

QUALITY CONTROL IN FOUNDRY AND ANALYSIS OF THE DEFECTS

Jatoth Ramachander

HOD & Assistant Professor of Mechanical Engineering, S.V. Engineering College, Suryapet.

ABSTRACT

Quality can be perceived in accordance with requirements, customer needs. It, in return, implicates necessity of verification of this accordance, i.e. quality inspection. And that means how, on the ground of this inspection, to improve quality of articles and services. To speak about possible usage of repairing methods in firm, it is necessary to mention exact qualifications of criteria usage of quality improvement tools. Separations of quality criteria take place to investigate all spheres of formation and usage of products: preproduction, production and after production phase. Casting defects can negatively impact the bottom line of a foundry. At the simple level, they manifest as rework costs or casting scrap costs. However, in many cases, the casting defects may be discovered at the machining stage, at the assembly stage or during use of the component. The resultant value added costs and warranty costs may sometimes be passed on to the foundry by their customer. In this paper the most common foundry defects in three kinds of castings are analysed. It was observed quantity of defected castings and kinds of defects in the castings during the year. The attention was paid to sand inclusions and factors that can influence the sand inclusions origin.

Keywords: *foundry, integrated management system, casting defects, sand inclusion*

I. INTRODUCTION

Foundry industry owing to its complex character of producing operations has specific place in proposals of management systems. Foundry production process consists of preparation of moulds and moulding mixtures, preparation of liquid metal, casting, cleaning of castings, thermal and surface treatment of castings. Besides quality management each step has its marked response to problems of environment and to problems of safety and risk. From this follows it is necessary for foundry plants to introduce, keep and develop all three management systems. As most of the foundry factories are small or medium – size plants, it is substantial for them to create such system that is less cost and administration pretentious: integrated management system.

Quality of production, protection of environment, safety and protection of health in working conditions are integral part of modern management systems. Integrated management system is the system that integrates management systems into one continuous system enabling to reach determined goals and mission.

Casting defects can negatively impact the bottom line of a foundry. At the simple level, they manifest as rework costs or casting scrap costs. However, in many cases, the casting defects may be discovered at the machining stage, at the assembly stage or during use of the component. The resultant value added costs and warranty costs may sometimes be passed on to the foundry by their customer. These charges may be

significantly more than the cost of the casting itself. Foundry personnel may not have the time to conduct a detailed casting defect analyses, determine root causes and implement effective corrective actions to prevent re/occurrence of these defects. Elementary tools of quality assurance serve to assembling operating data about production process. It can be said, that these tools are methods to observe and diagnoses production process. Their meaning comes from the fact, that without honest and full information's about process it is difficult to speak about undertaking whatever efficient activities in management.

In this paper is given a proposal for Integrated Management System – Quality Management System in foundry an example of continuous improvement process in iron and steel foundry: research of casting defects occurrence in iron and steel castings

II. METAL CASTING INDUSTRY PROCESS

Foundries produce ferrous and non-ferrous metal castings. Ferrous castings comprise iron and steel, while non-ferrous castings primarily include aluminum, copper, zinc, lead, tin, nickel, magnesium, and titanium. Castings are produced by melting, pouring, and casting the ferrous and nonferrous metals. Many foundries cast both materials.

Many different casting techniques are available. All involve the construction of a container (mold) into which molten metal is poured. Two basic casting process subgroups are based on expendable and nonexpendable mold casting.

- Expendable mold casting, typical to ferrous foundries although also used in non-ferrous casting, uses lost molds (e.g. sand molding).
- Non-expendable mold casting, adopted mainly in non-ferrous foundries, uses permanent molds (e.g. die-casting). Lost molds are separated from the casting and destroyed during the shakeout phase, while permanent molds are reused. A variety of techniques are used within these two mold casting processes depending on the melting, molding and core-making systems, the casting system, and finishing techniques applied.

A typical foundry process includes the following major activities: melting and metal treatment in the melting shop; preparation of molds and cores in the molding shop; casting of molten metal into the mold, cooling for solidification, and removing the casting from the mold in the casting shop; and finishing of raw casting in the finishing shop. Different types of melting furnaces and metal treatments are used to produce ferrous and non-ferrous materials depending on the type of metal involved. Cast iron is typically melted in cupola furnaces, induction furnaces (IF), electric arc furnaces (EAF), or rotary furnaces. Cast steel is typically melted in electric arc furnaces or coreless induction furnaces. Cast steel metal treatment consists of refining (e.g. removal of carbon, silicon, sulfur and or phosphorous) and deoxidization depending on the charge metal and required quality of the casting product.

Before metal casting can take place, a mold is created into which the molten metal will be poured and cooled. The mold normally consists of a top and bottom form, containing the cavity into which molten metal is poured to produce a casting. The materials used to make the molds depend on the type of metal being cast, the desired shape of the final product, and the casting technique. Molds can be classified in two broad types:

- Lost molds (single use molds).

- Permanent molds (multi-use).

Pouring the melted metal is the most significant activity in the casting process. Different pouring systems are used depending on the mold and metal type used for casting. The mold can be filled with the liquid metal by gravity (lost mold) or by injection under low pressure or high pressure (diecast) or by centrifuga forces. A pouring furnace is often utilized in automatic casting lines. After pouring, the casting is cooled to allow for solidification (first cooling) and it is then removed from the mold for further controlled cooling (second cooling). In sand casting foundries, sand castings enter the shakeout process to remove the mold after solidification.

All remaining operations necessary to yield a finished produkt are conducted in the finishing shop. Depending on the process used, different steps may be required such as removal of the running and gating system, removal of residual molding sand from the surface and core remains in the casting cavities, removal of pouring burrs, repair of casting errors, and preparation of the casting for mechanical post-treatment, assembly, thermal treatment, coating.

III. INTEGRATED MANAGEMENT SYSTEM IN FOUNDRY

Concept of integrated management system is based on compatibility of principles of management systems set by the standards ISO 9000:2000, ISO 14000:2000 and OHSAS 18001:1999. Discussion in Committee TC 176 resulted in the change: in present not integration of the standards is considered, but their compatibility and possibility of “combination” is discussed. Because the organizations use different ways of management systems, applications and each organization has its own history of introduction and development of the systems, its unique environment, workers, culture of the organization, different forms of the management systems exist in different organizations. It is the reason why no “the best method” of combination or integration exists. Integration rate will depend on complexity of present management level also on will to integrate. In following text fully integrated model is discussed.

Close ties exist among three management systems, though each of them is focused on different aim:

- Quality management system – fulfillment of customer needs.
- Environment management system – protection of environment and public.
- Management of safety and health protection system - protection of employees.

The compatibility of systems ISO 9000 and ISO 14000 is explicitly defined in point 0.4 of the ISO 9001, where is possibility for organization to harmonize or integrate its own quality management system with requirements of related system. Though the standard ISO 9001 does not contain all requirements specific for the other management systems, the organization can adjust its quality management system (ISO 9001:2000).

A lot of similarities exist among the three above mentioned systems:

- Control of documentation and records.
- Commitment of organization’s management.
- Orientation to customer.
- Politics and goals of the management.
- Responsibility, authority, communication.
- Management representative.

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- Management review.
- Providing of sources (human, financial, material, information).
- Competence, education and training.
- Metrology.
- Internal audits.
- Monitoring and measurement.
- Corrective and preventive actions.

For establishment of effective and operative integrated management system, following requirements must be met:

- Integrated management system and his principles must be included in all documents of the organization.
- Responsibilities and authorities must be defined.
- Entry audit for evaluation of present state.
- Strategy, policy and goals for quality, environment, safety and health protection must be defined.
- Improvement programs for significant risks must be worked out.
- Internal audits of integrated management system must be planned and realized.
- Corrective actions must be defined.

IV. ANALYSIS OF CASTING DEFECTS

Quality can be perceived in accordance with requirements, costumer needs. It, in returns, implicates necessity of verification of this accordance, i.e. quality inspection. An means how, on the ground of this inspection, to improve quality of articles and services. To speak about possible usage of repairing methods in firm, it is necessary to mention exact qualifications of criteria usage of quality improvement tools. Separations of quality criteria take place to investigate all spheres of formation and usage of products: preproduction, production and after production phase. Each of these phases is characterized by occurrence a sequence of information about quality, quality features evidenced in certain forms. Result assembled criteria of production can be used for effective application of different kinds of analytic tools.

Casting defects can negatively impact the bottom line of a foundry. At the simplest level, they manifest as rework costs or casting scrap costs. However, in many cases, the casting defects may be discovered at the machining stage, at the assembly stage or during use of the component. The resultant value added costs and warranty costs may sometimes be passed on to the foundry by their customer. These charges may be significantly more than the cost of the casting itself. Foundry personnel may not have the time to conduct a detailed casting defect analyses, determine root causes and implement effective corrective actions to prevent re/occurrence of these defects. Elementary tools of quality assurance serve to assembling operating data about production process. It can be said, that these tools are methods to observe and diagnoses production process. Their meaning comes from the fact, that without honest and full information about process it is difficult to speak about undertaking whatever efficient activities in management.

For the characteristic criterion of quality level measuring it assumed quantity of defects in one year. The first step of analysis is the assessment of process by means of Ishikawa's diagram, Fig: 1. Ishikawa' s diagram - diagram of cause and effect, or "fish bone" diagram - makes possible identification of sources of problems

formation, helps quality a sequence of causes of non-conformance's in following stages: researches, diagnosis and choice of therapy and makes easy problem solution.

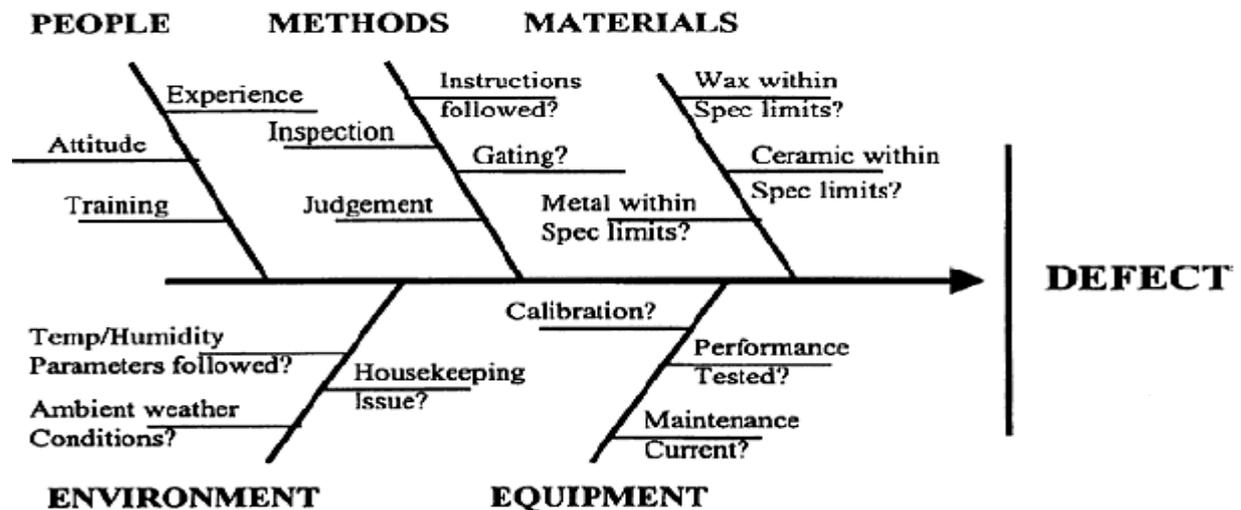


Fig: 1 Part of Ishikawa's diagram for problem of non-conformances formations in process of pouring casting articles.

Ishikawa's diagram makes possible choice of five main areas which are responsible for failures formation. These areas are: accepted technology – in investigated firm casting is realized by means of sand mould with partly automat zed production-line and by manual pouring of mould; this technology, as every other, possesses its own advantages and defects which are responsible for formation of foundry defects, man-qualifications, experience of workers, engagement in works which in significant manner influences final product quality, machine – outfit and its defectiveness, ease of use etc., environment – conditions of work, variability of temperatures and other factors which influence process, material – used raw material on mould, and patterns making and also pig iron casting – and its chemical composition. Part of Ishikawa's diagram (and more exactly speaking – one of higher cited areas) is represented on Fig: 1. Represented diagram shows only a little part of the graph, which in reality is more complicated.

V. THE MOST COMMON CASTINGS DEFECTS

Several types of defects may occur during casting, considerably reducing the total output of castings besides increasing the cost of their production. It is therefore essential to understand the causes behind these defects so that create a deficiency or imperfection contrary to the quality specifications imposed by the design and the service requirements. Defects in castings may be of three basic types:

- Major defects, which cannot be rectified, resulting in rejection of the casting and total loss.
- Defects that can be remedied but whose cost of repair may not justify the salvage attempt.
- Minor defects, which clearly allow the castings to be economically salvaged and thereby leave a reasonable margin for profit. Broadly, the defects may be attributed to.
- Unsuitable or unsatisfactory raw materials used in moulding, core making or casting.
- The application of unsatisfactory moulding or casting practice by the individual worker or incorrect advice by the supervisor.

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- The use of improper tools, equipment, appliances, or patterns, and
- Unprofessional management policies procedures, faulty organization and poor work discipline, or lack of training.

Under practical circumstances castings, like all metallurgical products, contain voids, inclusions and other imperfections which contribute to normal quality impairment. Such imperfections begin to be regarded as true defects only when the satisfactory function or appearance of the product is in question. In such cases, the possibility of salvage, if worse, rejection and replacement should be considered. The decision should be based upon not only the defect itself but also upon the significance in relation to the service function of the casting and the quality and inspection standards being applied.

A defect may arise from a single clearly defined cause which enables the remedy to be more specific and straightforward. It may, however, result from a combination of factors, so that the necessary preventive measures are more obscure. All men are familiar with the persistent defects which defy explanation and finally disappear without clarification of its original cause. Close control and standardization of all aspects of production technique offers the best protection against such troubles. More specific precautions can be taken in those cases where there is a known susceptibility to a particular defect, while the radical approach of design modification may need to be considered in the extreme cases which do not respond to changes in foundry technique. Defects can, above all, be minimized by a clear understanding of their fundamental causes.

One of the most common defects in castings are inclusions, which can be found on the casting surface or inside the casting. Some inclusions have the shape of compact particles, while other inclusions form thin films but of large surface dimensions. Some inclusions are separate particles, whereas other inclusions agglomerate into compact clusters. Some inclusions are not bonded to the alloy microstructure and others concentrate in intergranular spaces. Depending on all this, the negative effect of inclusions can manifest itself in various ways. Deterioration of casting surface quality – inclusions are detrimental in that they impair the appearance of the casting surface and in those large inclusions (particularly those formed in steel re-oxidation) reach deep into the casting. Removing such defects is expensive and, moreover, it requires considerable machining allowance. As a consequence of the inclusions reacting with the mould material, both the amount of burned-on sand and the surface roughness can increase.

Deterioration of mechanical properties – an inclusion is a foreign particle that interferes with the metal matrix. Inclusions make the mechanical properties deteriorate, in particular ductility and fatigue strength. Considerably reduced is mainly the low-cycle fatigue strength. Apart from the quantity of inclusions, the significance of this effect depends on the volume and the shape of inclusions. Inclusions that form films have an adverse effect. They damage large areas of the metal structure and they also cause the notch effect. A very negative effect is inclusions that form a network along the grain boundaries, inclusions that are arranged in lines, and inclusions with sharp edges.

VI. DESCRIPTION OF CASTINGS AND CONDITIONS OF THEIR PRODUCTION

An example of foundry defects was made for research period of one year – in 2016 in foundry producing cast iron (grey and nodular cast iron) and steel castings. Occurrence of casting defects was observed by production of 3 types of castings:

- Bearing plate,
- Cylinder,
- Chucking head.

VII. BEARING PLATE

Two pieces of bearing plate with raw weight of 39,5 kg in one moulding flask were poured. Pouring temperature was 1480 - 1530°C. Castings were made from Hadfield steel. Sand mixture type ZM-I was used. Its properties were in the next limits:

Compression strength	100 – 170 kPa
Venting property	400 – 700 j.P.
Sand temper	3.15%
Medium grain	$d_{50} = 0.5$ mm
Active bentonite	6 – 7.5%
Ramming property (ability)	47 – 53%

VIII. CYLINDER

Eight pieces of castings were poured in a moulding flask with raw weight 37 kg, pouring temperature was 1310 - 1360°C, raw weight of one casting was 4,625 kg and gross weight was 2,80 kg, pouring time was 11 s. A core was made in metal core box by hand and its weight was 0,70 kg. Casting material was STN 422420 LLG (Grey cast iron). The sand mixtures ZJED was used. Its properties were followed:

Compression strength	130 - 220 kPa
Venting property	150 – 350 j.p.
Sand temper	3,25%
Medium grain	$d_{50} = 0,5$ mm
Active bentonite	6 – 8%

IX. CHUCKING HEAD

Ten pieces of castings were poured in the moulding flask with raw weight 27 kg, pouring temperature was 1430 - 1480°C, raw weight of one casting was 2,7 kg and gross weight was 1.9 kg, pouring time was 9 s, the casting was without core. The sand mixture was the same like by cylinder. Casting material was STN 42 2304 (nodular cast iron).

Melting

Two basic electric arc furnaces (type IHF –JA) with loose cover with capacity of 3 tones were used for melting. Furnace input was 2, 2 MW and frequency 50 MHz. Furnaces were lined with basic magnesite or chromiummagnesite brickwork. Furnace cover was from chromium – magnesite shaped pieces and bricks.

A charge into the electric arc furnace depends on the kind of molten metal. The base of the charge for the cast iron was cast iron scrap and for the steel it was steel scrap and flux material. Steel was produced in two steps. The first step was oxidation period in which C, Si, Mn and P were oxidized, after slag treatment and alloying the

reduction mixture was added. After chemical and thermal homogenization the metal was poured into the moulds. By cast iron production the charge was melted and after chemical composition treatment an inoculation was made in the ladle (by nodular cast iron production, the inoculation and modification were made in the ladle).

Moulding and pouring

Moulds production was made on moulding line AFA -20, AFA – 30, AFA – 40, jar rammings was made with repressing. Moulding mixture contained bentonite (KERIBENT 30) and opening material contained new sand Š22ŠH Šajdíkové Humence and regenerated sand. Pouring temperature was depended on casting material and on wall thickness. Slagging off and pouring was made to 20 minutes from the tapping because of access time effect. Moulding flasks with dimensions 700x600x180/140 mm (width x length x height upper flask/height bottom flask) were used for forming.

X. OCCURRENCE OF FOUNDRY DEFECTS IN FOUNDRY DURING THE YEAR 2010

During the year 2010 34 melts of nodular cast iron were made. Number of poured castings was 19 079 pieces and number of defect castings were 2838 pieces – it is 14,875%. Fig: 2 is Pareto – Lorenzo diagram for occurrence of defect on chucking head castings. Usage of Pareto – Lorenzo analysis is often the first step in process of analyzing assembled data about failures. Causes and effects are aligned in descending order and as cumulating amounts. It permits in final effect to identify little amount of causes, with develop and results.

On the base of Pareto – Lorenzo analysis, Fig: 2, it is identified, that more than 50% of all observed defects depend only upon 2 problems (sand inclusions more than 30% and discreteness of metal more than 20%). During the year 2010 the castings "cylinder" were poured only from 14 melt. Number of castings – cylinder was 4400 pieces, defect castings were 276 pieces (6.216%). More than 50% of all defects of castings were sand inclusions, Fig: 3.

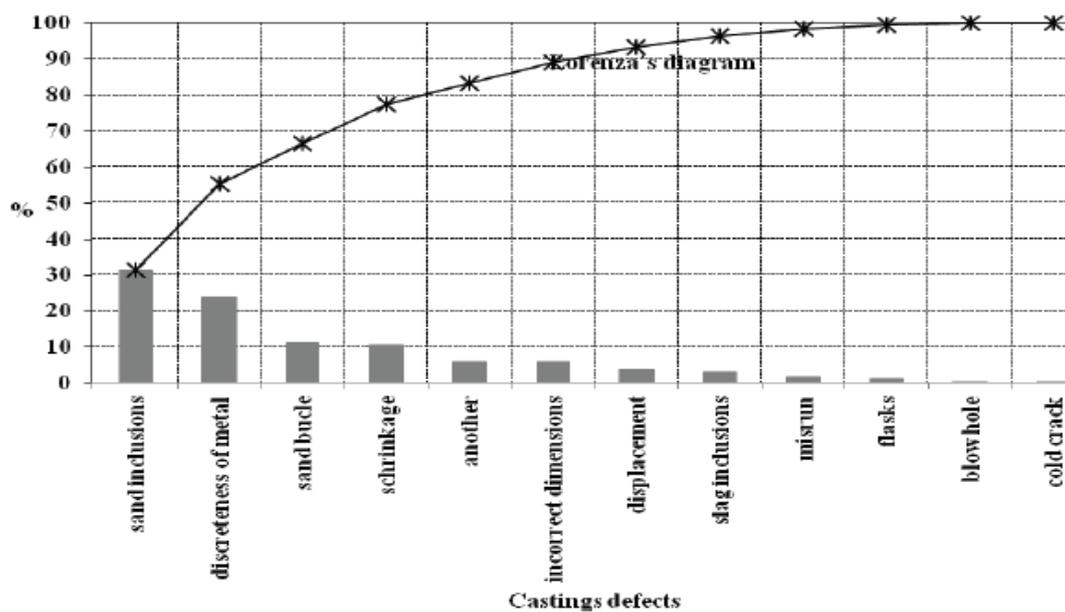


Fig: 2 Pareto-Lorenzo diagram for year 2016 “chucking head”. 23027 pieces of castings – bearing plate - were made in year 2016.

Number of defect castings was 749, it is 3.2%. Fig: 4 show that more than 50% of all defects are discreteness of metal and sand inclusions. From the analysis of occurrence of castings defects in foundry produced steel and cast iron castings follows, that the most occurred castings defects were sand inclusions, then discreteness of metal and misruns. The most occurred castings defects are sand inclusions. They are cavities or surface imperfections on a castings caused by sand washing into the mould cavity. They are non-metallic oxides. They come from disintegrated portions of mould or core walls and/or from oxides (formed in the melt) which have not been skimmed off prior to the introduction of the metal into the mould gates. Careful control of the melt, proper holding time in the ladle and skimming of the melt during pouring will minimize or obviate this source of trouble. Fig: 5 shows defect castings with sand inclusions.

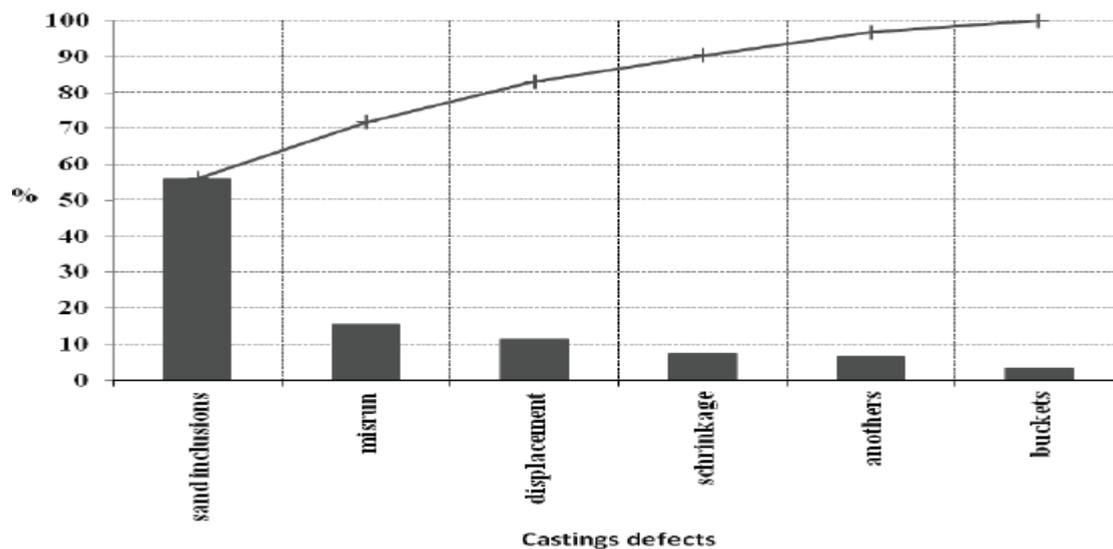


Fig: 3 Pareto-Lorenzo diagrams for year 2016 “cylinder”.

Sand inclusions are one of the most frequent causes of casting rejection. It is often difficult to diagnose, as these defects generally occur at widely varying positions and are therefore very difficult to attribute to a local cause. Areas of sand are often torn away by the metal stream and then float to the surface of the casting because they cannot be wetted by the molten metal. Sand inclusions frequently appear in association with CO blowholes and slag particles. Sand inclusions can also be trapped under the casting surface in combination with metal oxides and slags, and only become visible during machining. If a loose section of sand is washed away from one part of the mould, metallic protuberances will occur here and have to be removed.

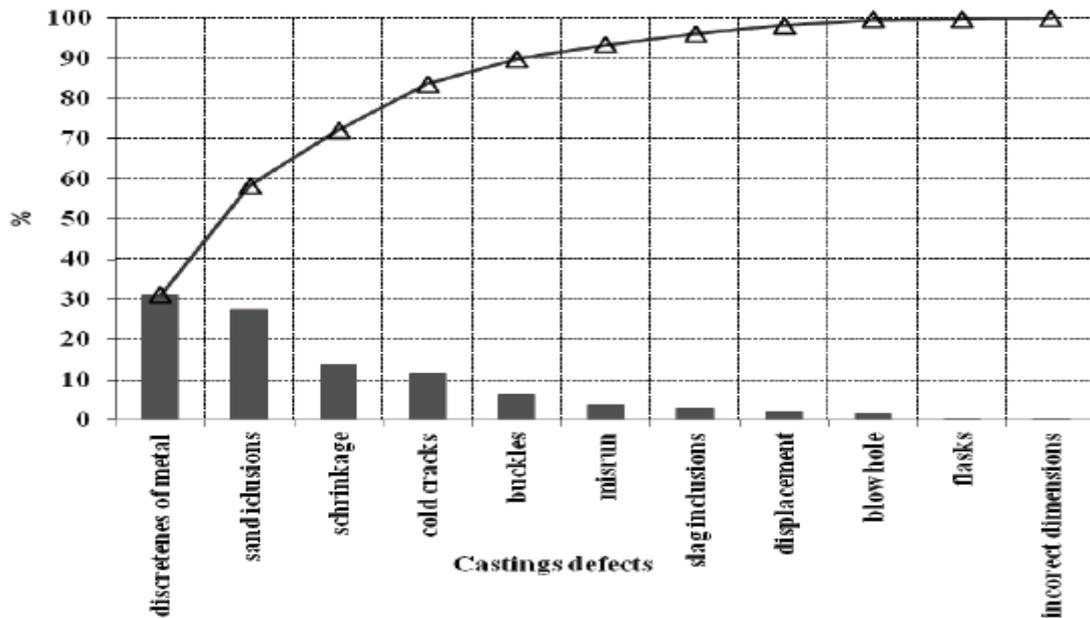


Fig: 4 Pareto-Lorenzo diagram for year 2016 "bearing plate".

Sand is normally generated within the mould, loose sand around the downsprue or erosion of sand if the metal is dropping a large distance onto sand at the bottom of the sprue. Sharp corners are also a common cause of sand erosion. Care should be taken to blow loose sand from the mould during the assembly of the mould and frequent examination of pattern plates in horizontal moulding machines should be made to ensure that nothing is sticking to the plate. Sand can be distinguished from slag in that has a single phase and the sand grains are relatively regular shape.



Fig: 5 Castings with sand inclusions.

Sand inclusions are a common macro defects in foundry castings and can be caused by:

- Loose sand that is emulsified during steel pouring into the mould ,
- Erosion of packed or loosely bonded sand under areas of turbulent stream contact with the mould,
- Corrosion of mould due to the combination of a turbulent stream and reoxidation,

- Corrosion of the mould due to steel chemistry issues, exacerbated by high pouring temperatures and high mould preheats.

In general all casting and pattern design factors which lead to concentration of fluid flow and local turbulence will lead to erosion problems. The use of coating materials which promote wetting of steel will lead to easy impregnation of the steel into the coating and the potential for separation of the coating. The use of moulding sands with poor physical properties, which react with the steel, which have low fusion points or are wet can lead to large sand based macro-inclusions.

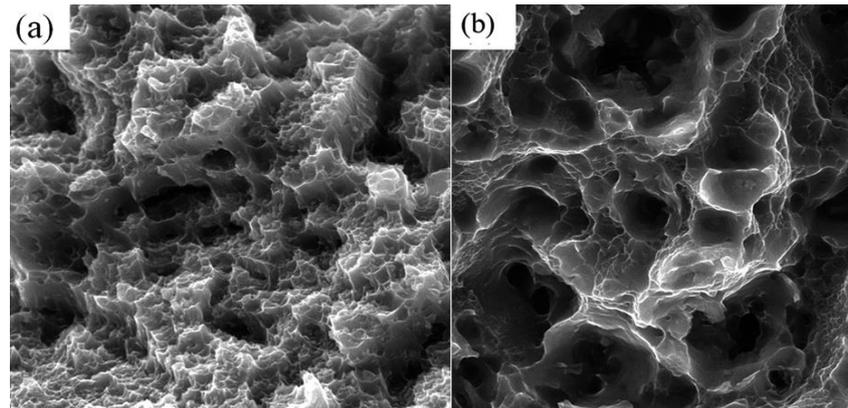


Fig: 6 (a) Sample taken from defect casting and (b) chemical analyze of grain.

Sand inclusions can be identified visually, Fig: 5. but microscopy analysis is necessary. Fig: 6a shows sample taken from the defect casting and analysis of grain shows that it contains SiO₂. Fig: 6b shows boundary line between sand and basic material (nodular cast iron) and its chemical analysis. Metal flowing into the mould cavity can detach sections or individual sand grains from the mould during pouring, and transport them to remote parts of the casting. Portions of the gate are often carried away through erosion. This leads to sand inclusions in the proximity of the gate of the casting. Measures required counteracting this are any of those which increase the resistance of the mould to erosion.

Edge disintegration results in whole sections of the mould being carried into the casting during pouring. Edge disintegration arises during moulding, during assembly of the moulds, during core-setting and, above all, when the sand has insufficient plasticity. Torn out areas of the mould cannot be visually detected and, during pouring, frequently cause disintegration of whole sections.

XI. ANALYSIS OF FACTORS INFLUENCING OCCURRENCE OF CASTINGS DEFECTS

A lot of factors influence on occurrence of castings defects. Pouring temperature, quality of sand mixtures and quality of moulding are the most important factors. Meteorological influences (humidity and aerial temperature) were observed too.

Different defects on the castings were found during the experiments, but the most often occurred defects were: sand inclusions, misruns and discreteness of metal. Other defects like shrinkages, sand buckles etc. were not evaluated because of lower frequency. Air temperature and humidity are factors that can influence the occurrence of sand inclusions in iron alloys castings. There were compared average air temperatures and average humidity (average value was done from temperatures and humidity only in days when our three types of castings were poured) with average frequency of sand inclusions incidence, discreteness of metal occurrence

and total quantity of damaged castings in given month. Fig: 7 and Fig:8 shows air temperature and air humidity course and occurrence of sand inclusions.

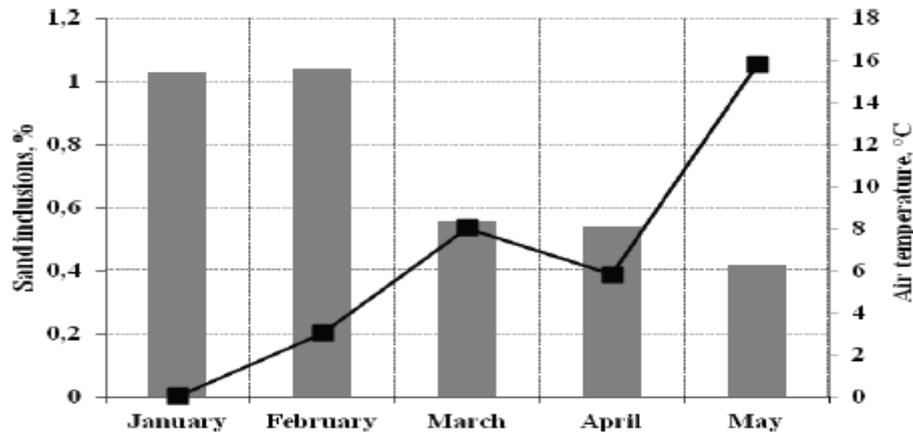


Fig: 7 Air temperature and average occurrence of sand inclusions during 5 months.

Average occurrence of sand inclusions in castings “bearing plate” and average temperature in the months January – May are showed in Fig: 7. Fig: 8. shows an influence of average air temperature on occurrence of sand inclusions. There is visible decreasing occurrence of sand inclusions by increasing of air temperature.

During the winter months the occurrence of sand inclusions was twice higher than during next three months. Influence of air temperature on the occurrence of sand inclusions is evident in Fig: 8. Influence of air temperature on other castings defects was not registered, in spite of decline in sand inclusions occurrence the total quantity of defect castings didn’t have the same trend.

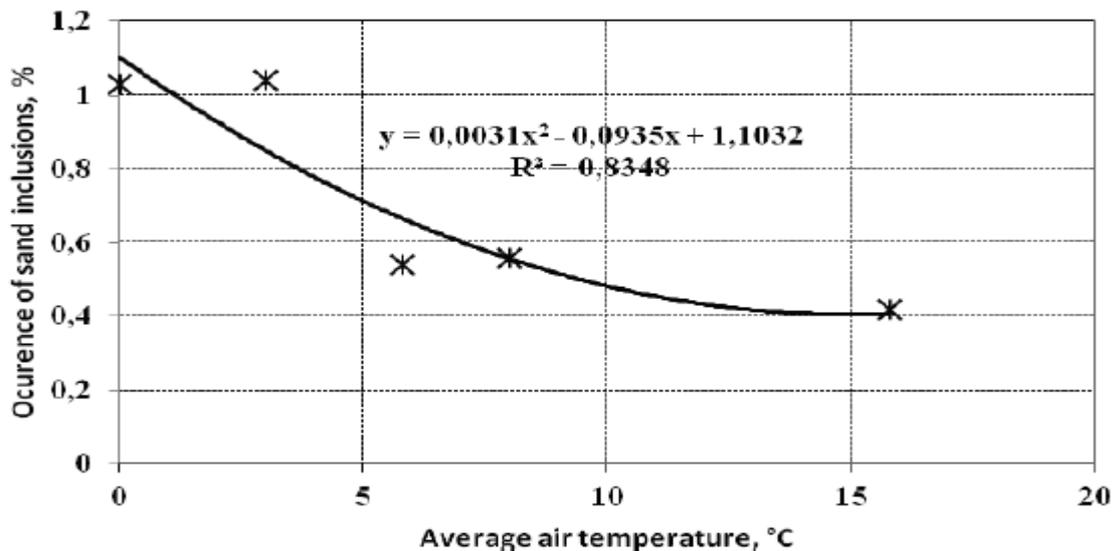


Fig: 8 Influence of average air temperature on the occurrence of sand inclusions.

Fig: 9 shows air humidity course and occurrence of defect castings during the period January to May. Higher humidity caused the higher occurrence of defect castings. Pouring temperature is one of technological parameters that can influence the occurrence of defect castings. The clearest influence of this parameter on occurrence of defect castings was observed by bearing plate production. By pouring of metal with temperature

1550 – 1570°C the highest number of defect castings was observed. By higher temperatures the number was less than 10%.

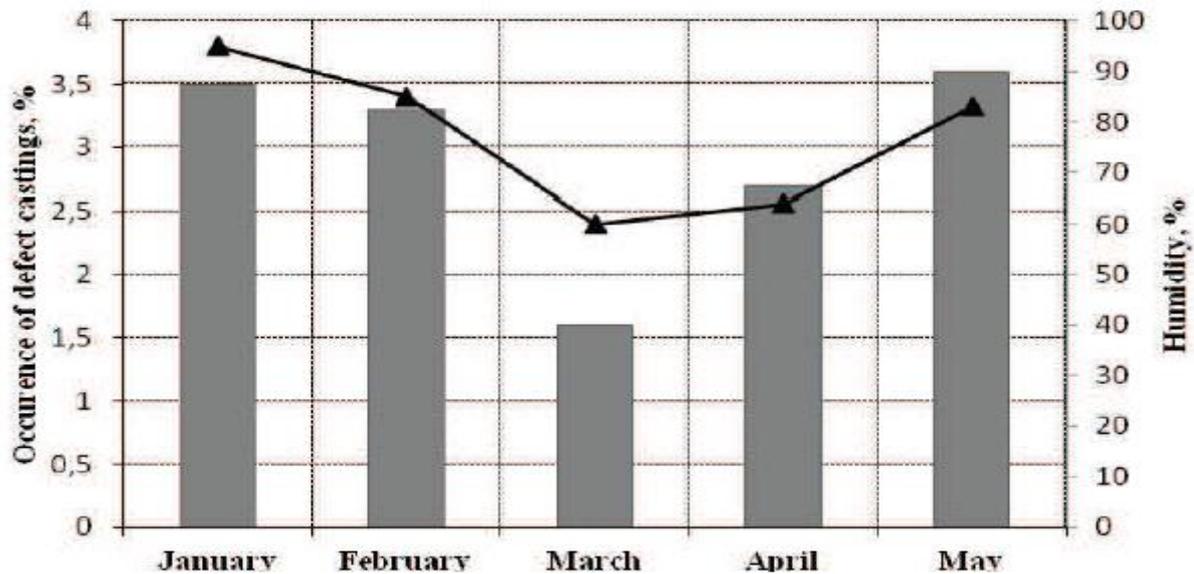


Fig: 9 Air humidity course and occurrence of defect castings during 5 months

Opposite influence of pouring temperature was determined in the occurrence of sand inclusions. Negative influence of higher pouring temperature on occurrence of sand inclusions was observed by castings cylinder and chucking head. Number of cold shuts descends with higher pouring temperature. Influence of pouring temperature on other castings defects was not found.

Sand mixtures properties and moulding process play a very important function by production of good castings. Influence of followed sand mixtures properties on occurrence of defect castings and sand inclusions were observed: compression strength, venting property and sand temper. Visible influence of sand temper of sand mixture on the number of defect castings and occurrence of sand inclusions was observed only for casting cylinder. The lowest number of defect castings and castings with sand inclusions was observed by sand temper 2.8 – 3.4%. Influence of compression strength on number of defect castings and sand inclusions was found by castings “chucking head” and “cylinder”. Compression strength rise affected a decline of number of defect castings.

XII. SUMMARY

Working process in iron and steel foundry consists of many different interconnected steps, many different technologies and their variations. A few types of casting defects are presented in the chapter. One of them, the sand inclusions in the castings, was selected for study. As can be seen from Pareto’s diagrams included in the Thesis, the sand inclusions are one of the most occurring defects.

What are the reasons of sand inclusions occurrence? The first one is the quality and the parameters of moulding and core mixtures. Number of the defects was affected by temperature and humidity of ambient air, both in store yards and in moulding mixture preparation shop. Consequently, it is reflected in moisture content of silica sand and moulding mixture. This fact can affect the quality of moulding and core mixtures and their prone to

disintegration by molten metal flow. The second one is complicated design of the cavity in the mould, containing thin walls, profiles, runners. From this fact follows the necessity to design parameters of moulding mixtures from the mould complexity point of view.

The third one is chemistry and pouring temperature of molten metal. Viscosity of poured metal is extremely important. It is clearly visible from Pareto diagrams in the Thesis, when sand inclusions are the main defect in castings made from iron, but not from Hadfield steel. Close control of pouring temperature is substantial to avoid or at least decrease the number of sand inclusions in iron and steel castings.

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