



ARCHIVES
of
FOUNDRY ENGINEERING

DOI: 10.1515/afe-2015-0086

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences



ISSN (2299-2944)

Volume 15

Issue 4/2015

91 – 94

The Sources of Surface Defects in Castings Produced in Automated Process Lines

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Received 30.04.2015; accepted in revised form 15.07.2015

Abstract

This study summarises the research efforts undertaken in iron foundry plants in which the process are mostly automated and mechanised. The research program was limited in scope, focusing on causes of surface defects in castings products that are attributable to the bentonite-containing sand and the mould system. One of the potential roots of surface defects is heterogeneity of sand grains, containing lumped ball-shaped grains and irregular pellets with a layered-structure. The moisture contents of those lumped grains is different than the moisture level required in the process, besides these grains may contain various elements and metallic compounds which, when cast into moulds, may react with molten metals in an uncontrolled manner. As a result, surface defects are produced, such as surface blowholes, burst penetration, sand holes, slag inclusions, pinhole porosity. This study investigated the efficiency of key sand preparation and moulding machines and installations integrated into the casting process line. The efficiency of machines and installations is defined in terms of quality parameters of sand mix and moulds, which are associated with the emergence of surface defects on castings.

Keywords: Surface defects, Sand mix

1. System analysis of the iron casting process

Mechanised and automated foundry mostly use the moulds made of synthetic sand with bentonite and rely on the wet casting method. With the advent of mechanised and automated systems, this technology is now predominant and recent studies show it is being further developed and improved because of its universal applications, good quality of castings and relatively low manufacturing costs when producing a wide assortment of castings. Another major advantage is the compliance with environmental regulations.

The process line for sand preparation incorporates the following systems [6]:

a) return sand line; beginning with the knocking-out through separation of metallic inclusions, screening, cooling and homogenisation to storage in containers over the mixers;

b) refreshed sand line; beginning with the weighing and dosing of used sand and refreshing agents, through mixing in mixers to sand aeration and transfer to sand hoppers over automatic core making machines and, finally, mould making;

c) sand-in-mould line; from pouring into moulds to knocking-out to separate the sand and core mix from the castings.

In each of these lines sand is processed to change its properties and parameters and its state of aggregation: lumpiness, grain size heterogeneity, temperature and moisture content. Key machines and installations include:

- screeners, used to separate the return sand into fractions;
- coolers, used to cool the hot knocked-out sand down to 30-14 °C to homogenise the values of major process parameters;
- mixers, used to mix sand components and control and adjust the sand parameters via the measurement and control systems;

These three groups of machines were considered in the study investigating the main causes of surface defects.

The sand preparation line is integrated with a mechanised or automated mould making and pouring system. In the mould making system, the manufacturing processes take place in foundry lines. Each foundry line incorporates an automatic mould making machine implementing the snap-flask or flask moulding processes, the conveyor system to carry the moulds to the pouring and cooling section and the knock-out machine. Main advantages of automatic mould making machines are: low labour demand, high quality of castings in terms of their shape and symmetry. The high quality of casts is associated with high quality of moulds, measured by uniformity of distribution of the sand compaction. As the distribution of sand compaction is a function of sand homogeneity when it enters the system, the study investigates the influence of the presence of sand lumps and pellets on quality, measured in terms of smoothness and roughness of inside walls of modelled moulds. Inside surfaces of moulds are in direct contact with molten metal and reproduce the castings' outside surfaces, which prompts the formation of surface defects.

2. Distinctive features of surface defects on iron castings

Surface defects on iron castings display some common features in terms of their main causes. Diagnostics, therefore, is targeted mainly on metal processing technologies and, in a lesser extent, on the mould making technology.

As regards metal processing technologies, the chemical composition of metals is analysed in the micro-scale and the defects on castings are compared with the reference atlas of iron microstructures. In terms of studies of sand mix with bentonite, the diagnostics is restricted to the description of defects and the impact of the sand mixing quality, though in general terms only.

According to the reports in literature [1], surface defects include:

- surface blowholes (Fig 1a) revealed in the surface as oblong or ball-shaped voids. Blowholes emerge due to the presence of gases trapped between the mould and the metal. These voids are often connected to slag or oxides. Blowhole formation is caused by too high moisture content in sand and large amounts of gases released from the lustrous carbon carriers.
- sand holes (Fig 1b), irregularly shaped inclusions located in the subsurface layer, often occurring in combination with CO bubbles and slag particles. The causes of sand holes include the excess number of pellets, non-uniform distribution of bentonite in the sand, excessive amount of non-active sand fractions.
- slag inclusions (Fig 1c), non-metallic inclusions with irregular shapes. The causes of slag inclusions are: formation of oxides which may react with the moulding sand or its components, non-uniform distribution of bentonite.

The examples discussed in the study and those reported in literature [2,3] clearly reveal that surface defects are mostly attributable to factors associated with sand quality.

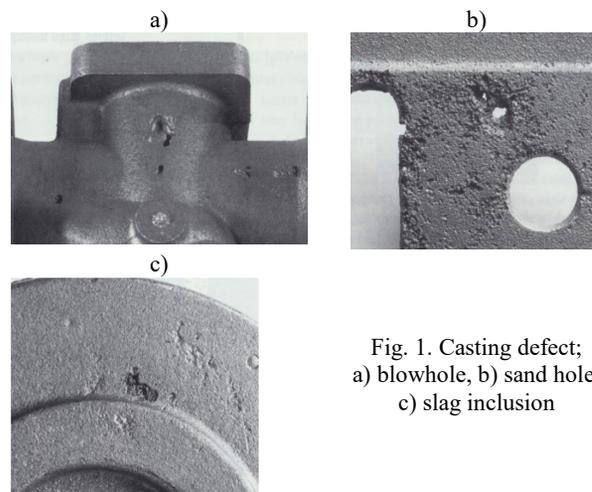


Fig. 1. Casting defect; a) blowhole, b) sand hole, c) slag inclusion

3. Industrial test results

Tests were performed to investigate surface defects in castings produced in an automatic foundry line implementing the snap-flask moulding process, with the vertical parting plane. The sand mix used in the test was prepared in the mechanised system incorporating a cooler and a turbine (rotor) mixer, in accordance with the process technology. Even though the process parameters of the sand (resistance, moisture content, permeability, compaction, roasting losses) were within admissible tolerance limits, its physical condition defined by the grain size distribution revealed the presence of large amounts of pellets and layer-structured flat bits. These bits were similar to plastic elements polished on one side. Separated (manually-screened) fractions differing in size are shown in Fig 2.



Fig. 2. Pellets in moulding sand

Defects identified on tested castings include surface blowholes, sand holes, slag inclusions and lustrous carbon inclusions (Fig 3). To establish the relationship between surface defects and sand heterogeneity, two types of tests were performed:

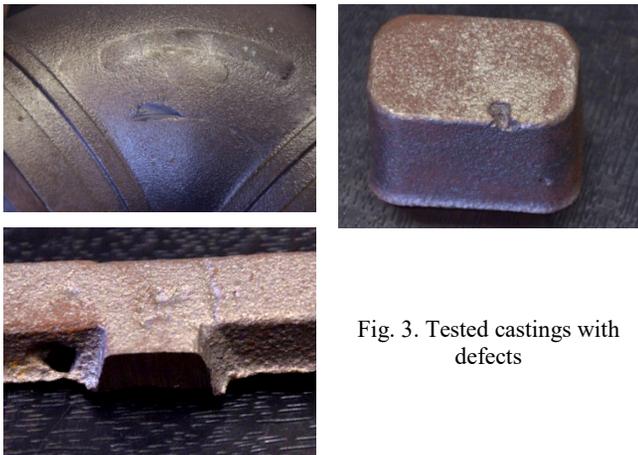


Fig. 3. Tested castings with defects

a) SEM and EDS analysis of chemical composition in the region in the blowhole defect and sand hole regions. Results obtained with the use of the Jeal 5000 LV microscope, shown in Fig 4, reveal the presence of ceramic particles containing such elements as: C, Mg, Si, Al., Ca, Fe, O and copper. There can be precipitates of enstatite, MgO, SiO₂ or forsterite 2MgO SiO₂ which also contain Al., Ca (inoculant) and carbon, probably graphite. These inclusions may be attributed to large proportions of spheroid home scrap in the melt. Other determinants include the quality of magnesium master alloy used for metal spheroidisation and the inoculant composition whose bath- insoluble components will be surrounded by oxides-silicates.

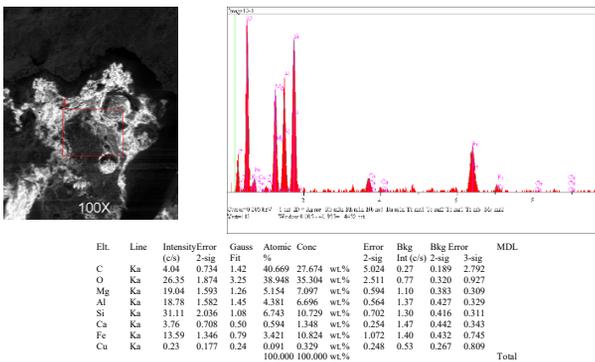


Fig. 4. SEM+EDS analysis of chemical composition in the regions of defect occurrence

b) Micro-analysis of sand in the form of layered-structured bits. Results are suggestive of the presence of montmorillonite grains in the moulding sand. Montmorillonite contains the elements Na, Ca and Fe, which are summarised in the SEM+EDS test data (Fig 5). It is reasonable to expect the occurrence of calcium carbonate CaCO₃ (and high Na contents) which react with molten metal forming CO₂ and giving rise to surface defects. Iron oxide in contact with molten metal also triggers the formation of defects.

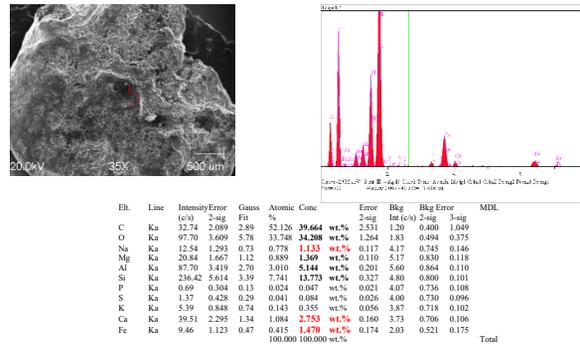


Fig. 5. SEM+EDS analysis of chemical composition of sand forming irregular lumps

c) Micro-analysis of (lumped) sand pellets. Results are shown in Fig 6. Sand pellets are formed in the consequence of processes occurring:

- after pouring into moulds, when sand undergoes thermal processes which are not uniformly distributed within its entire volume;
- in coolers; as the results of sand mixing and cooling in the added water atmosphere where adhesive sand components tend to agglomerate and stick to uncrushed solid grains from cores and to fine grains of the inoculant;
- in turbine mixers, as a result of insufficient crushing and grinding of clay binders in the entire volume of sand with the non-uniform grain size distribution.

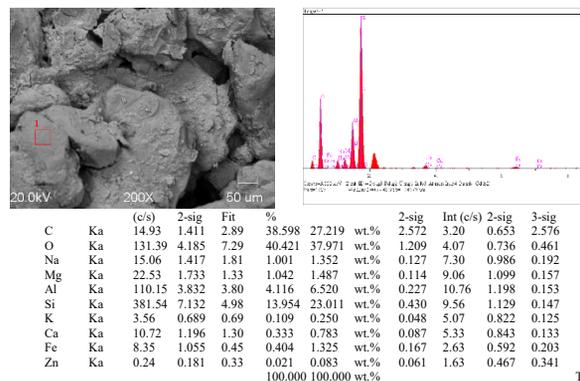


Fig. 6. SEM+EDS analysis of chemical composition of lumped mass (pellets)

Monitoring of sand preparation processes, particularly sand mixing in turbine (rotor) mixers has revealed the formation of solidified sand layers on the inside of the side surfaces and on the bottom of the mixer pan. This process is associated with the working condition of mixer units that scrape and handle the sand during mixing. In the consequence of fatigue wearing of scraping units or in the event of inadequate control, the sand scraping processes and self-cleaning of inside surfaces in the pan will be limited. As a result, sand layers stuck to the surface will further accumulate and then crack and break away, which leads to contamination and sand homogeneity tends to deteriorate. To

investigate the effects of sand heterogeneity on surface defects in castings, the sand pellets and heterogeneous bits of sand with a layered structure were analysed under the electron microscope. The results are shown in Fig 7 and Fig 8.

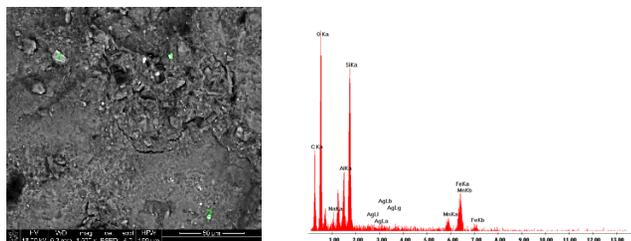


Fig. 7. Microscope analysis of sand pellets

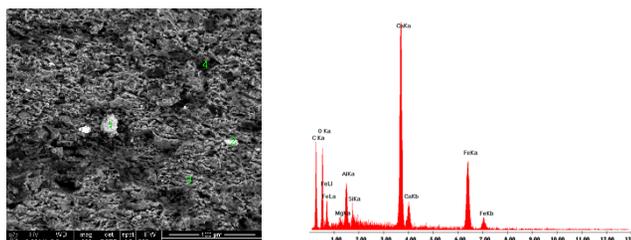


Fig. 8. Microscope analysis of layered lumps

Special attention was given to very high moisture contents in sand lumps, approaching 8.5% whilst the process requires 3.2-3.4% moisture content in sand with homogeneous structure. Such high moisture content gives rise to the blowhole process, i.e. water evaporation process at spots where the stream of molten metal flows at a higher rate or when the flow profile is changed. Blowhole defects tend to appear mostly in highly compacted moulds. Comparison of results obtained for casting and sand samples reveals a high degree of correspondence as regards the occurrence of particular elements, giving us a better insight into the defect formation mechanism.

3. Conclusions

The study investigating the causes of surface defects reveals the sand mix and mould making technologies to be the key factors. During those processes the properties, parameters and the physical state of sand are changed in subsequent stages of sand mixing, treatment, and mould-making and pouring metals in moulds. These processes take place in machines and installations integrated into specialised process lines. The functional feature of the machine or device is the first consideration, and it is the resultant of the engineering design, effective use of mechanisms and control devices with the specified operational parameters and capacity. Machine operation involves its use and maintenance procedures. Of particular importance is machine operation aimed at maintaining its full capability such that the sand quality requirements should be met. Sand quality is as required for the process when its parameters fall within the admissible levels, it is homogenous, free from lumps and bits which may trigger the occurrence of surface defects.

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