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OVERVIEW OF CASTING DEFECTS IN DUCTILE CAST IRON

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Preliminary note

Abstract

Objective of this article is to provide an overview of common casting defects occurred during production of ductile cast iron (DCI) and the influence of non-metallic inclusions in the DCI. These defects are referred to slag, sand mould or other foreign substances that are imbedded in the surface, or underneath. The research was investigated on ductile cast iron samples using optical microscopy and scanning electron microscope (SEM) with energy dispersive spectroscopy (EDS). With SEM image position, shape and type of inclusion could be defined while EDS analysis reveals chemical composition of particular formations. The investigation of casting defects indicates necessity of DCI production parameters control. This article deals with investigation of surface defects in DCI such as non-metallic inclusions (Al_2O_3, SiO_2, MgO, CaO, MnO, FeO, Fe_2O_3) which mostly originate from slag, melt oxidation, reactions with refractory materials, mould erosion, and melt treatment interactions.

***Keywords**: ductile cast iron, casting defect, non-metallic inclusion, SEM, EDS.*

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INTRODUCTION

Common foundry defects are sand and slag inclusions, pinholes, blowholes, shrinkage and cracks. Sand inclusion could be entrapped due to sand cut, wash or hole, mould erosion or drop, raised, broken or crushed sand core, damaged mould elements. Possible causes for these problems are related to gate, runner and riser design. On the other side, possible causes related to mould material are inferior quality of resin, insufficient cohesive strength of sand, low green strength, improper moisture content, defective mould and core drying, incorrect mould and core permeability, improper mould hardness and high compressive strength. The causes like improper alignment of mould halves, pattern and match plate, moulding boxes and machine, careless pattern removal, improper procedure and parameter control during moulding also cause defects [1].

Inclusions can be defined as non-metallic and sometimes intermetallic phases embedded in metal matrix. They are usually oxides, silicates, sulphides, nitrides or other complex forms. In most cases they are detrimental to the performance of the cast component. Mechanical properties can be adversely influenced by inclusions, which act as stress raisers. Some properties are more sensitive to the presence of inclusions than others. There are essentially two classifications for all inclusions: exogenous from external causes and indigenous which are native, innate, or inherent in the molten metal treatment process [2]. Slag, entrapped mould materials and refractories are examples of inclusions that would be classified as exogenous. In most cases these inclusions would be macroscopic and visible at the casting surface. When the casting in sectioned, they may also appear beneath the external casting surface if they have had insufficient time to float out or settle due to density differences with respect to the molten metal. Indigenous inclusions include oxides, silicates, sulphides and nitrides derived from the chemical reaction of the molten metal with the local environment. Such inclusions are usually small and require microscopic magnification for identification [2].

Ductile cast iron (DCI) is also known as spheroidal or nodular cast iron produced by melt treatment (preconditioning) of corresponded composition with magnesium (Mg) which promotes the precipitation of graphite in spheroidal form [3]. Melt treatment is important step in producing ductile cast iron and have influence on casting performance. Most elements in inoculants and nodularisers are highly reactive metals, such as magnesium (Mg), aluminium (Al), silicon (Si), titanium (Ti) and calcium (Ca). These elements are creating finely distributed oxides in reaction with oxygen (O) and sulphur (S) in the DCI melt forming inclusions [4-7].

In DCI production, reaction between oxygen (O) and the elements like magnesium (Mg), silicon (Si), calcium (Ca), manganese (Mn) and aluminium (Al) can result in long accumulated particle formations – slag. Slag, as a non-metallic inclusion can be found in ductile cast iron, containing elements such as Al, Ca, Mg, Si, Fe and O [8]. More complex oxide inclusions can contain strontium (Sr), barium (Ba) and other rare earths as constituent elements [9].

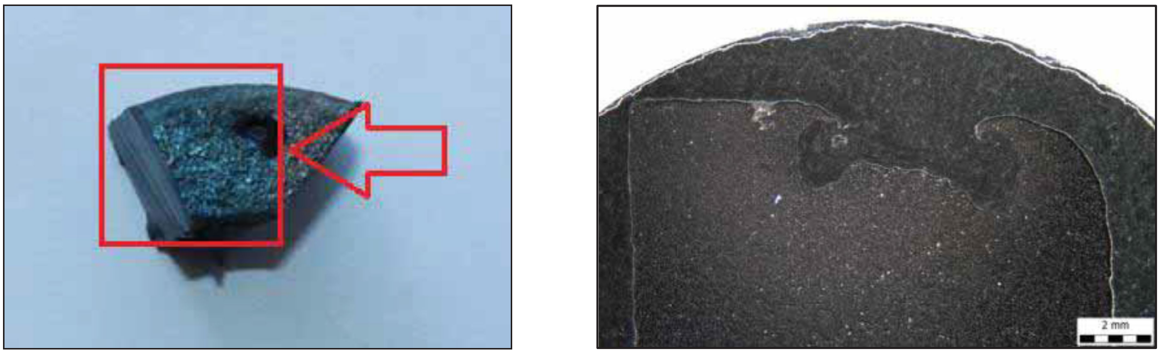
Sand inclusions are casting defects mostly developed as a result of turbulent mould cavity filling causing mould erosion. Turbulent mold filling causes thermo-mechanical stresses on mould and cores. According to Giesserei Lexikon *“The considerable compressive and shear stresses acting on the mould and core surface under the metallostatic pressure can lead to mould fracture followed by isolation and withdrawal of particular grains or their agglomerates.”* Sand inclusion along with slag inclusion and other oxides it can cause defects on or under the casting surface once when they get in the mould cavity. If one part of the mould gets damaged, there is probability that casting will have outgrowth on surface [10].

Inclusions in DCI are separated in three categories. Square-shaped inclusions contain magnesium, calcium, sulphur and silicon as the main constituent elements. Rectangular-shaped inclusions appear mainly in iron matrix and they mostly contain elements such as Mg and Si. Irregularly-shaped inclusions are located in DCI interdendritic areas. Major elements are magnesium (Mg), phosphorus (P), and rare earth elements (Ba, La, Ce) [11].

This investigation represent an microstructural confirmation of common surface defects in DCI samples on the base of non-metallic inclusions occurred due to interaction in melt-mould system and refractory materials features, as well as melt oxidation and slag formation. Also thickwall sections often indicate degeneration of graphite shape and require specialcare relating to heat and mass transport.

MATERIALS AND METHODS

The research was performed on ductile cast iron samples. Several types of surface defects were noticed. Figure 1a) shows an example of the casting section with defect. Figure 1b) shows prepared sample for metallographic analysis.



a) b)

Figure 1. Overview of casting section with surface defect: a) photography of sample, b) sample prepared for metallographic analysis

Samples were submitted to metallographic analysis positioned vertically to the defect in order to define development of the defect. Microstructural analysis was performed in order to determine their main characteristic such as shape, size and dimension which could lead to determination of theirs origin.

The metallographic and microstructure analysis was performed by light microscopy using Olympus BX51 equipped with DP70 digital camera and AnalySIS Materials ResearchLab automatic image processing system. The sample for metallographic and microstructure analysis was prepared by standard grinding and polishing process and etching in 4% nital (solution of alcohol and nitric acid). Chemical composition of inclusions and other phenomena were established by scanning electron microscope (SEM) Tescan Vega TS 5136 MM equipped with Bruker energy dispersive spectrometer (EDS).

RESULTS AND DISCUSSION

Figures 2a) and 2c) represent an example of sample microstructure before etching, while 2b) and 2d) are corresponding micrographs after etching.

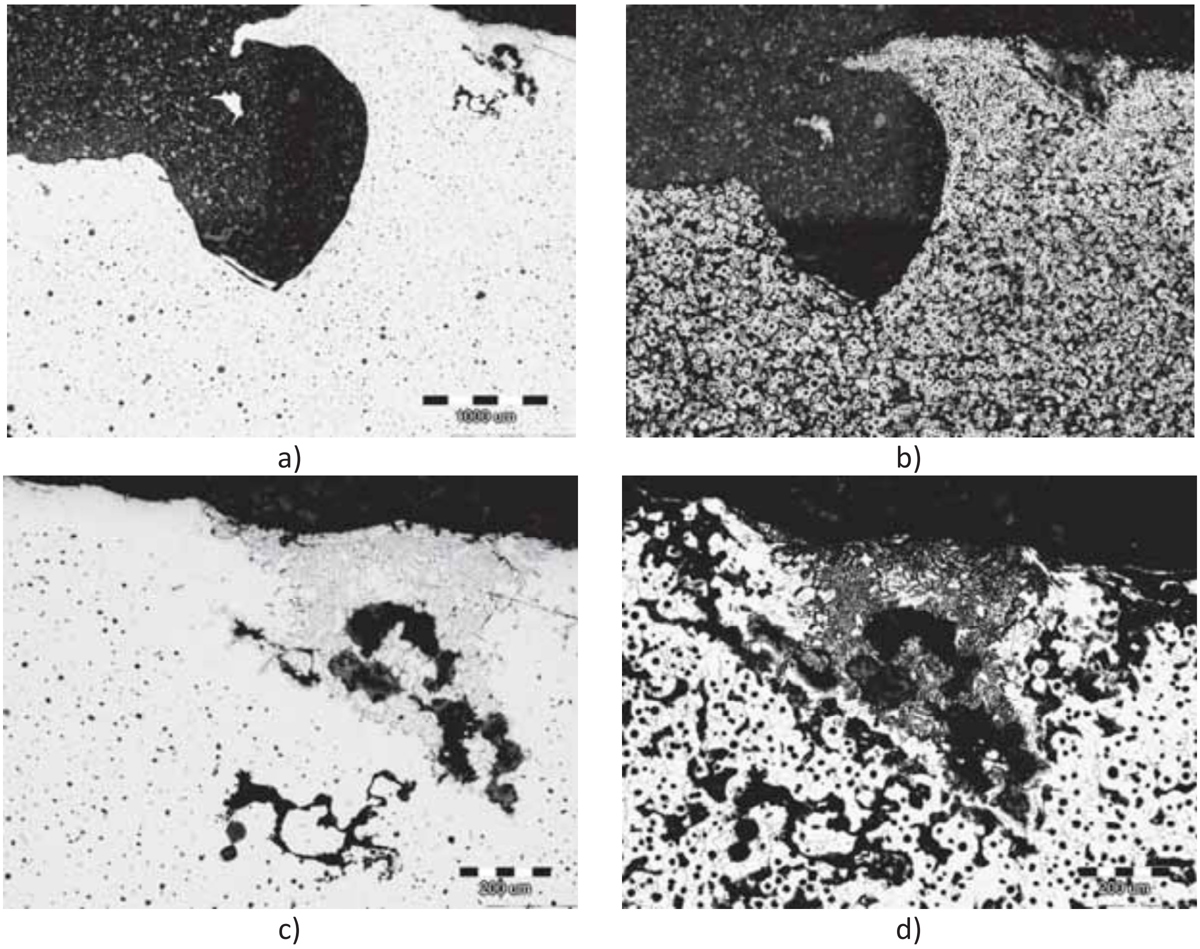


Figure 2. Microstructure of the sample in area of defect vertically to the sample surface

Figure 2 shows the gas porosity along the surface of the sample. Gas porosity often occurs in combination with heterogeneous non-metallic inclusions under the surface.

Comparison of inclusion morphology with literature survey indicates development of oxide and silicate inclusions. Presence and composition of these inclusions was investigated by SEM mapping and EDS analysis. SEM mapping analysis indicates intensity and distribution of chemical elements within the inclusion, and therefore enables identification of its type. Figure 3 represent a mapping analysis of inclusion under the surface of the casting.

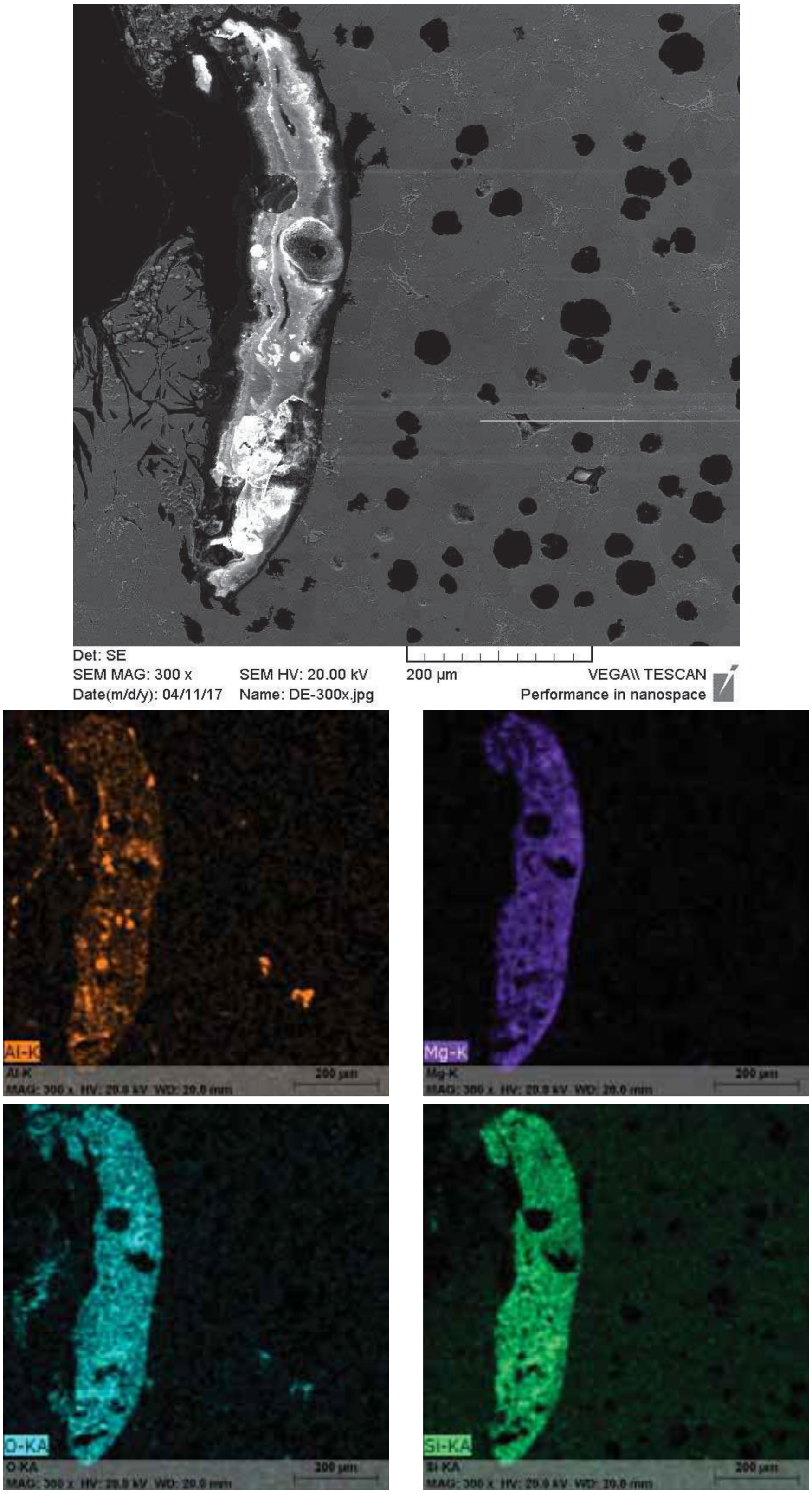


Figure 3. Mapping analysis of inclusion

Figure 3 shows an example of distributed elements and formed Al-, Mg- and Si oxide. Melt turbulence and low mould mechanical strength could result in mould erosion and sand

entrapping. Influencing factors on mould erosion are sand strength, hardness, wall thickness, feeding and gating system size and position.
Slag and sand inclusions reveal in mostly irregular shape as shown in Figure 4.

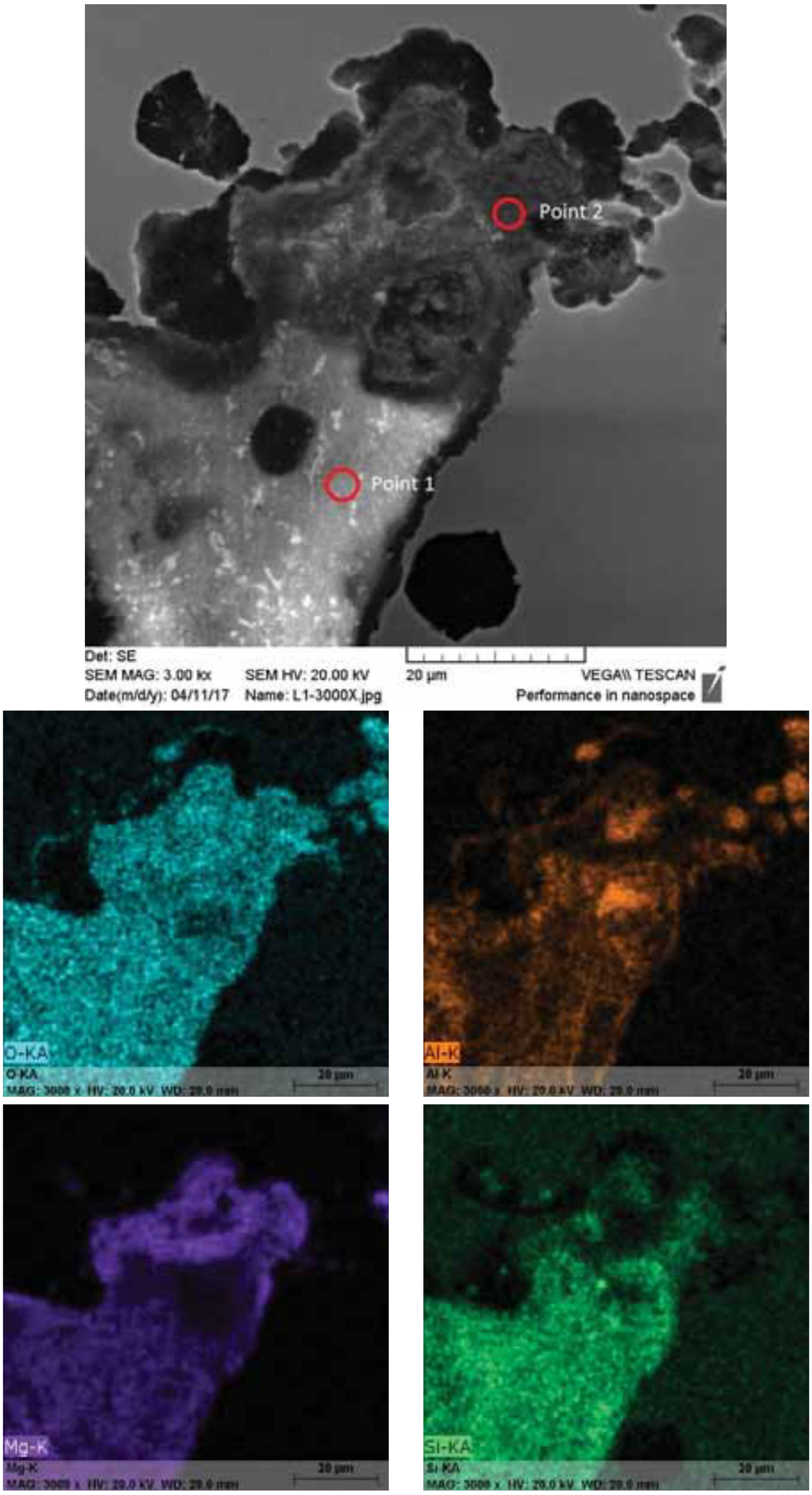


Figure 4. Distribution of elements using SEM image with mapping and EDS

Figure 4 shows an example of oxide inclusion entrapped beneath the casting surface. EDS investigation revealed that behind standard elements like aluminium (Al), magnesium (Mg) and silicon (Si), there is also calcium (Ca) as integral part of typical inoculation agent for DCI on FeSi base. Table 1 shows results of chemical composition in characteristic points indicated in Figure 4.

Table 1. Chemical composition of marked positions

Element	O	Mg	Al	Si	Ca
Point 1 (wt%)	48.42	14.24	6.45	11.08	17.20
Point 2 (wt%)	46.41	28.64	0.95	4.33	13.97

Obtained results indicate the oxidative atmosphere during DCI melt treatment.
Other example of non-metallic inclusion indicates entrapped oxide, as shown in Figure 5.

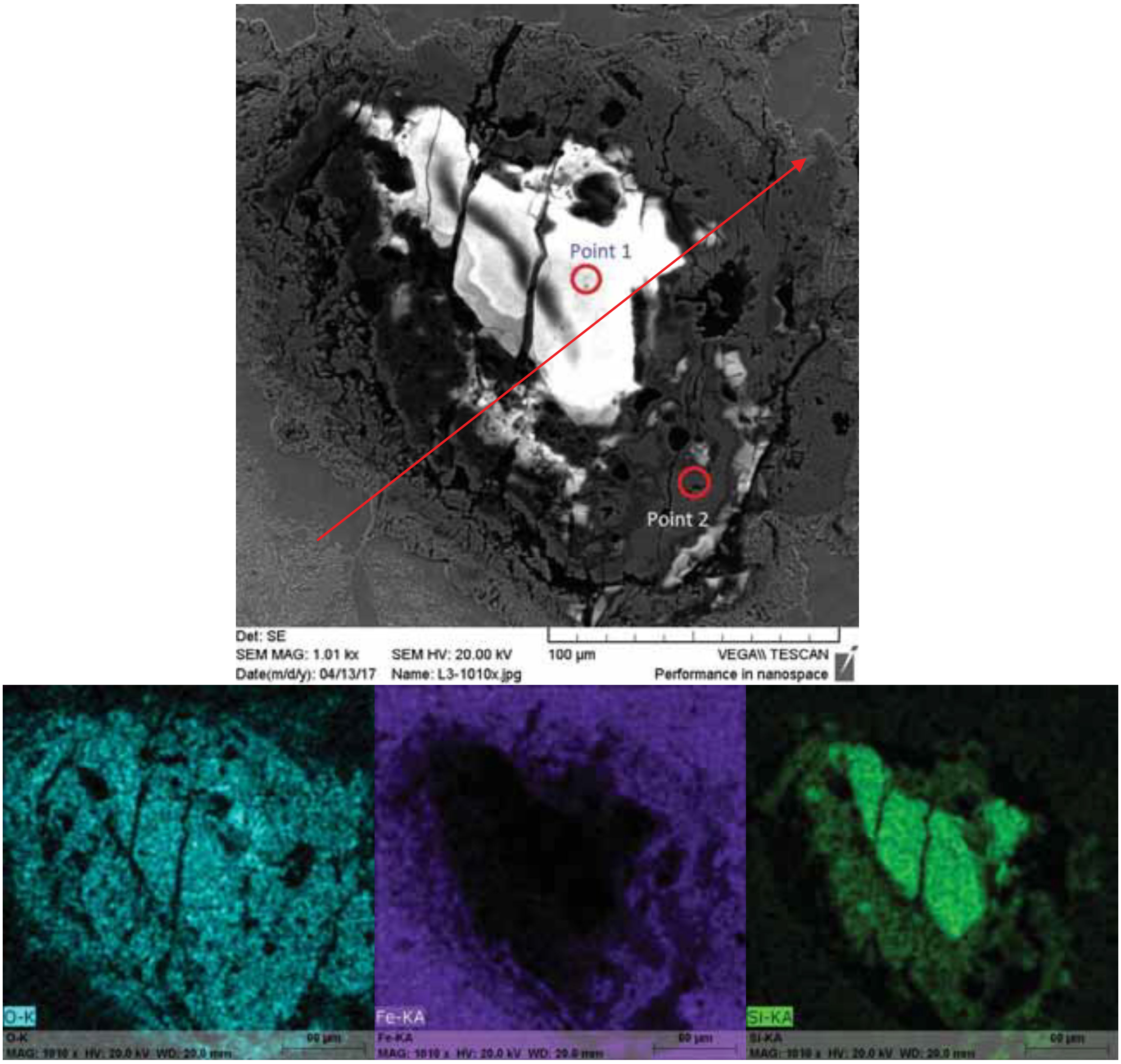


Figure 5. Mapping analysis of non-metallic inclusion with distribution of O, Fe and Si

Table 2 indicates chemical composition in corresponding positions marked in Figure 5 using EDS analysis.

Table 2. Chemical composition of marked positions in Figure 5.

Element	O	Si	Fe
Point 1 (wt%)	58.72	36.41	0.89
Point 2 (wt%)	20.00	-	77.53

SEM image reveals existence of non-metallic inclusion on the silica base surrounded by Fe-based oxide, which indicates the origin from metal reaction with sand. Turbulent mould filling induce mould erosion, segregation of particular sand grains or their agglomeration followed by oxide formations. Those phenomena resulted in Si- and Fe- oxide occurrence.

Figure 6 shows line analysis of inclusion indicated in marked direction on SEM image in Figure 5.

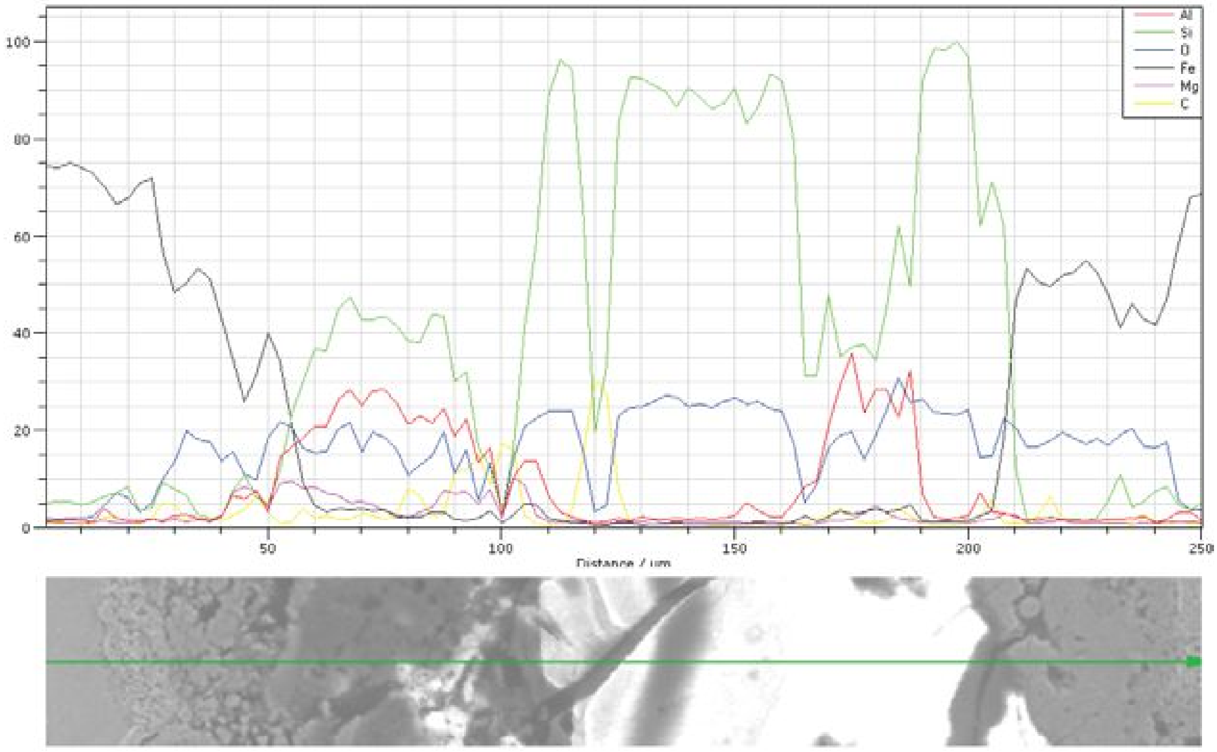


Figure 6. Line analysis of inclusion

Line analysis confirms the oxidation of silica sand. Surrounded area indicates higher amount of Si- and Al- oxide. Whole area is significantly poor in Fe content.

Next case represents an example of Fe-based oxide inclusion surrounded by graphite nodules, as shown in Figure 7.

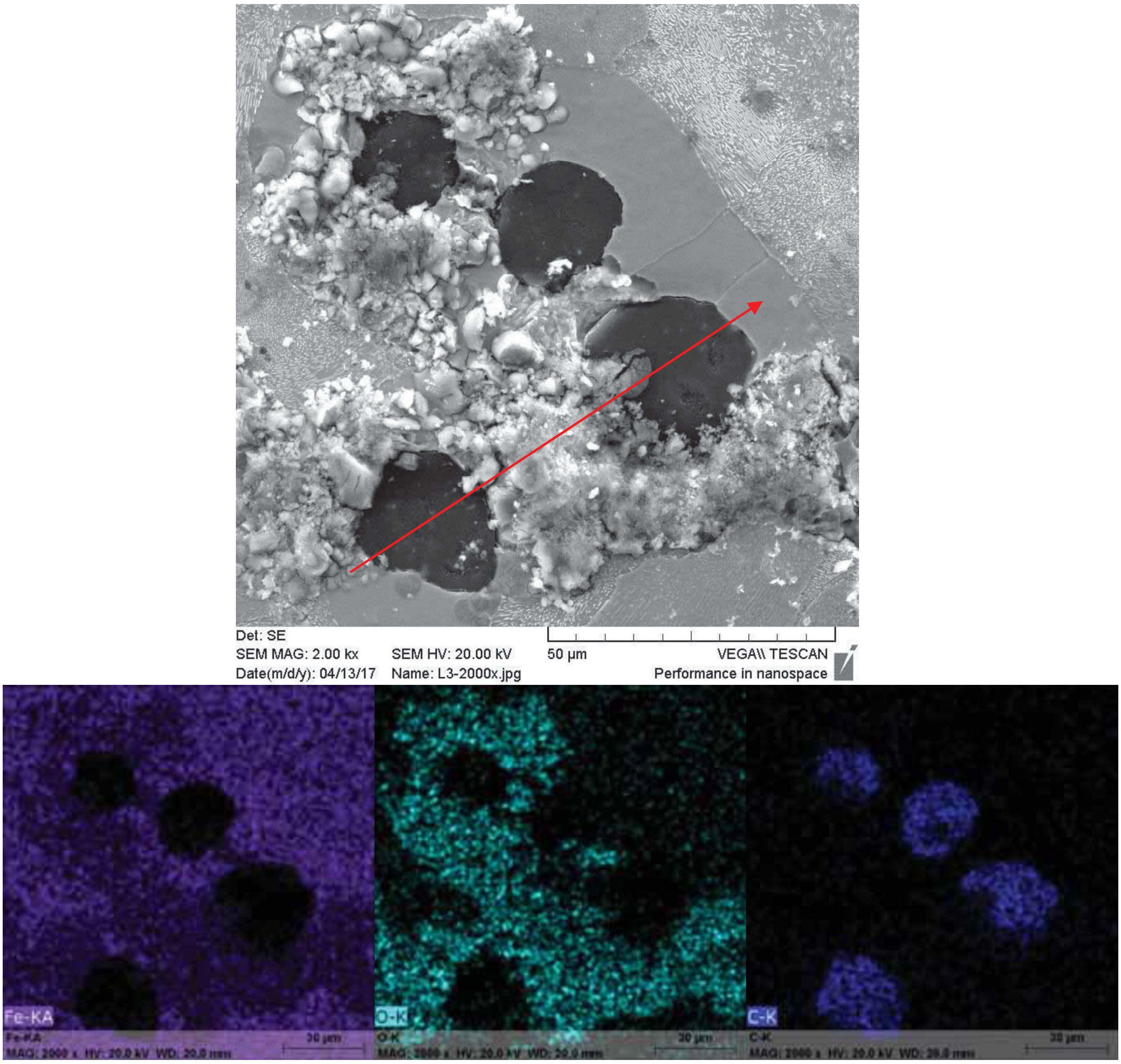


Figure 7. Distribution of chemical elements using SEM mapping analysis

Figure 7 reveals an example of Fe- oxide in metal matrix surrounded with graphite nodules. This defect occurred due to melt oxidation. In order to establish intensity changes in chemical composition line analysis was performed, as shown in Figure 8.

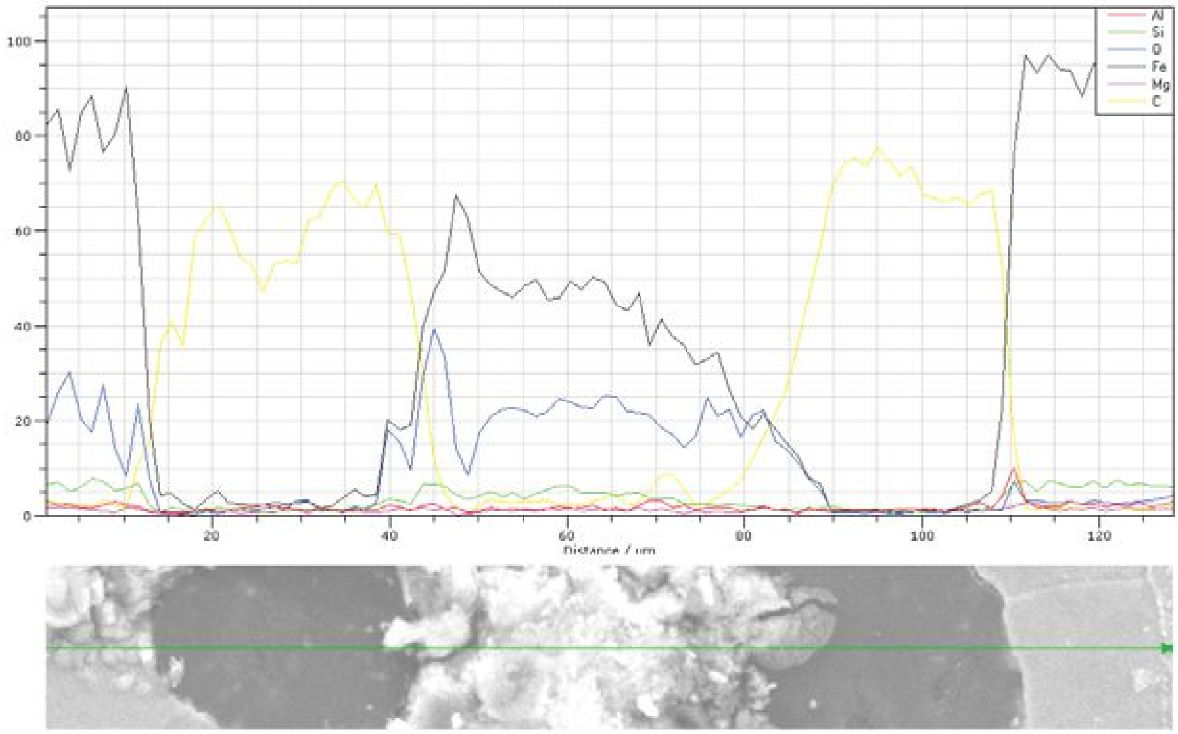


Figure 8. Line analysis of distributed elements on marked position in Figure 7.

Figure 8 shows line analysis indicating distribution of elements along the line with significant increase of Fe and O in the oxide area, and marked positions of graphite (C line). Other present elements do not reveal any significant change.

Figure 9 shows an example of entrapped Fe-oxide in the form of slag, followed by silicate inclusion under the surface of casting.

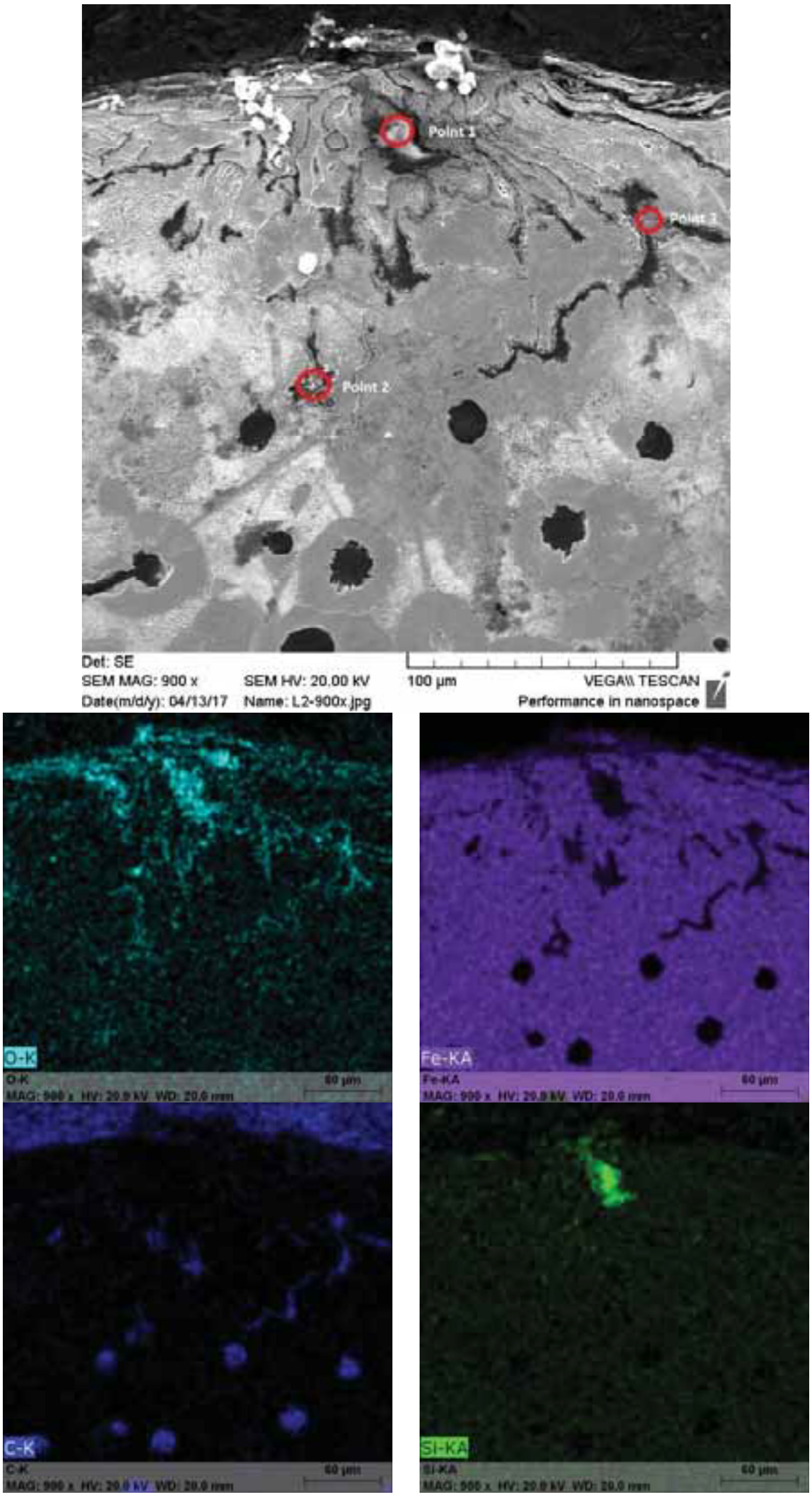


Figure 9. Distribution of chemical elements using SEM mapping analysis

Figure 9 reveals slag formation (Fe-O) in the form of stria followed by Si-O inclusion and degenerated graphite types in the area of defect. Presence of silicate inclusion indicates that erosion of sand mould also occurred during filling of mould cavity. Oxide formations were investigated using EDS. Analysis was performed on 3 points as shown in Figure 9 and Table 3.

Table 3. Chemical composition of corresponded positions in Figure 9.

Element	O	Si	Fe
Point 1 (wt%)	51.47	31.31	1.76
Point 2 (wt%)	16.67	1.69	74.53
Point 3 (wt%)	22.23	4.68	74.09

Chemical composition confirms the presence of Fe-based and Si-based oxides which all occur due to mould-melt interaction.

CONCLUSIONS

Casting defects represent a major problem in foundries, from technological to financial aspect, respectively. These defects causes scrap. It is very important to identify them and eliminate their origin. This investigation resulted in determination of following casting surface defects in DCI:

- Gas porosity due to melt treatment and inner reaction in mould-melt system
- Non-metallic oxide inclusions on the base of Al, Fe, Mg, Si
- Sand inclusions due to inadequate mould features
- Slag formation due to melt treatment

Melt quality and treatment, correct casting technology, mould features are significantly influencing parameters on defect occurrence. Establishing the defect nature, characterization is the first step to determine its origin. Follow-up of whole process parameters should lead to recognizing and avoiding defect occurrence.

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