technical note

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An Investigation of Casting Defects Revealed in Forming Process of USD7 Steel

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Abstract

USD7 is one of the steel products of Isfahan Iron Melting Complex. It is cast in continuous casting moulds and rolled up to a rod of 5 mm diameter. Finally, it is wire drawn up to 3 mm and used as welding electrodes. This steel contains 0.05 to 0.09 wt. % carbon. The acceptable limit of the aluminium in this class of steel is less than 0.003 wt%. Therefore, it is categorized as rimmed steel. During forming process, there are some defects such as tearing and laminating that stop the forming process.

The aim of this research is to evaluate the factors causing the aforementioned defects. It was found that there were many porosities in the cast ingot. The area around these porosities was analyzed with EDS method, and inclusions with MnO and (Fe, Mn)O chemical composition were observed. It was found that they were external inclusions (slag inclusions caused by reoxidation and entrapment phenomena). Because of the presence of these inclusions, these porosities are not welded together during rolling process. Therefore, in the next steps of the forming process, these defects are revealed.

Keywords: Rimmed Steel, Continuous Casting, Porosity, Inclusion, FeO, MnO, Tearing, Laminating.

Introduction

Inclusion generally infers to some unwanted particles which exist in solid structure of casting or rolled parts that involve impurities, metallic or nonmetallic compounds formed by chemical, physical and/or mechanical reactions [1-4)]. Inclusions have harmful effects such as their elongation and strength on mechanical properties of products. Coarse inclusions are more harmful than fine ones; therefore, their control and removal are more important. According to chemical composition, the inclusions which exist in steel are divided into two main groups: oxide and sulfide inclusions [5)]. According to source of formation, the inclusions are divided into two groups: inclusions with internal and those with external sources. Internal inclusions form as a result of reactions occurring in liquid and solid steel. However, external inclusions form because of entrance and entrapment of slag, refractory or materials in contact with melt [6)]. External inclusions are big, with irregular shapes, complex structure and random distribution [7,8)]. Internal inclusions are small in size and are usually uniformly distributed in the cross section [9)]. External inclusions form from two main mechanisms, including reoxidation, and entrapment [4)].

In hot working temperatures, flexibility of steel product strongly depends on the absence of oxide inclusions. Thus, improvement of hot workability is possible by controlling quantity, distribution, size and/or by modifying the composition of these inclusions [10)].

To purify steel from dissolved gases (hydrogen, nitrogen and oxygen), low partial pressure of these gases is created on the surface of liquid steel. This procedure is done by applying high vacuum over the molten steel. The higher the vacuum, the more effectively degassing process occurs.

Gases such as argon, nitrogen and air are injected to the melt to homogenize the temperature and chemical composition of steel. During bubbling process some of non-metallic inclusions adhere to the rising gases and leave the melt. Also because of the convection current in the melt, some inclusions float

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on the surface of the melt. If the casting and solidification rates are high, gas bubbles cannot float and exit the melt. Therefore, bubbles freeze near the ingot surface [11].

Because of lack of strong deoxidizing elements such as Si and Al in USD7 steel, the amount of dissolved oxygen in the melt is high. This steel contains maximum 0.03Wt% Si (Table1). Therefore, Si cannot deoxidize the melt effectively. Mn in this steel is not a strong deoxidizing element. Aluminum is not used in this steel because of the following reasons:

1. Aluminum causes the formation of Hersenite ($FeO. Al_2O_3$) in tundish nozzle, and blocks it.
2. The aluminum content of this steel is maximum 0.003 percent, which does not permit the addition of aluminum.

Experimental Procedure

Samples of USD7 cast ingot with 250×250 mm^2 cross section; samples of crystalizator melt slag of continuous casting from casting unit, samples from LF unit, samples of USD7 ingot with 125×125 mm^2 cross section from different melts number from 650 hot rolling unit, and rod samples with 5.5 and 7 mm diameters from 350 rolling unit were prepared. To investigate the samples, the surface of samples was ground and polished. To determine quantity and kind of existing impurities, a Scanning Electron Microscope (SEM) equipped with EDS was used.

Result and Discussion

Chemical composition of three different melts of USD7 steel produced in steel making unit were determined with quantometery analysis. The chemical compositions of the samples are listed in Table 1. USD7 steel contains less than 0.1wt% carbon, so it is categorized as rimmed steel. Rimmed steels contain a large number of gas bubbles in the melt most of which are CO_2. If the gas bubbles cannot exit the melt, they remain in the ingot as porosities during solidification. If the gas bubbles contain CO, during rolling process, the bubbles weld to each other. But if the bubbles contain oxidizing gases (e.g. CO_2, which can also produce oxide inclusions around the porosities) or if some inclusions exist around the porosities, the welding process does not occur during rolling, and the product fails.

To study the existing pores in the surface of samples prepared from LF, metallographic images were taken from the pores regions. In metallographic investigations, it was observed that numerous inclusions could be seen around the pores. In Figure 1, optical microscopy micrograph of one pore is shown. Figure 2 shows that inclusions of FeO type exist around the pore. These inclusions are formed around the pores, and are usually uniform. It is concluded that these inclusions are internal inclusions and are formed before solidification process of metallic phase. Samples of cast ingot of USD7 steel melt were also prepared. In the cross section of samples, in regions near the surface and around the ingot, pores with 2 to 5mm diameter were found (Figure 3). At first, a solid layer forms near the walls of crystalizator in the ingot. When ingot came out from crystalizator, the temperature of molten steel in the center of the ingot decreased.

Table 1. Chemical Composition of Samples.

elements (%) / sample	C	Si	Mn	S	P
1	0.07	0.02	0.49	0.02	0.018
2	0.06	0.03	0.52	0.013	0.013
3	0.06	0.03	0.64	0.021	0.02
standard	0.06 – 0.1	Max 0.03	0.45 – 0.65	Max 0.025	Max 0.025

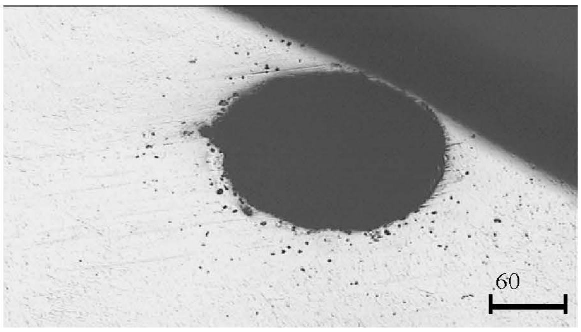

Fig. 1. Optical Microscopy Image of one of the Pores in the LF Samples (95.8X).

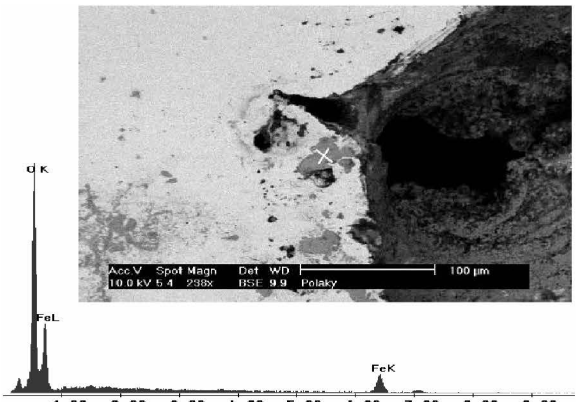

Fig. 2. SEM Image and Elemental Spectrum of the Inclusions around the LF Sample Pore.

With decreasing the temperature, gas solubility in the melt decreases and gases tend to exit from the melt. The viscosity of melt near the walls of crystaliozator is relatively high; therefore, the gases can not escape and remain in the ingot (Figure 3). The inclusions existing in the melt adhere to the gas bubbles wall. Vast dispersion of inclusions with small and big sizes around the pores was observed in metallographic micrographs. Figure 4 shows the inclusions existing around one of the pores present in ingot. Chemical composition of the specified inclusion was determined with EDS system. Figure 4 shows that these inclusions are of FeO type inclusions with (Fe, Mn)O composition.

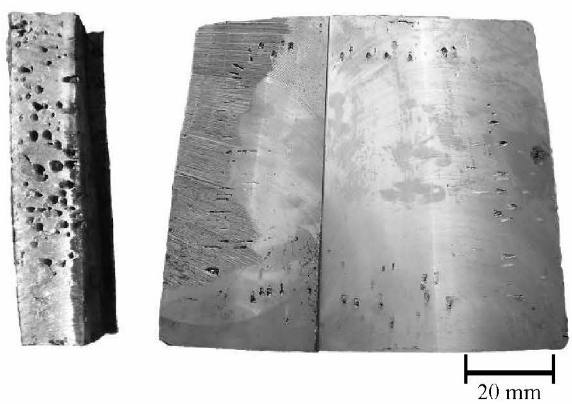

Fig. 3. Cross Section of Casting Ingot and Transverse View of Porous Region.

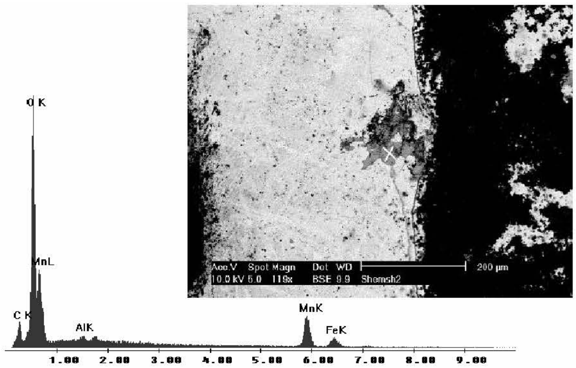

Fig. 4. SEM Image and Elemental Spectrum of Inclusions Around the Casting Ingot Hole.

Manganese peaks were found in the chemical composition of inclusions. The slag accumulated from the top of the crystalizator was investigated. In the slag structure, big zones of impurities were seen and analyzed with EDS system. Figure 5 shows one of these zones. Elemental spectrum of specified spot shows that those zones have (Fe,Mn)O composition. Thus, crystalizator slag was identified as a source of (Fe,Mn)O inclusions inside the ingot.

Since liquid steel with USD7 mark is in rimmed steel category, if degassing (deoxidation) were not adequate, there would be a severe turbulence in the crystalizator that would lead to slag entrance inside the ingot. Therefore, if removing the slag is not done well enough, entrance of slag to the melt will be inevitable.

Figure 6 shows one of the slag inclusions in the ingot. Point analysis of the inclusion as shown in Figure 6 indicates that those zones are inclusions of FeO type with (Fe,Mn)O composition. Slag inclusions existing inside ingot are the result of entrapment phenomenon.

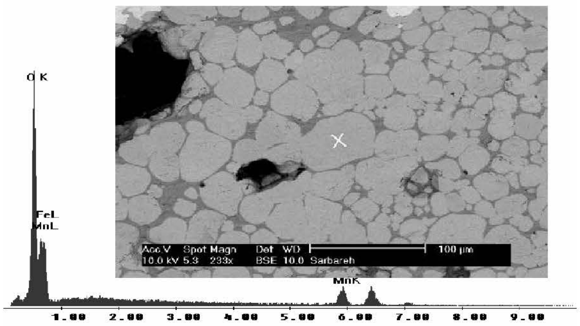

Fig. 5. SEM Image and Elemental Spectrum of Slag.

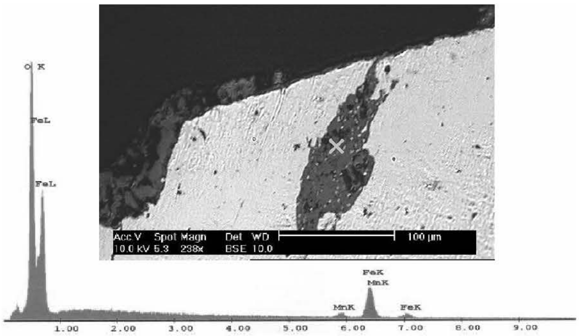

Fig. 6. SEM Image and Elemental Spectrum of Slag Inclusion of Casting Ingot.

Investigation of rupture regions on the surface of ingots with 125×125 mm^2 cross section shows that there are high colonies of inclusions around these regions. As seen in Figure 7, zones with dark color are rupture zones and those with light color are inclusion colonies around rupture zones. Therefore, the reason for detached or ruptured layers on the surface of the steel products is poor weldability of gas pores surrounded with inclusions. These inclusions were analyzed with SEM by point analyzer and the results are shown in Figure 7. Elemental spectrum of specified spot shows that those inclusions are of MnO type.

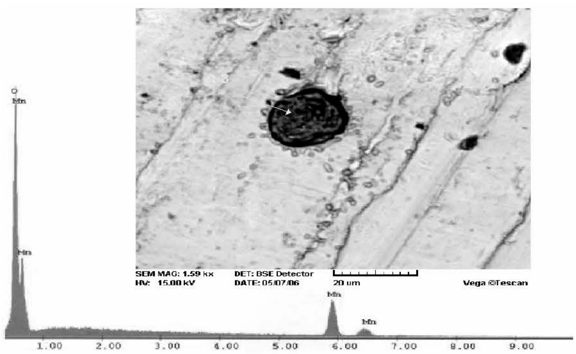

Fig. 7. SEM Image and Elemental Spectrum of Inclusions Around Ruptured Regions of Rolled Ingot.

In fact, preheat temperature of ingot with 250×250 mm^2 cross section in the first step of rolling is 1230 to 1280 °C and formability of FeO inclusions will decrease in temperatures higher than 400 °C, thus the inclusions observed in ingot with 125×125 mm^2 cross section are the same inclusions as the ingot with 250×250 mm^2 cross section. These inclusions have been crushed in rolling process under applied stresses.

To produce USD7 steel, manganese in the form of ferromanganese is added to the melt in LF. Since manganese oxide is more stable than iron oxide, Reaction (1) most probably occurs.

$$[Mn]+[FeO]=[MnO]+[Fe]$$
$$\Delta G° = -132900+22.64T \qquad (1)$$

ΔG° of the reaction (1) is negative in all working temperatures. Therefore, dissolved manganese is able to reduce iron oxide according to reaction (1). Consequently, (Fe,Mn)O inclusions form even in the solid state. On account of the fact that ingots preheat temperature in the furnace is 1180 °C through 1220 °C and minimum preheat time for rolling is 3 hours, the possibility of manganese diffusion and performing reaction (1) is evident.

Since transferring of melt from LF to casting station lasts from 10 to 50 minutes or even sometimes an hour, reoxidation is possible and formation of manganese oxide occurs. In fact, MnO forms in reoxidation process.

Inclusions aggregation was seen in rupture regions of rod surface layers and/or the regions where rupture begins in all rod specimens. To analyse the chemical composition of those inclusions, scanning electron microscopy was used and the result showed that all inclusions existing in surface rupture regions were of FeO type inclusion with (Fe,Mn)O composition (Figure 8).

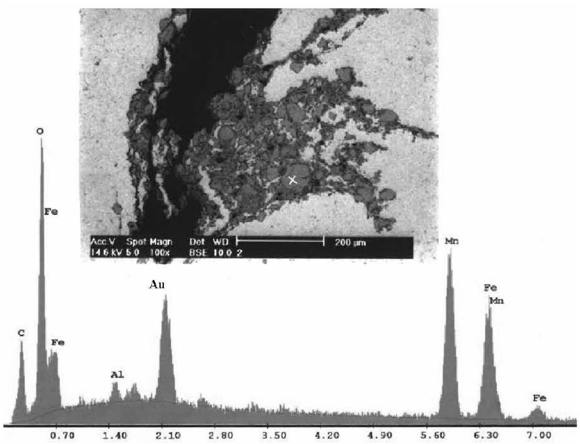

Fig. 8. SEM Image and Elemental Spectrum of Inclusion in Regions where Layers Detached from Rod Surface.

Investigation of torn specimens in rolling process showed that the reason for rods tearing in rolling process and twisting these inside rolling machines is detachment of layers from the rod surface and their aggregation in rod transmission location from rolling caliber. If these layers accumulate near the caliber of rolling machine, the rod will rupture.

In the end, it is useful to note that there are many ways to decrease oxygen content and remove inclusions from melt. Some of them are listed below [12]:

1- Applying proper technology for production of such steels (e.g. arc furnaces instead of converters).

2- Argon injection in the melt.

3- Using deoxidizer materials such as Al and CaSi.

In this research, determining the present inclusions; and in the next works, decreasing and removal of them were investigated, and related papers have been published.

Conclusions

In this research the following conclusions were achieved:

1- Since USD7 steel melt is categorized as rimmed steel and degassing process (deoxidation) is not well done, there is severe turbulence in crystalizator that could lead to entrance of slag into melt. Indeed, precise slag removal from the top of the mold has to be done.

2- If rimmed steel melt is not well degassed(deoxidized), since there is not enough time for exiting the gases from the mold, those gases will remain in the ingots as porosity.

3- If pores formed inside the casting specimen are surrounded with (oxide type) inclusions of (Fe,Mn)O type, defects like rupturing and detaching can occur in rolling.

4- FeO type inclusions that are crushed in initial steps of rolling become detaching oxide layers from the surface in the last steps in which rods reach 5.5 mm in diameter.

5- Tearing and twisting of USD7 rods in rolling process occur in the region of aggregation of detached layer from the rod surface and their accumulation behind the rod transmission caliber acts as a barrier for passing the rod from the rolling caliber.

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