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CHARACTERISTICS OF DEFECTS PRESENT IN INDUSTRIAL STEEL CASTINGS DUE TO METAL-MOULD REACTIONS

CHARAKTERYSTYKA WAD POWSTAŁYCH NA PRZEMYSŁOWYCH ODLEWACH STALIWNYCH W WYNIKU ODDZIAŁYWANIA METAL – FORMA

Studies were made on surface defects formed in industrial steel castings. It has been concluded that the defects are formed due to an interaction between molten metal and moulding sand constituents. The microscopic analysis indicated strong non-homogeneity of the examined defects in respect of both structure and chemical composition. Basing on the examinations carried out under the scanning electron microscope, it was observed that within each defect two characteristic regions could be distinguished. One of them was formed of the silica sand grains, while the other contained a complex oxide phase, the chemical composition of which depended on the type of protective coating and the cast steel grade.

Przeprowadzono badania wad powierzchniowych powstałych na przemysłowych odlewach staliwnych. Stwierdzono, że powstałe wady są rezultatem oddziaływania ciekłego metalu ze składnikami masy formierskiej. Przeprowadzona analiza mikroskopowa wskazuje na silną niejednorodność badanych wad pod względem budowy i składu chemicznego. Na podstawie badań przeprowadzonych z wykorzystaniem elektronowego mikroskopu skaningowego stwierdzono, że w obrębie każdej z nich można wyróżnić dwa charakterystyczne obszary. Jeden z nich tworzą ziarna piasku kwarcowego, natomiast drugi obszar stanowi złożona faza tlenkowa, której skład chemiczny zależy od rodzaju powłoki ochronnej i gatunku staliwa.

1. Introduction

The general tendency to raise the quality of steel castings and improve their properties also includes an improvement of their surface quality. When steel castings are poured in green sand moulds, there is an imminent danger of the formation of surface defects caused by various phenomena that occur between the molten metal and the oxidising atmosphere present in mould cavity, or result from the metal-mould reactions (mainly SiO_2, MnO and FeO oxides) [1-6]. Due to these effects, it becomes possible for some of the elements (e.g. Mn) to migrate from the liquid steel to moulding material and the other way round. An outcome of these effects is the change of the concentration of elements in the casting subsurface layer and the occurrence of conditions promoting defects formed on the casting surface.

Protective coatings applied on foundry moulds are generally considered the tool very effective in preventing the molten metal – moulding sand interaction [3]. The main task of the coating is to reduce the casting surface roughness and prevent the formation of burn-on defects on the casting surface and metal penetration inside the mould or core [3, 7, 8].
Moreover, when applied on sand moulds, the protective coatings should prevent changes of structure and chemical composition in the casting skin and reduce gas penetration into metal when the mould is poured. Nevertheless, though protective coatings are used nearly always and nearly everywhere, cases happen when defects still appear on the casting surface. This is, first of all, due to the technique by which the coatings are applied (painting or spraying); another cause of the defects may be failure in strict observance of the coating application regime and mould drying parameters.

This article presents the results of the studies on the occurrence of surface defects in industrial castings made from carbon and alloyed steels. Basing on the obtained results, a mechanism of formation of the secondary slag inclusion defects has been examined.

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2. Research methods

The studies included an analysis of the defects formed on the upper and vertical surfaces of industrial castings made from the following steel grades: unalloyed (straining pulley), low-alloyed L30GS (link), L35GMA (toothed wheel), and manganese steel (plate and fan). Castings selected for the studies were made in moulds without protective coatings and with coatings of two types, i.e. alcohol coatings based on zirconium orthosilicate and coatings based on MgO (Silico K55).

The qualitative phase analysis was made on powdered samples using an X-ray Krystaligraph 4P diffractometer. The obtained results were processed by an XRayan phase analysis program.

Some surface defects in steel castings are shown as an example in Figure 1.

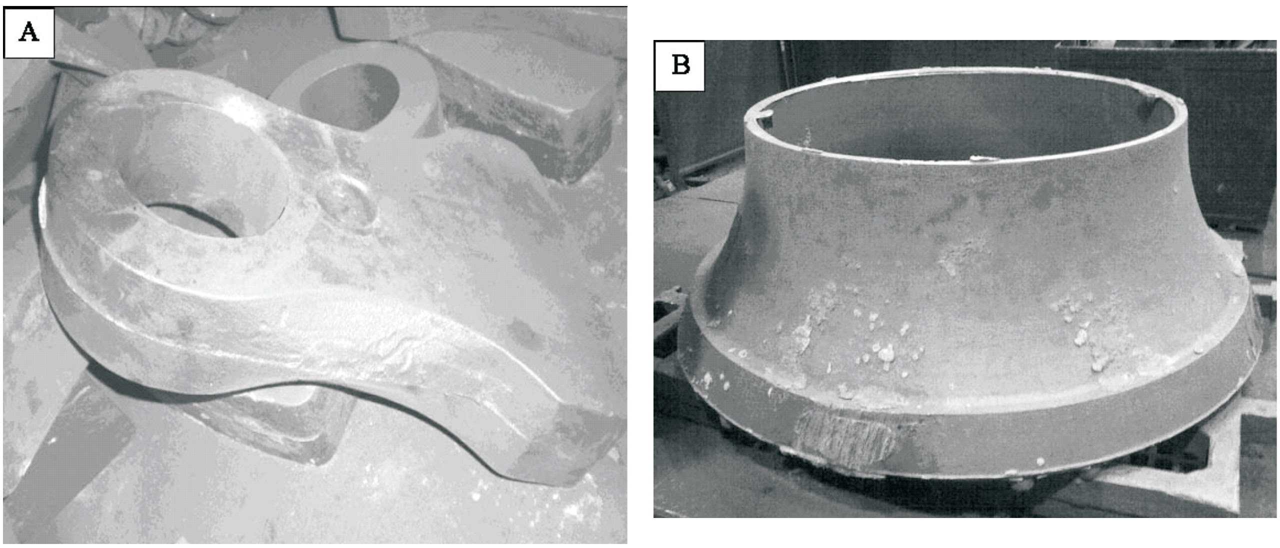


Fig. 1. Examples of castings made from L120G13 steel – hammers cast from L120G13 steel (A); a cone cast from 120G13 steel

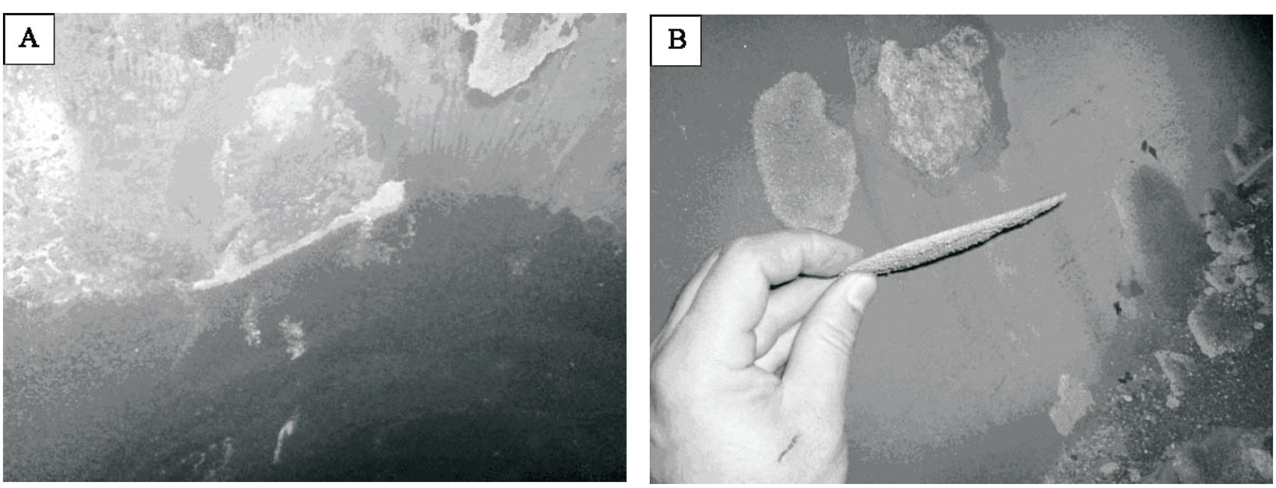


Fig. 2. Examples of surface defects in castings made from L120G13 steel

The specimens taken from the castings were embedded in resin. Then, on each of the specimens, an appropriate field was selected for the microscopic examinations. The examinations included mapping of the elements distribution and the scanning and linear quantitative analyses of chemical composition. Changes of chemical composition in the examined areas were determined by the energy dispersive X-ray analysis (SEM – EDS) using an EDAX apparatus.

3. Results and discussion

Figure 3 shows examples of surface defects present in castings and examined under the scanning electron microscope.

The distribution of elements in the region of the defect and the results of quantitative linear analysis are shown in Figures 4 and 5, respectively. From the surface distribution of elements it has been deducted that the defects are composed of the two characteristic areas. One area consists of the irregular silica sand grains, while the other is composed of a complex oxide phase containing elements like Mn, Si, O and Al.

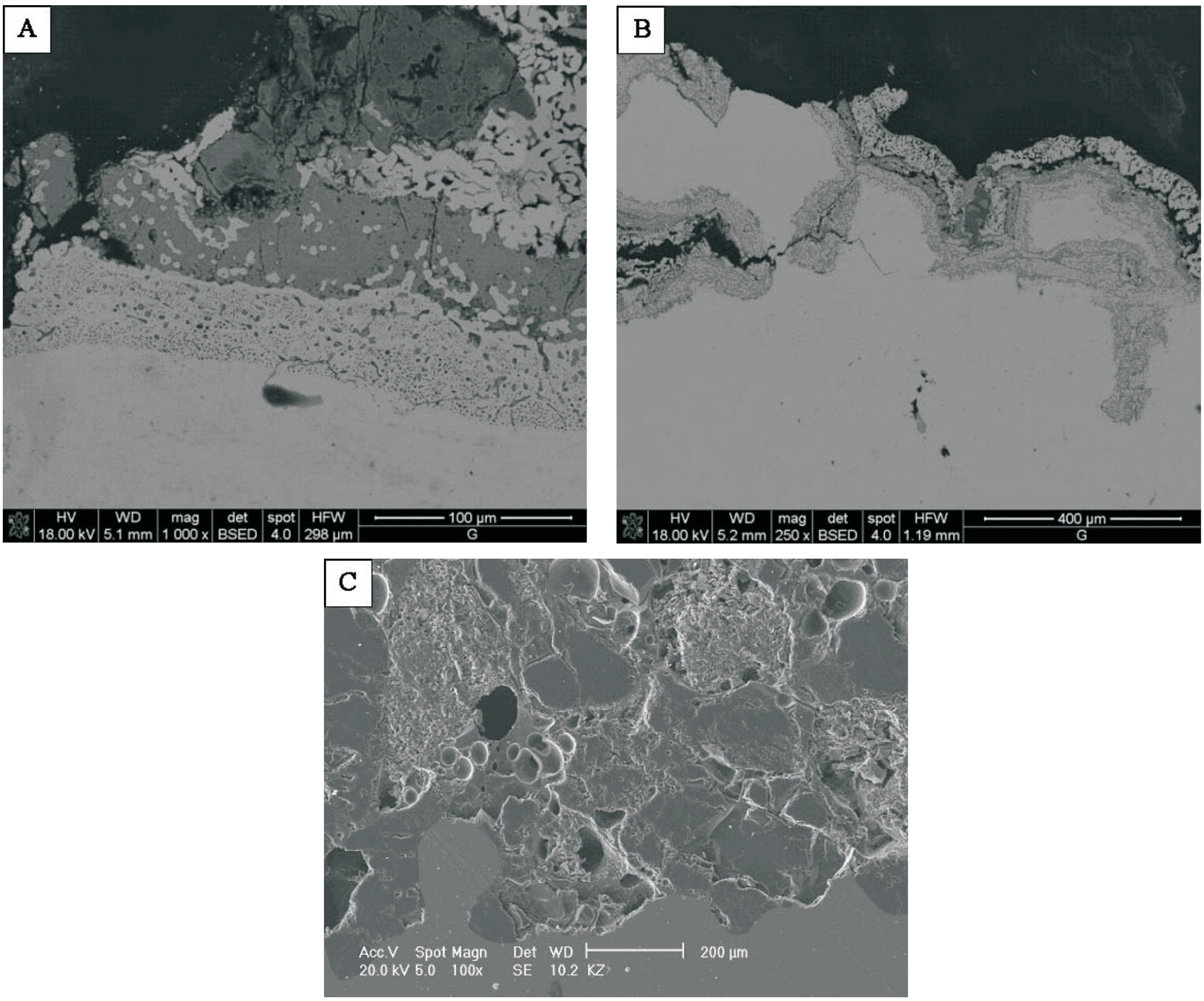


Fig. 3. Examples of images obtained from the examined regions by SEM-BSE

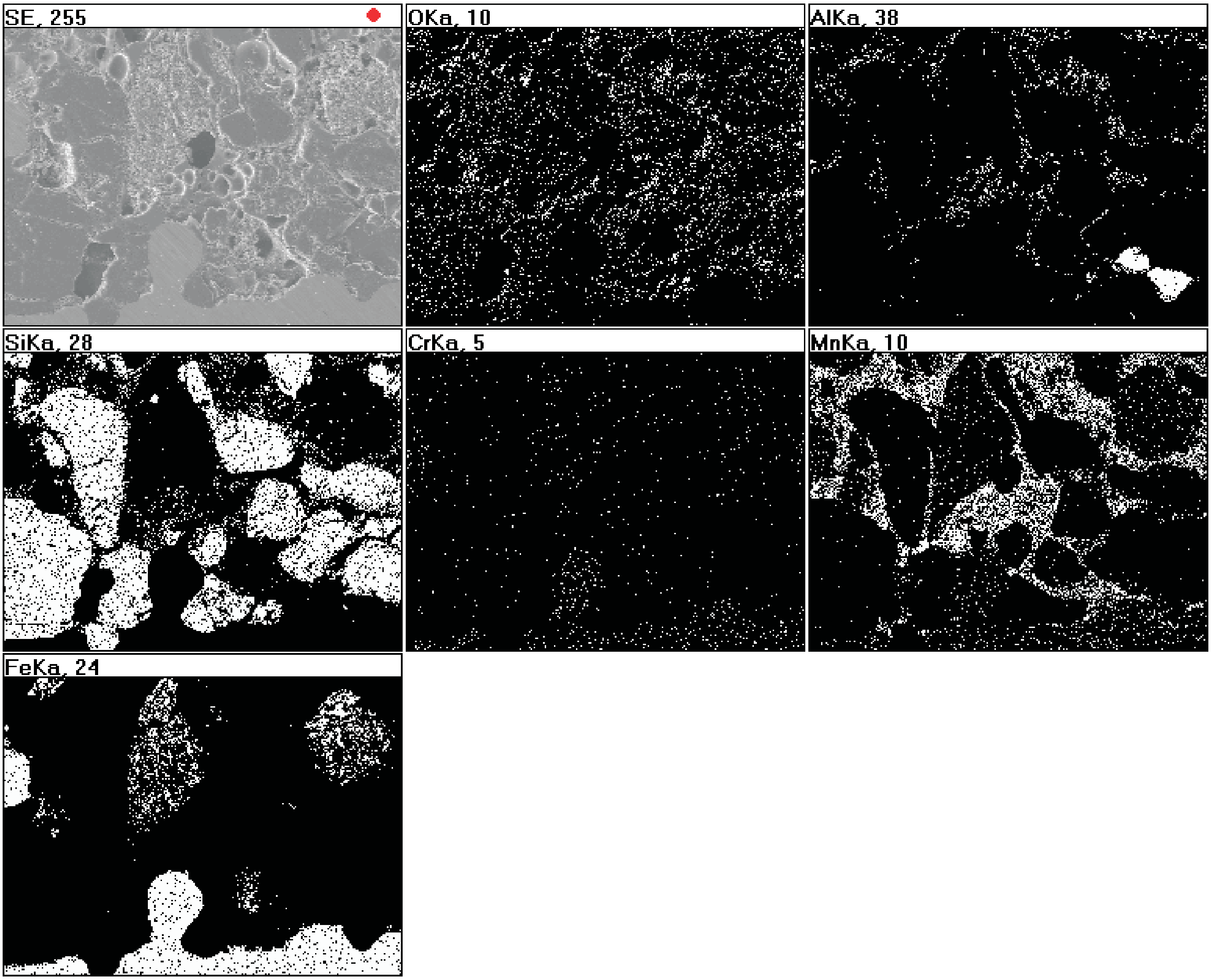


Fig. 4. Mapping of elements distribution in the region of defect on the surface of the cast toothed wheel

In all the examined areas of oxide phases (present in various castings), the changing content of manganese has been observed (Figs. 4–6). The obtained results point out to an interaction between manganese contained in molten metal and silica present in the moulding sand. From an analysis of the chemical composition of complex oxide phases bonding the SiO_2 grains it has been concluded that these are the areas of highly non-homogeneous character as regards both structure (porosity) and chemical composition. The chemical elements prevailing in these regions included silicon, manganese and oxygen. Their concentration varied and depended on the steel grade of which the castings with defects had been made (carbon cast steel: 25-34%Si, 17-23%Mn, 24-36%O; Mn-Mo cast steel: 33-41%Si, 32-39%Mn, 18-21%O, Hadfield cast steel: 39-40%Si, 27-40%Mn). Moreover, depending on the type of the coating applied, in some areas the presence of aluminium, iron and magnesium or zirconium was noted. This indicates that in the reactions between molten metal and moulding sand, manganese oxidation and the reaction between manganese oxide and silicon oxide play very important part. Oxidation of iron and aluminium is of secondary importance. The presence of a peak from aluminium leaves some doubts, considering the fact that the presence of this element may have its origin in either the deoxidation process, or in the technique used for preparation of the metallographic specimens (polishing with Al_2O_3).

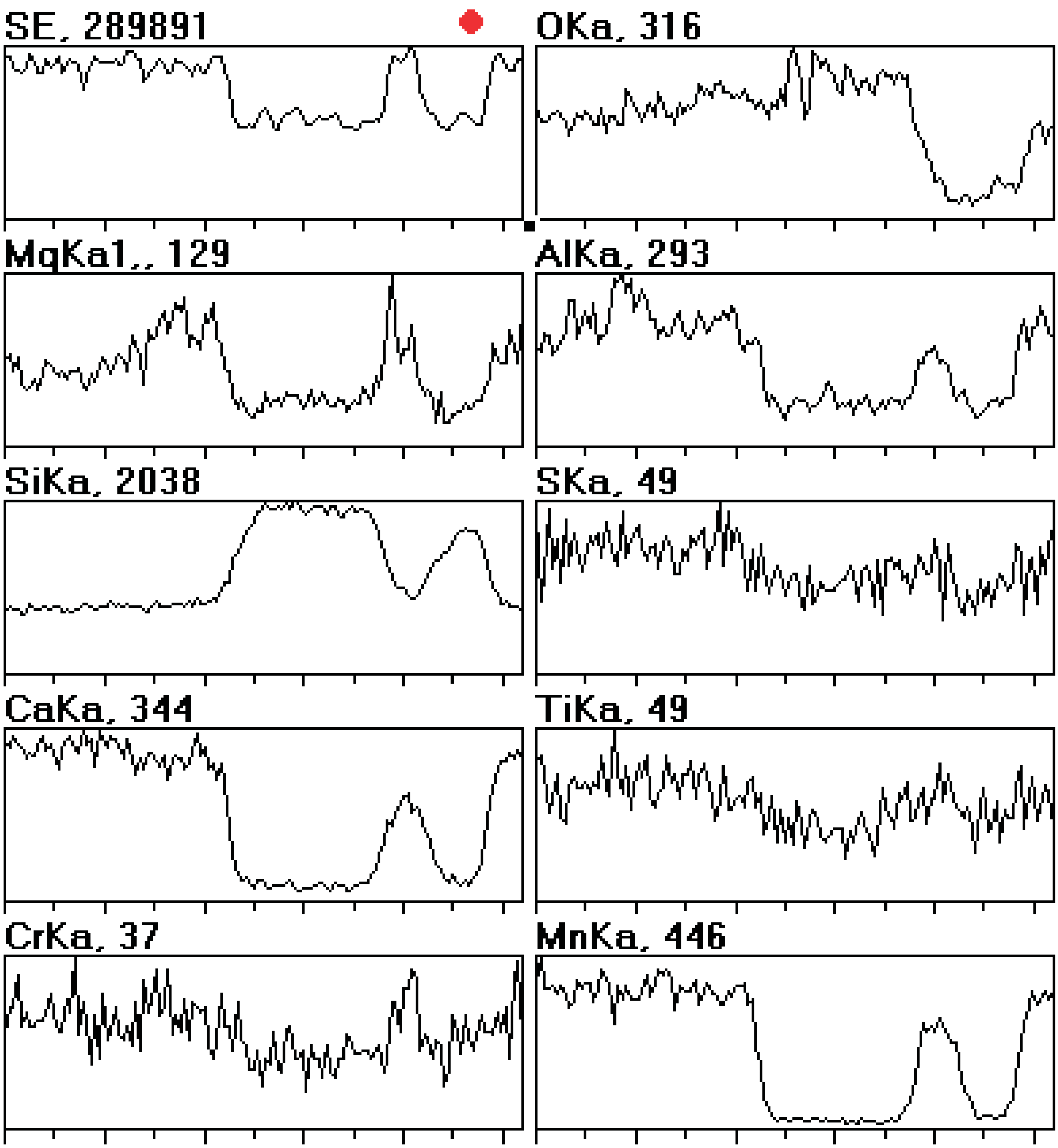
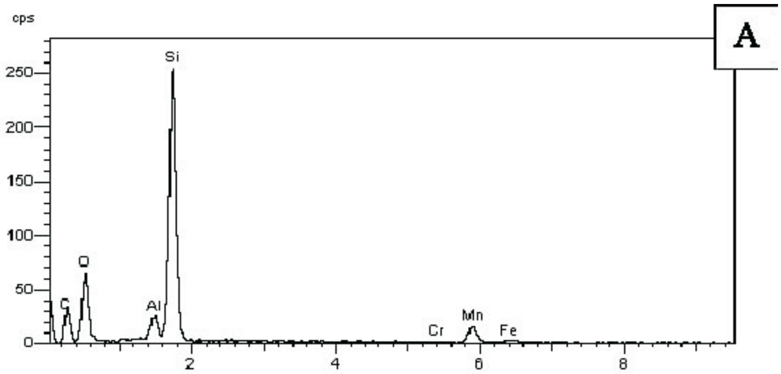


Fig. 5. Linear distribution through the region of oxide phase and SiO_2 grains

The high content of manganese in the examined regions of oxide phases may testify the fact that under the conditions applied when moulds are poured with molten metal (the temperature of about 1500-1600 °C), in places where the protective coating has either been damaged or applied in an incorrect way, the reaction of manganese oxidation (due to oxygen present in the atmosphere inside the mould cavity) and penetration of manganese vapours occured. Due to the manganese affinity to oxygen stronger than the affinity of iron, manganese oxide MnO is formed, and it reacts strongly with the constituents of the moulding sand (SiO_2). As a result of this reaction, silicates of a general formula $Mn_nSi_mO_{2m}$, are formed [4]. In the case of L120G13 cast steel, on the surface of the solidifying casting, an $MnSiO_3 + Mn_2SiO_4$ eutectic is formed [2]. The high content of silicon, manganese and oxygen can confirm this fact, while the X-ray phase analysis confirms the presence of $MnSiO_3$ (Fig.7).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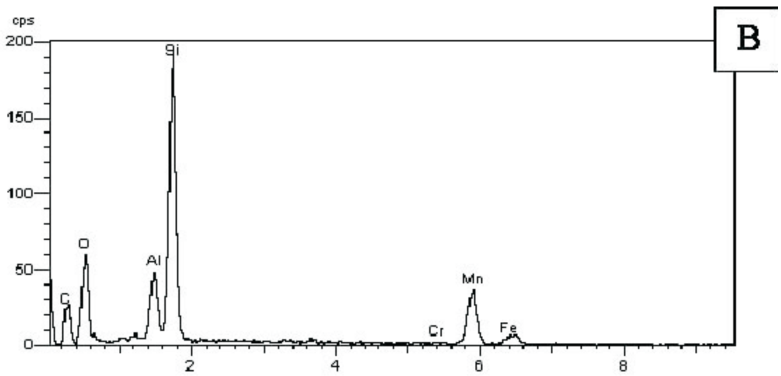
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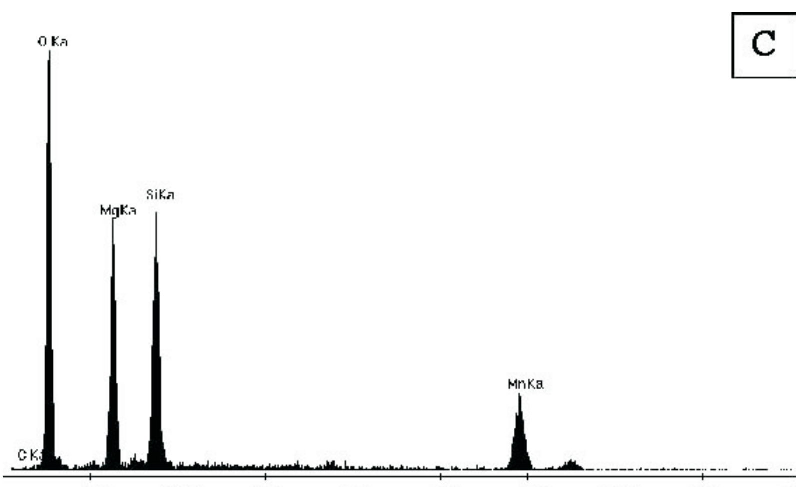
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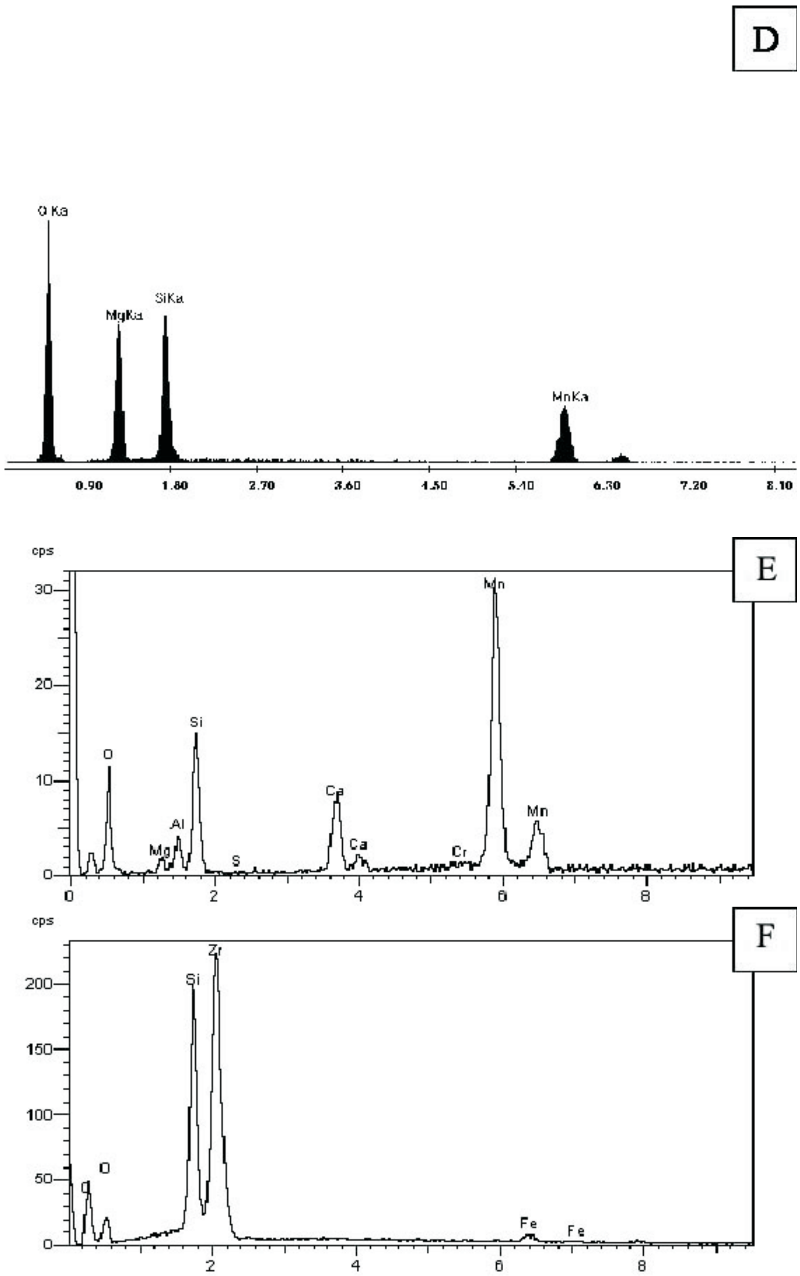

Fig. 6. Representative EDS spectra from the examined regions of defects present on the surface of steel castings – the regions of silica sand grains (A); the regions of oxide phases (B); complex oxide phases containing Mg from the coating (C, D); complex oxide phases containing Mg or Zr from the coating (E, F)

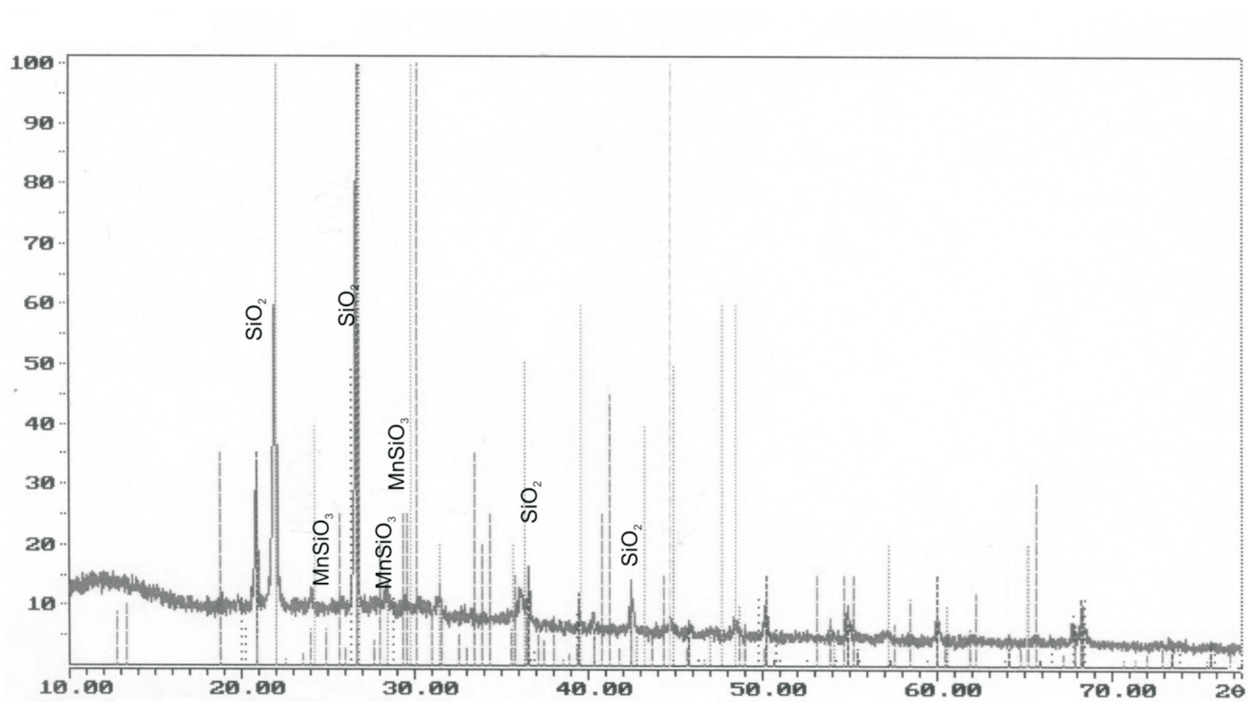

Fig. 7. An example of diffraction pattern from the region of surface defect [7]

The linear analysis of chemical composition carried out in the regions composed of oxide phases, adhering closely to the casting surface and penetrating into its interior, has revealed that they are characterised by different concentration levels of manganese and chromium. Some attention deserves the fact that the presence of chromium was recorded only in the areas lying on the side of the casting and only in the cast steel grades containing Cr [9,10].

4. Conclusions

From studies carried out so far, the following basic conclusions have been drawn:

1. The surface defects present in the examined castings are caused by an interaction that occurs between the molten metal and moulding sand constituents; the defects strongly adhere to the casting surface, have an irregular shape, and occur as single forms or in clusters.
2. In reactions taking place between the molten steel and bentonite moulding sand, oxidation of manganese and reaction between MnO and SiO_2 are of primary importance. The oxidation of Fe and Al plays the secondary part and occurs in further reactions proceeding between the molten steel and moulding sand.
3. Microscopic analysis of specimens taken from the examined defects has revealed strong heterogeneity of both structure and chemical composition. All the examined regions show the presence of SiO_2 grains and complex oxide phases; their chemical composition depends on the type of protective coating and the steel grade.
4. The main elements detected in the examined areas are Si, Mn, O, Fe and, though to a smaller degree, magnesium, present in all those cases when coatings based on this element were applied (castings made from Hadfield steel), or zirconium if coatings were based on this element (castings made from carbon and alloyed steel).
5. In the subsurface layers (the layers directly adjacent to the defect) of castings made from alloyed steel, the structure impoverishment in manganese and chromium was observed for Hadfield steel and Cr-Ni steel, respectively.

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