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RESEARCH PERSPECTIVES IN THE FIELD OF ACOUSTIC TREATMENT OF LIQUID ALLOYS OF IRON

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One of significant factors affecting properties of steel is uniform distribution of non-metallic inclusions and alloy elements across the steel product cross-section. Acoustic treatment may be the final technological stage enabling the quality of steel to be influenced. Further research to be undertaken in this field should be focused on the design of power heads with application of a stack of several piezoceramic elements or what is referred to as a mosaic head, or consisting in simultaneous use of several heads. What is additionally required is to determine ranges of parameters of the acoustic treatment process for individual groups of steel grades.

Key words: steel, acoustic treatment, piezoceramic elements, quality

INTRODUCTION

Production of any material goods is inextricably linked with a search for solutions enabling the product quality, in the broadest understanding of this notion, to be improved. At the turn of the 20th and 21st century, dynamic development of quality management systems based on standards of the ISO 9000 series could be observed. However, in the industrial practice, quality is not merely perceived as repeatable actions undertaken in all areas of an enterprise's activity, defined in specific procedures, but primarily as a pursuit of obtaining products of repeatable properties expected by the recipient.

The metallurgical industry, a part of which is the steel industry, has sought technological solutions enabling homogenisation of the ingot structure for years.

The relevant solutions developed address improvement of quality understood as homogenisation of chemical composition across the ingot volume and of its primary structure as well as elimination of both internal and superficial flaws. One of the consequences of these efforts has been intense technological development, particularly noticeable in the sphere of secondary processing and continuous casting of steel. Secondary processing makes it possible to control and adjust the chemical composition as well as to reduce the amount of non-metallic inclusions, whereas continuous casting has enabled elimination of superficial and internal flaws to a certain extent. Homogeneity of continuously cast steel is primarily improved by using electromagnetic agitators in the crystalliser area and along the band being cast. The continuous casting technology has grown in popularity for the high efficiency of equipment, opportunities of mechanisation and automation, unit cost reduction and improvement of working conditions. The possibility to affect the crystallisation structure and simultaneously reduce costs has led us to a point when ca. 90% of steel is currently continuously cast.

However, both the available selection of technologies and the market demand cause that several per cent of steel is still cast by traditionally techniques, i.e. in ingot moulds. This technology is usually used for large forging ingots or when special steel grades must be produced upon individual orders. And although the technology has been improved throughout the years, for instance by adjusting dimensions of ingot moulds (making them slimmer) for specific steel grade groups or by using refractory linings characterised by superior thermal insulation properties, no additional efforts aimed to homogenise the iron alloys cast are to be expected. In conventional ingot casting, the function of electromagnetic stirrers (EMS) may be replaced by ultrasonic processing, also referred to as acoustic treatment. Dating back to the beginning of the 20th century, this technology consists in affecting the crystallising iron alloy with an ultrasonic acoustic wave with the frequency of ca. 20 kHz, triggering the cavitation phenomenon to take place in the liquid zone and constitute a source of impulse waves as well as rotary motions inside solidifying steel. It causes crushing of the expanding dendritic arms, breaking of the bridges formed and thermal homogenisation of liquid alloy inside the ingot mould, consequently leading to improvement of the steel ingot quality owing to the structure refinement [1,2].

Structural changes in solidifying steel are triggered by processes taking place in the liquid-solid two-phase zone such as formation of crystal nucleuses and mixing. All the said changes are caused by the impact of ultra-

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sonic waves penetrating steel with a specific power and frequency. The propagation of waves also leads to such phenomena as cavitation, acoustic wind and radiation pressure.

ACOUSTIC TREATMENT OF LIQUID STEEL

Studies on the application of acoustic treatment of liquid ferrous alloys conducted in the second half of the 20th century confirmed that acoustic treatment may indeed be used with these alloys [3-5]. However, one of the obstacles encountered was the stage of advancement of contemporary technology, which made it necessary to apply magnetostrictive transducers of relatively poor efficiency, reaching not higher than 40%. It was also one of the reasons why the acoustic treatment technology did not find practical application in industry. Further significant barriers were the large dimensions of magnetostrictive transducers as well as the necessity of cooling them. It had been for the development of material engineering, and ceramic materials in particular, that ultrasonic transducers could be built, where magnetostrictive elements were replaced with piezoelectric ceramics characterised by far better performance and higher Curie temperature [6].

As implied in rather scarce publications [2,7-10], a decided majority of the contemporary studies in acoustic treatment of liquid steel only include the laboratory phase which allows for processing of up to several kilograms of steel. The progress observed in the sphere of functional materials has made it possible to undertake studies on the options of applying acoustic treatment to modify the structure of solidifying ingots of ferrous alloys using a piezoceramic power head on a semi-industrial scale. Results of the studies conducted at the Silesian University of Technology imply that acoustic treatment of liquid steel can indeed be used under industrial conditions [11].

Industrial tests of the application of acoustic treatment were performed at a test rig (Figure 1) comprising a power generator featuring a frequency analyser and a thermally insulated power head. The loading and the radiating part of the power head were made of steel, whereas the vibrating piece was a stack of piezoceramic plates. The radiating part included a steel wave-guide and a replaceable resonator immersed in liquid steel on the ingot head side [12].

Steel was melted in an electric induction furnace. The acoustic treatment conducted for individual steel grade groups involved low-carbon, high-carbon and high-alloy (austenitic) steels.

The tests were run using 130 kg circular ingots. The active power recorded at the generator output came to 200 W, with the acoustic wave frequency of 17,5-18,5 kHz and the acoustic treatment time of 69 - 300 s.

Based on metallographic tests and a comparative analysis using reference ingots, the following conclusions were drawn:

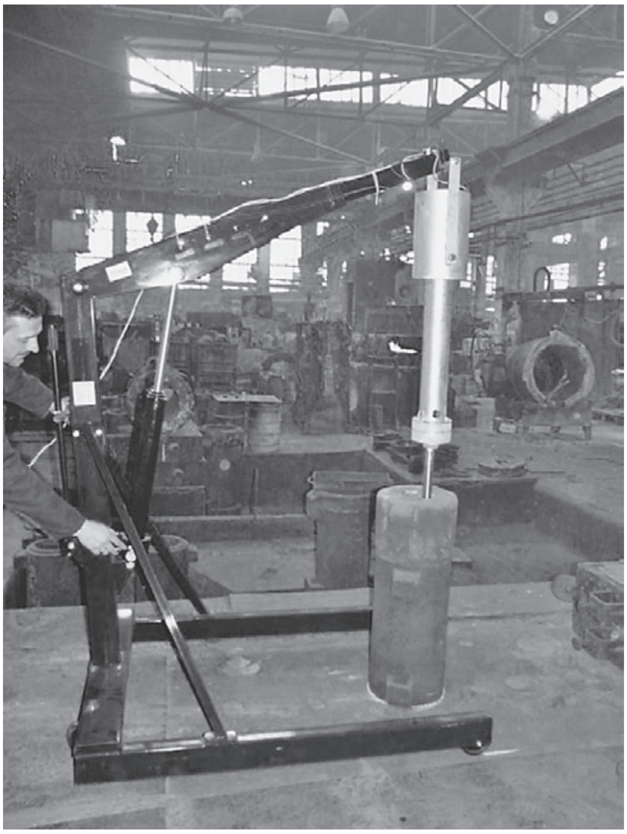

Figure 1 Liquid steel acoustic treatment station

- acoustically treated steel was characterised by more homogeneous distribution of sulphides across the ingot volume and it demonstrated that the acoustic treatment influenced reduction or elimination of type V segregation,
- in carbon steel ingots subject to acoustic treatment, one could observe the fraction of the equiaxed zone to increase,
- acoustic treatment of ingots triggered structure refinement in austenitic steel as well as fading of the dendritic structure in the middle section of high-carbon steel ingots,
- hardness and density of acoustically treated steel increased.

PROSPECTS FOR FURTHER RESEARCH

What is required in order to develop such a technology is further research on the choice of various design variants of the instruments used, more accurate determination of the acoustic field parameters as well as appropriate handling of the process while using different steel grade groups.

A prerequisite that must be taken into account while designing an industrial-scale sound amplification station for liquid steel is the amount of power transferred from the generator to the head. The choice of the piezoceramic head's power is associated with the number of layers and the type of piezoceramic elements used. While conducting the studies discussed, specific design assumptions were made, involving two or four piezoceramic plates to be used. Based on these studies, one may reach a conclusion that piezoceramic elements of the largest possible thickness should be used. This precondition finds its confirmation in the fact that a stack of two 17,8 mm thick piezoceramic plates would generate as much energy as a stack of 8,8 mm thick piezoceramic plates. Further research in this area should entail an optional head design featuring a stack of several piezoceramic elements comprising a single head, whereas for sound amplification of a larger mass of liquid steel, this process should be performed on piezoceramic stacks in the mosaic head, as it is referred to, made of several stacks of piezoceramic elements.

Another available technological solution, particularly dedicated to ingots of large cross section, may be acoustic treatment conducted by means of several heads at the same time. A significant research problem tackled in this respect is establishing the number of heads and points of wave-guide (resonator) immersing in a manner ensuring that synergy of the energy delivered takes place. A separate research problem is to determine the resonant frequency of such a system of piezoelectric heads. One can apply an option which assumes identical frequency for all heads as well as frequency diversified within a specific range.

Industrial tests conducted in this scope confirmed an assumption that efficient thermal insulation of the piezoceramic power head would make it possible to eliminate the negative impact of thermal radiation of solidifying steel. The solution applied concerned ingots with the weight of ca. 130 kg. For ingots of several Mg of weight, the negative impact of thermal radiation may become intensified, therefore another important subject of research is to determine options of using a bent wave-guide which could make it possible to place the piezoceramic head outside the ingot mould axis.

The aforementioned research prospects are related to technical solutions. However, the most significant area of research is the necessity to determine ranges of parameters of the acoustic treatment process for individual groups of steel grades. Results of studies conducted on comparable parameters of the acoustic treatment process imply considerable discrepancies in terms of the effects attained for individual steel grades. Therefore, it is necessary to accurately determine the acoustic wave power, time, amplitude and frequency for individual steel grade groups as well as the liquid steel mass and the ingot mould shape entailing the casting temperature. By establishing the impact of acoustic parameters on the efficiency of acoustic treatment, one will be able to manage the process more precisely, with the final effect being the structure refinement and homogenisation of the steel ingot chemical composition.

The ultimate research problem tackled in the area of acoustic treatment of steel is the application of this technology for the continuous steel casting purposes. It is for the COS technology, being the most popular and highly advanced steel casting technology, that acoustic treatment must face up to additional challenges caused by various reasons, including the casting campaign duration time and the necessity to maintain skin continuity after the band being cast leaves the crystalliser.

SUMMARY

The results discussed in the article pertain to acoustic treatment tests conducted on liquid steel in 130 kg ingots made of three steel grades: low-carbon, high-carbon and alloy steel. The acoustic treatment was handled using a wave-guide immersed in liquid steel. As a result of follow-up metallographic tests, changes were found to occur in the structure of the steel subject to acoustic treatment as well as an increase in its hardness and density was evidenced.

The study results obtained have provided prospects for the continuation of industrial-scale works. However, what these studies require first and foremost is solving a number of technical problems related to the mass of the steel processed and thermal radiation of a solidifying ingot.

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Note: P. Nowak is responsible for English language