have been used for as a tool for evaluating and obtaining optimum electromagnetic stirrer (EMS) parameters i.e. current and frequency. Macro structural features revealed by ultrasonic C-Scan were analysed for determining the best combination of EMS parameters. The most significant improvement was found at 280 ampere EMS current and frequency 3.5Hz. Beyond this there was only a marginal improvement in the billet quality as well as equiaxed zone. Based on the experimental observations, it is recommended to operate EMS at 280A current and EMS frequency should not increase beyond 4Hz in the plant.

Introduction

As the demand for clean steels increases day-by-day, the quality of steel billets, in terms of internal defects and macro structural features (central porosity, equiaxed zone, etc.), has become of paramount importance. A cleaner steel greatly improves many physical and mechanical properties such as fatigue life, machinability, and corrosion resistance [1]. The severity of defects, area of columnar zone as well as central porosity, in continuously cast billet can be effectively minimized by optimizing the Electro Magnetic Stirrer (EMS) parameters viz., EMS current and frequency. Hence, most of the integrated steel plants have introduced electro-magnetic stirring (EMS) process in their LD/steel-melting shops for continuous cast (CC) steel billets. The primary benefits obtained with EMS are extensively treated in the literature [2-4]. Simply put, the purpose of EMS is to homogenize the steel melt in order to obtain a favourable solid structure after solidification. The benefits are as follows:

i) Improvement in cast structure through increased volume of equiaxed grains.
ii) Reduced degree of macro-inclusions, especially in the central portion of cross sections.
iii) Improved surface quality and reduced shrinkage porosity.

Material and method

Chemical composition of material used

One close casting grade of low carbon (LC) grade of steel billet was considered. This is a cold heading quality grade for high tensile fasteners. The chemical composition of steel grade considered in the present work is shown in Table I.

Table 1: Chemical composition and other details of LC grade

Liquidus (ºC)	Super Heat (ºC)	Chemical Composition (wt %)							
		C	Mn	S	P	Si	Al	Cr	Ni
1507	47	0.21	0.83	0.011	0.018	0.59	0.028	0.14	0.016

EMS Parameters

The experiments were conducted on the above grade of CC billets with EMS currents 240, 260, 280 and 300A, while frequency was kept constant to 3.5Hz during casting. In some of the heats, EMS frequencies were set at 3, 3.5 and 4Hz while EMS current was kept constant during casting. In both the cases, the corresponding CC billet samples were collected and its effect on billet quality was assessed by using ultrasonic immersion C-Scan imaging technique. Each billet sample was sliced into transverse and longitudinal sections (approx. 20 mm thick), as shown in Fig. 1, and ground to good surface finish.

Ultrasonic immersion C- Scan imaging technique

All the transverse sections of steel billet samples were examined using the ultrasonic immersion C-Scan imaging technique. The microstructural features observed, in each case, were recorded and analyzed subsequently. Finally, the data on axial porosity, columnar/ equiaxed zone, % defective area (which includes segregation, inclusions, pinhole, internal as well as subsurface cracks) of the total scanned area in each grades of steel were compared for determining the best combination of EMS parameters.

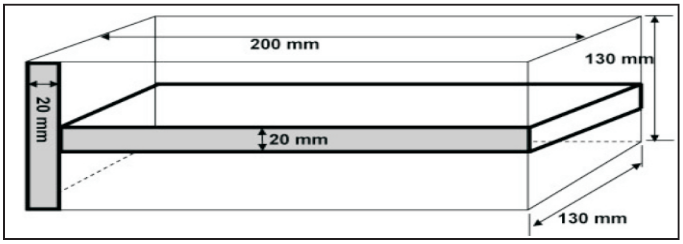
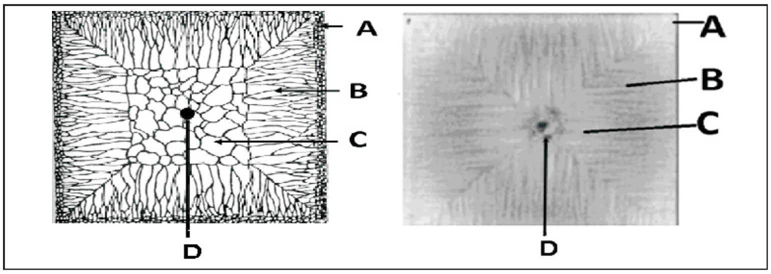


Fig. 1: Schematic diagram of CC billet sample (cross section, 130 x 130 mm) collected for C-scan ultrasonic evaluation.

The samples were tested in a water tank using a 15 mm diameter 5 MHz ultrasonic focused beam probe. The C-scan images were obtained with the help of a computer controlled immersion ultrasonic C-scan system.

During the continuous casting process, due to the differential cooling from the outside surface to the inside, the grain structure is expected to take the distribution as represented by the classic schematic shown in Fig. 2 (a). Here, the chill zone (A) is found on the outer most layer that is in contact with the mould. The anisotropic columnar grain structure (B) is found below the chill zone. The inside regions are found to be equiaxed (C). At the centre, owing to the metal shrinkage, central void (D) is found. The relative areas of these zones will depend on various casting process parameters. Ultrasonic technique was applied to evaluate the above mentioned zones of the billet samples. This method revealed the four different regions in the samples, chilled zone, columnar zone, equiaxed zone and central void, in different gray/colour scale Fig. 2 (b).



(a) **(b)**

Fig. 2: Macro-structure of a continuous cast billet sample (a) Schematic diagram; (b) Image revealed by ultrasonic C-Scan

Ultrasonic C-scan can image different intermediate layers of billet samples and plot the results in two dimensions. Therefore, all the internal defects appear as well giving an advantage over normal macro-etching where only the top etched layer of the sample can be inspected. One major advantage of ultrasonic C-scan over A-scan is that classification of different kinds of defects is possible by imaging of the defects by this method.

A series of C-scan tests were carried out with varying parameter settings. The instrument variables for these tests were as follows:

- PRF : 100Hz
- Gain : 40 dB
- Energy : 50 uj
- Damping : 100 ohms
- Voltage output (amplitude) : + 3 to - 3
- Resolution : 0.2 mm x 0.2 mm

Grey scale was used to evaluate and analyze the results obtained from the gated area. Referring to ultrasonic C-scan images, and based on a grey scale that depicts attenuated signals darker, one may see clear identification of different macro structures by the darker areas. Although not very sharp, each and every one of the areas is reproduced with a certain degree of dimensional accuracy. However, the boundary of each defect is not well defined. The two dimensional image obtained from the C-scanner distinguished different macro structural regions e.g. equiaxed, columnar and chilled zones, and casting defects, if any [5].

Results and discussions

To determine the optimum combination of EMS current and frequency to produce billet with good internal quality consistently, EMS current was set to 0 (non-EMS), 240, 260 (existing practice), 280 and 300A during casting and billet samples were collected to examine to find out the effect of change in current.

Optimization of EMS current

Fig. 3 shows the ultrasonic C-Scan image of transverse section of non-EMS billet sample of HC grade. It can be easily observed that there is a very small equiaxed zone with a large columnar zone and a huge defective area in non-EMS billet samples when compared with the EMS billet samples. After use of EMS, there was a significant improvement in quality of CC billets in terms of larger % equiaxed zone, small axial porosity and low % defective areas, which is desirable. It is also evident from the Figs. 4-7 which show the C-Scan images of transverse sections of CC billet sample of HC grade, at EMS current 240, 260, 280 and 300A. The quantitative values of the effect of EMS current on the quality of HC grade billet samples in term of % equiaxed zone and the % defective area of total area has been depicted in Fig. 8.

It can therefore be concluded that the % of equiaxed zone increases sharply and % total defective area, with respect to the total area of billet section, also decreases considerably with the increase in EMS current up to 280A.

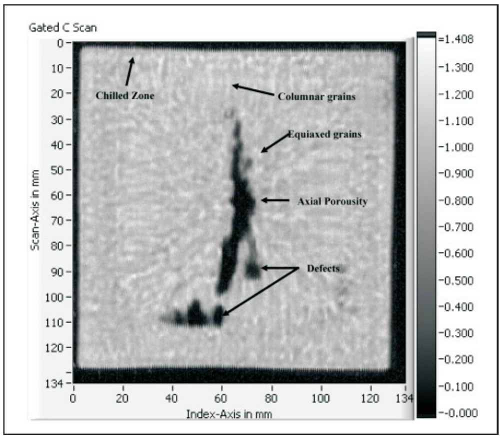


Fig. 3: Non-EMS billet sample

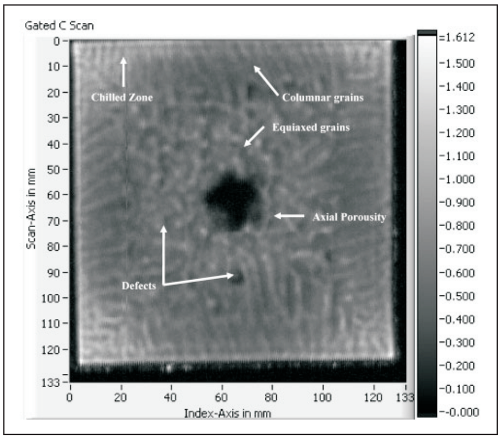


Fig. 4: EMS current 240A and freq. 3.5Hz

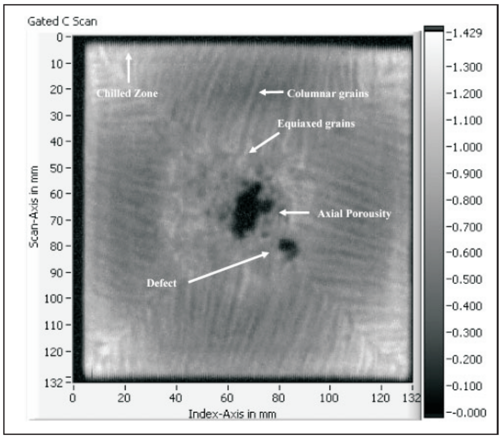


Fig. 5: EMS current 260A and frequency 3.5Hz.

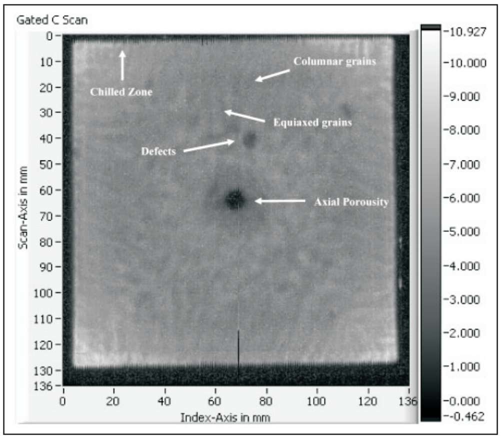


Fig. 6: EMS current 280A and frequency 3.5Hz.

Optimization of EMS frequency

After optimization of EMS current at 280 A, EMS frequency was, then set to 3, 3.5 (existing practice) and 4Hz during casting and billet samples were collected for ultrasonically evaluation.

Figs. 9-11 show the ultrasonic C-Scan image of transverse section of billet samples of HC grade at EMS current 280 A and EMS frequency 3, 3.5 and 4 Hz respectively. It was found that quality of the billet samples appears sounder, in terms of the % equiaxed zone, axial porosity and the % defective areas, when the EMS frequency was 3.5Hz, when compared to the same with the EMS frequency 3Hz and 4Hz. Fig. 12 indicates the quantitative values of the effect of EMS frequency on the quality of billet samples of both the grades in term of the % equiaxed zone and the % defective area of total area.

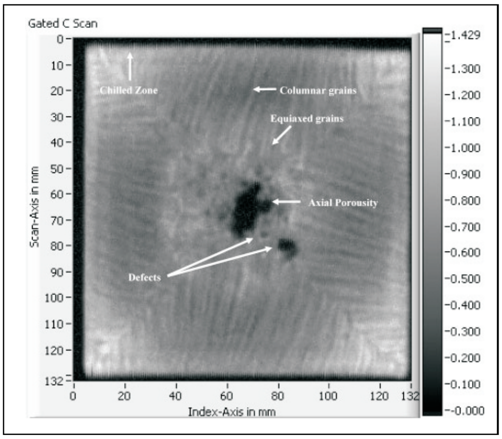


Fig. 7: EMS current 300A and frequency 3.5Hz.

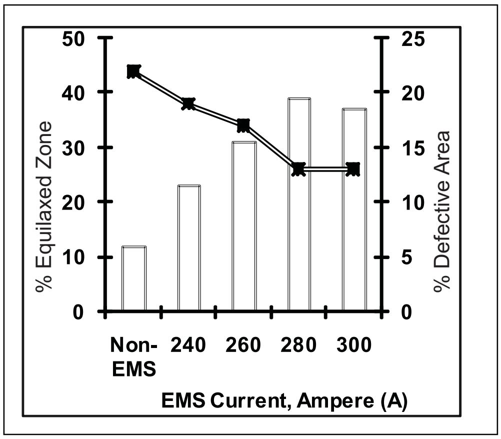


Fig. 8: Effect of varying EMS current at EMS frequency 3.5Hz

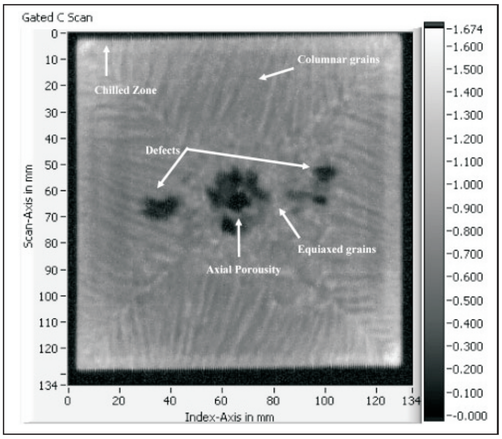


Fig. 9: EMS current 280A and frequency 3Hz

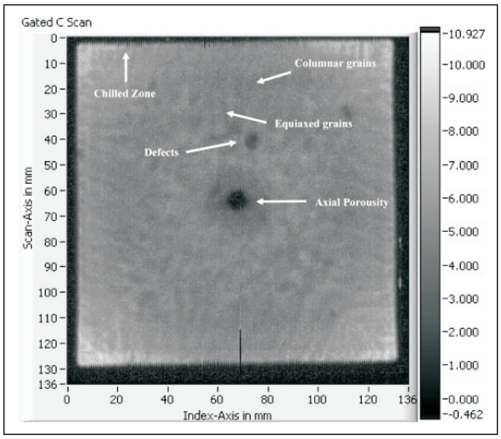


Fig. 10: EMS current 280A and frequency 3.5Hz

Hence, it can be concluded that, in this case also, the % equiaxed zone increases and % total defective area in the billet sample, with respect to the total area of billet section, also decreases considerably with the increase in EMS frequency till 3.5Hz and after that it increases marginally.

Conclusions

The analysis of ultrasonic C-scan images for optimizing EMS parameters during continuous casting of different grades of steel indicated the following :

i) The % equiaxed zone increase significantly and the % defective area (which includes segregation, inclusions, pinhole, internal as well as subsurface cracks) of the total scanned area reduced considerably with increase in EMS current up to 280A for the low carbon grades of steel considered in the study.

ii) The change in EMS frequency from 3.5Hz to 4Hz, at EMS current 280A, did not resulted in further improvement in billet quality as 4Hz frequency of EMS caused reduction in the equiaxed zone and large axial porousity in the billet samples.

iii) The qualitative as well as quantitative evaluation of defects and columnar/equiaxed zone in the continuously cast billets were possible using ultrasonic immersion C-Scan imaging technique.

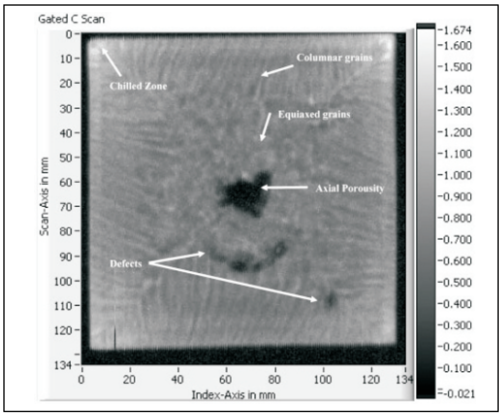


Fig. 11: EMS current 280A and frequency 4Hz

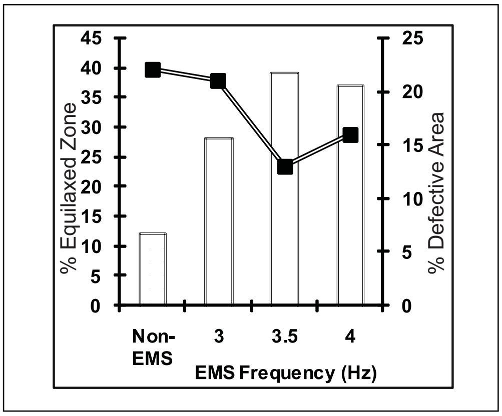


Fig. 12: Effect of varying EMS frequency at EMS current 280A

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