Vol. 02, No. 4 (2020) 353-360, doi: 10.24874/PES02.04.002

Proceedings on Engineering Sciences

www.pesjournal.net

APPLICATION OF ISHIKAWA DIAGRAM TO INVESTIGATE SIGNIFICANT FACTORS CAUSING ROUGH SURFACE ON SAND CASTING

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Keywords:

Castings defects; Rough surface; Ishikawa diagram; Foundry Tools; Foundry Processes.

A B S T R A C T

This paper discusses the identification, mechanism and causes for the rough surface defect on the sand castings. In foundries raw materials are transformed into finished casting using many intermediate processes like pattern making, moulding, core making, melting and fettling. It is very difficult to control all these processes due to the involvement of lot of people and materials. It is always a challenging task for the foundrymen to produce quality castings with good surface finish consistently. Generally rough surface on casting may occur due to a single cause or a combination of causes. Hence, identification and finding the root causes for rough surface defect are important to prevent its occurrence further. The possible causes for rough surface defect involving the foundry tools and processes are presented as cause and effect diagrams. The main outcome of this paper is to investigate the significant factors causing this defect and to prevent it on the castings.

1. INTRODUCTION

Generally a lot of processes are used to produce moulds and cores. Among these processes sand continues to be the most widely used as a moulding medium. Moreover seventy percent of the castings are produced by sand moulding processes (Vijayaram et al., 2006). At the beginning of the casting production, the foundrymen carefully study the required specifications, mechanical properties and the standards in which the testing are to be done. Mariajayaprakash et al. (2013) applied the Ishikawa diagram to identify the process parameters affecting the quality characteristics of the shock absorber during the process. The authors of this paper reported that the Ishikawa diagram is used to identify the possible causes which affect the quality of the shock absorber. Tegegne & Singh. (2013) have used Ishikawa diagram to analyze and find the root cause of burn on problem of the manganese-silicon alloy medium carbon steel shaft. They discussed elaborately the major factors causing the rough surface on the castings and finally concluded that this defect can be controlled by choosing an appropriate gating system, selecting the suitable reclaimed sand and providing proper mould ramming. Przystupa (2019) has discussed the various quality assurance methods especially on the hazards and potential product defects occurred in food processing. The main focus of the paper is to find the solutions related to automotive food processing industry. He analyzed the different causes of the defects and hazards

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related to bakery industry. He used various methods like decision tree, FMEA, Pareto chart, why why analysis and Ishikawa diagram to identify and eliminate the product defects emerging from the process. Among these tools, he adopted Ishikawa diagram to find the root cause among the various potential causes related to product shape and presented in graphical form. These quality control tools have used to develop a preventive action plan for the selected group of specific causes contributed the defect. Gartlehner et al. (2017) stated that Ishikawa diagrams are used in health care to analyze the causes related to patient safety and quality management processes. They used Ishikawa diagram to sum of their findings in the health care research. Further they stated that Ishikawa diagram is an effective tool to review systematically and present the results. They compared the Ishikawa diagram with summary of findings table which is used usually to present the findings in tabular format. Finally, they concluded that summary of findings tables have chosen by some of the participants over fishbone diagrams who found difficult to understand the Ishikawa diagram to answer their survey. Slameto (2016) applied fishbone diagram for the improvement of school quality. He used qualitative data and quantitative data to study the educational quality using fishbone diagram. He concluded that fishbone diagram was simple to communicate and very effective to improve school quality. Tegegne & Argu (2014) developed two types of quality light weight bio-based polymer matrix composite building material. They used Ishikawa diagram for the quality analysis of these materials.

Nowadays customers are expecting the foundries to produce quality castings. Their demands includes specified chemical composition, improved dimensional accuracy with consistency, better mechanical properties, free from internal as well as external defects and improved surface finish (Stefanescu et al.1988). However the foundrymen are not giving much importance to the surface finish of the casting when compared with other factors. Usually castings with rough surface defect are not rejected, whereas safety component castings which are subjected to dynamic load only are rejected. (Bryant & Thiel, 2018) emphasized that as cast surface finish is specifically essential for the better appearance of the castings. Moreover a better surface finish on the casting results in saving in the shot blasting, grinding and fettling operations. Above all, the foundry producing good surface finish in castings is well recognized by the customers. Above all, the foundry producing good surface finish in castings is well recognized by the customers. In this paper, identifying and finding root causes for rough surface defect were discussed in detail. Jain. (2003), Heine et al., (1996), Alagarsamy (2003), Beeley (2001), Plaines (1966) and Senthilkumar (2009) have focused the necessary remedial actions for casting defects. Ishikawa (1982). Tegegne & Singh (2013), Siekanski et al, (2003) have used Ishikawa diagram to find the probable causes for the defect. Even though defects analysis were discussed in the existing literature, correct identification, finding the root causes for the rough surface using Ishikawa diagram with foundry tools and processes to solve this defect have not been addressed. The aim of this paper is to identify and enhance knowledge on the influential factors causing this defect with the help of Ishikawa diagram adopted by Rao (2007), Gawdzińska (2011), Chokkalingam et al. (2017) and Gwiazda (2006).as well as to eliminate it on the castings.

2. COMMON SAND CASTING DEFECTS

The identification of the defect correctly in the casting is the most difficult for the foundrymen due to the involvement of lot of processes. Proper analysis, testing and experience is essential to identify the root cause of the defect correctly.More defects occur in the castings due to the moulding and sand system among all the departments in the foundry. Moreover, large numbers of components are involved in the production of sand moulds viz sand, clay, water and additives. Each of these components has their own properties that control the defect in the castings. However any one of these component is not in the required range, with relevant to the casting poured results in increase of the potential cause for the defect. The common castings defects occur due to sand are shown in figure 1.

2.1 Identification of rough surface

Rough surface casting defect occur in all the castings, however this defect is significantly higher in the sand castings. Imerys (2002) stated, generally rough surfaces on the castings are easily visible to the eyes. The casting surface is lacking its smoothness. The roughness on the casting surface occurs either on the mould side or on the core side. This defect occurred in various castings due to moulds and cores are shown in figure 2 and figure 3 respectively. The castings produced with smooth as cast surface is shown in figure 4.

2.2 Adhering sand defects

These defects are common to all alloys poured in green sand and are easily identified by rough casting surface or by adhering of sand particles on the casting surface. These defects may occur especially at a specific location on the casting viz hot spot besides over the complete casting surface. The mechanisms of the formation of this defect are mechanical penetration and chemical reaction.

2.3 Metal penetration

Metal penetration is the most important factors affecting the surface finish of grey cast iron castings. It is formed when the molten metal entered into the voids present in the mould and core further away from the mid surface layer of the sand grains.

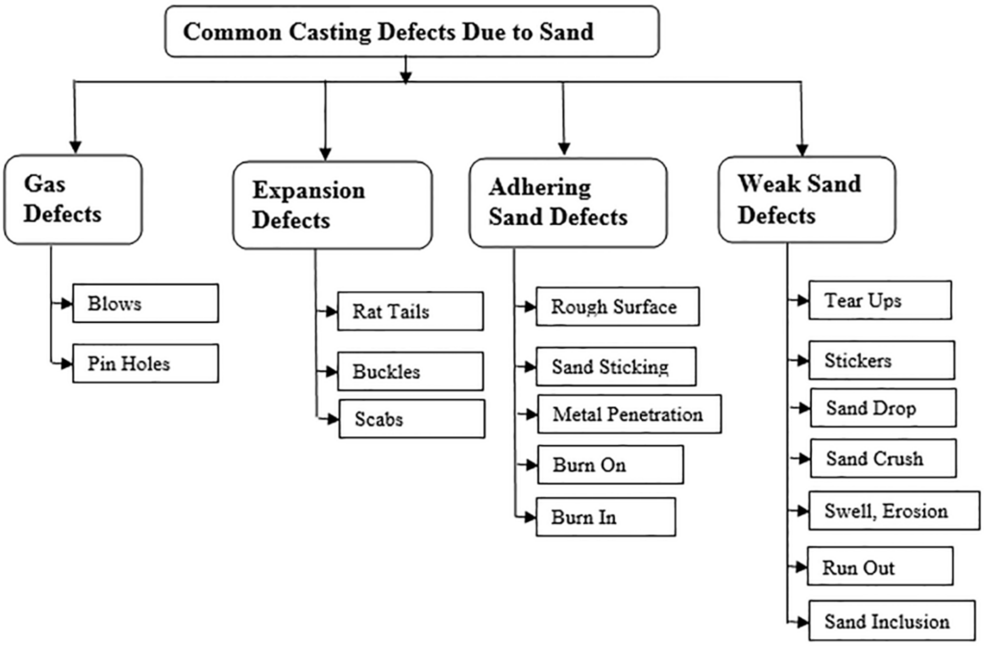

Figure 1. Common casting defects due to sand

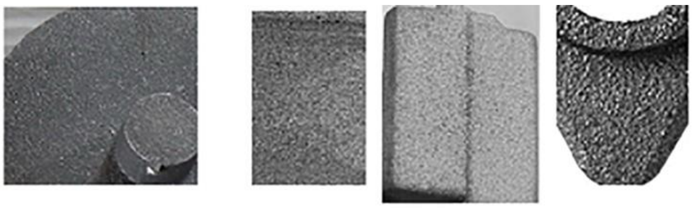

Figure 2. Rough surface on the casting due to mould

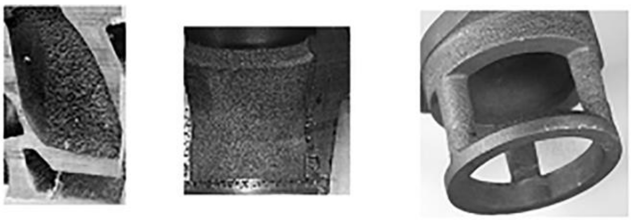

Figure 3. Rough surface inside the casting due to core

Figure 4. Smooth as cast surface

Generally metal penetration occurs in the castings at hot spots, heavy sections and the areas where wall thickness varies from thin to heavy sections.Molten metal penetrates into the voids in the sand moulds and cores due to its metallostatic pressure. Generally metallostatic pressure is higher when the sprue height is increased too much. This larger sprue height exerts more pressure on the liquid metal and forces it to penetrate especially into the voids between the sand grains. Consequently the liquid metal solidifies and as a result the sand particles stick on the casting surface. In addition, metal penetration occurs when the molten metal impinges on the mould wall. The pressure of the molten metal forces it to penetrate into the sand grain openings in the mould as well as core. Usually this type of defect occurs at the entrance of the ingate in the gating system. Moreover metal penetration defect occur also due to high metal enter into the sand openings in the moulds and cores. In particular, the major factors that affect the metal penetration are fineness of the sand and pouring temperature of the metal. Generally larger voids were found when coarse sand was used for moulding and core making. Lower pressure is enough for the molten metal to enter into these large voids and creates rough surface on the casting. When the pouring temperature of the metal is too high, it loses its heat when it contacts the mould surface. Subsequently a thin solid skin is formed against the sand mould. This solid skin prevents the molten metal from entering into the voids between the sand grains. The skin formation is delayed when the metal is poured at higher temperature. This additional heat available in the molten metal diffuses into the sand grains. The molten metal has enough time to enter into the voids in the sand grains results rough surface on the castings. This defect adheres the casting surface tightly and extensive chipping and grinding is widely used to remove it. The expansion penetration occurs due to the metallurgical characteristics of the solidifying metals and alloys also.

2.4 Chemical reaction

The reaction occurs between the liquid metal and mould material also causes rough surface on the casting. Products produced by these reactions act as glue and moulding sand adhere to the casting. Usually this reaction occurs in ferrous metals. This defect occur in two forms viz burn on and burn in.
The major difference between these two forms is the dense adherence of the sand on the casting surface. The sand adhere to the casting due to burn on is not held firmly and can be removed easily by fettling or shot blasting. On the other hand burn in requires grinding to remove it from the casting if it can be removed.

2.5 Mechanism of rough surface

This defect mainly occurs near the ingate areas of the sand mould where the hot metal contacts the mould for too long time. Moreover, it is mainly contributed by the shape, size of the sand grains and its distribution. Sometimes it is also found near the areas where the compaction of the mould and core is poor.

3. MEASURING OF SURFACE FINISH

The as cast surface roughness is measured using AFS C-9 micro finish comparator and is shown in the Fig.6. Volker (2016) stated that cast micro finish comparator is used qualitatively to measure casting surface. He elaborately explained the casting surface measuring technique and discussed the disadvantages of this method like interpretation of the standard vary with inspectors. The as cast surface roughness is measured using AFS C-9 micro finish comparator and is shown in the figure 5. The shape of the cast micro finish comparator is rectangular and it is the replica of the actual cast surfaces. The comparator comprises of nine cast surface specimens in the range 20 to 900 microns.

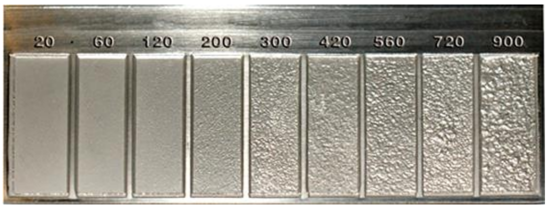

Figure 5. AFS C-9 Micro finish comparator

The cast micro finish comparator is kept at the side of the work piece to be examined. Then the comparator is moved along the casting and each surface finish of the comparator is compared with the casting surface using the tip of the finger. Finally, the as cast surface finish is determined if the finishes are found same in the comparator as well as in the rough casting.

4. CAUSES FOR THE ROUGH SURFACE

The initial step in the analysis of defect is to identify the key possible variables that cause the defect [The cause and effect diagram is an effective tool used to identify the potential causes of the defect. Subsequently the root cause of the defect can be found easily by careful analysis of the potential causes. The potential causes of the rough surface defect contributed by the foundry tools, processes and systems are presented as cause and effect diagrams as shown in the figure.6 and figure 7 respectively.

5. MOULD AND CORE RELATED FACTORS

The moulds and cores are the major contributors causing rough surface on the sand casting. The various mould and core related factors contributing this defect are discussed.

5.1 Mould and core

Rough surface is a major problem in the casting production. The liquid metal penetrates into the low density areas in the moulds as well as cores to form rough surface on the casting. Even though sand moulds/cores seems uniformly packed but in actual there is uneven packing of sand grains with binder and additives. The mould and core surface have wide range of densities and the liquid metal contacts these surfaces. Excessive penetration occurs in the lower density range when compared with higher density range. The mould surfaces made up of sand, binder and additives are of lower cost when compared with surface quality of final cast part which costs more. Foundries waste their major time to clean the rough surface castings. Instead of wasting time and resources to clean the rough surface castings, it is better to identify the factors causing the low density moulds earlier. Subsequently the necessary remedial measures can be implemented to eliminate this defect. Metal penetration is a common problem in ferrous metal casting processes.

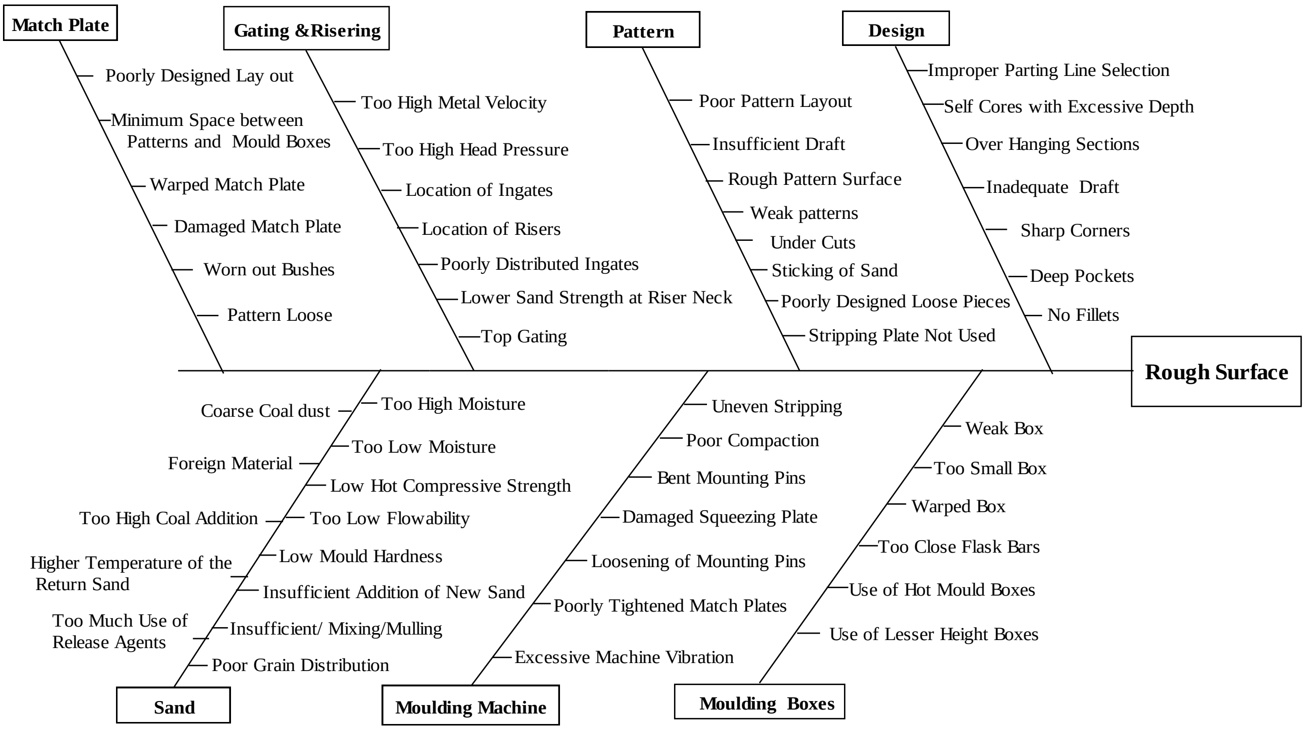

Figure. 6. Causes for rough surface on the casting - tools/systems

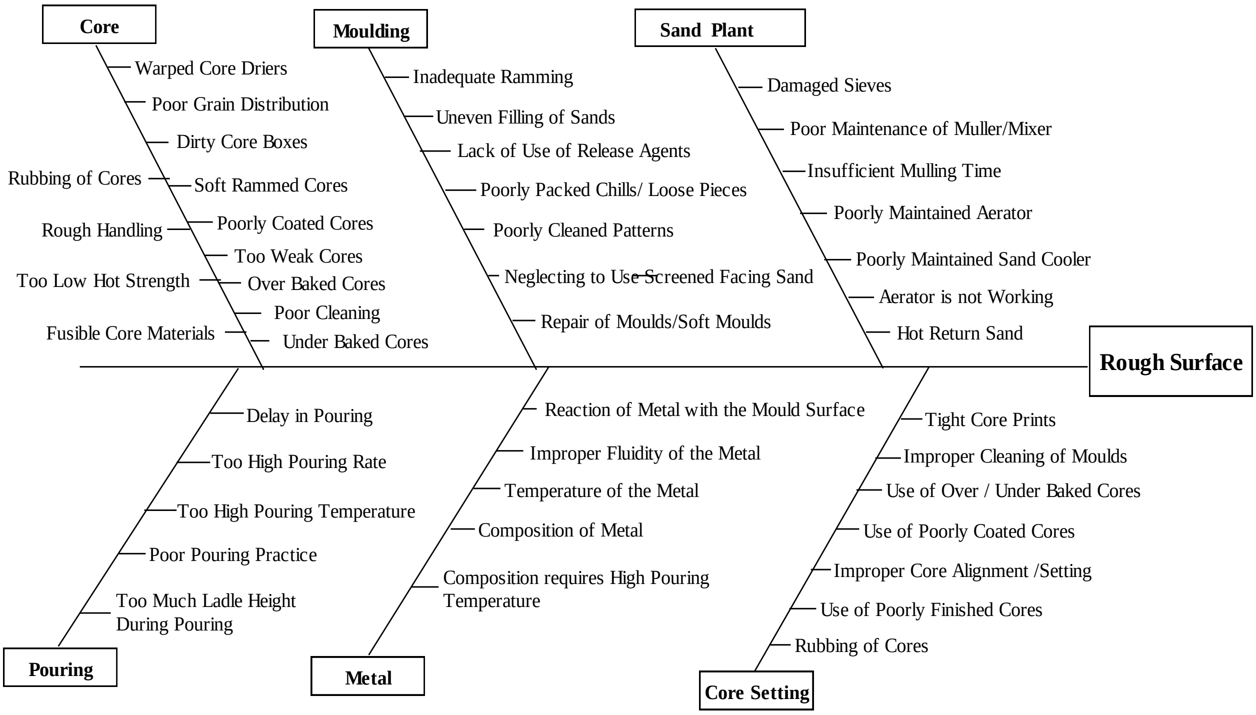

Figure. 7. Causes for rough surface on the casting- processes/systems

5.2 Recirculated sand

The recycled sands are less prone to expansion defects as the quartz is stabilized. However, when sand is used repeatedly, coated clay layer on the sand grains gets baked by calcination. The process of clay layer getting baked on to the sand particle is known as oolitizaion. Fusion point of the silica (1759^{0}C) is not affected when a thin layer of clay (fusion point 1200^{0}C) is coated on the silica sand grains. Layers and layers of calcined clay is built up over the sand grain due to oolitization. Consequently, the fusion point is around 1150-1200^{0}C.. Due to higher temperature of the molten metal, the sand particles stick to the castings causing rough surface on the casting.

5.3 Mould and core coatings

The main application of mould and core castings is to improve the surface finish of the castings. The chances of penetration of metal into the voids between the sand grains are increased especially when the surface of the sand grains is wetted by the metal. These voids in the rammed moulds cause rough surface on the casting. Furthermore, the chemical reaction between the metal and mould surface leads to adhere of sand particles with the metal surface. Coating gives a fine grained refractory layer between the metal and sand mould to prevent metal penetration, sand fusion besides sand erosion.

5.4 Ramming energy

Ramming improves as well as develops many of the sand properties. The green hardness of the sand is increased when the squeeze pressure is increased. A better ramming sand should produce maximum green hardness with lower squeeze pressure. Squeeze pressure increases air set strength and dry compressive strength significantly. If the sand rams easily and the mould face will be free of false voids between the sand grains, which gives a good surface finish on the castings.

5.5 Method of compaction

Generally the surface finish on the castings surface depends on the method of compaction. When the sand grains are packed tightly, uniform surface is produced molten metal flows over this surface and the same surface is reflected on the casting. Various methods can be used to get mould compaction. They are jolting, squeezing, blowing, combination of jolting and squeezing. The compaction is very poor in the hand moulding whereas blowing produces a smoother surface. Moreover simultaneous jolt and squeeze method produces a smoother and more compact mould than blowing. However automatic high pressure moulding machines produce smooth mould surface.

6. METAL RELATED FACTORS

Higher metal velocity generates more pressure and the metal penetrates between the sand grains results rough surface. Higher pouring temperature of metal causes penetration of the metal in the voids between the sand grains and spoil the surface of the casting. Surface finish of a casting is related directly to casting section thickness and the metal pressure. Especially the surface finish is poor when the metal pressure increases. The pressure produced by the liquid metal into the mould cavity is transmitted equally in all directions besides perpendicular to the mould surfaces. Therefore it is essential that the rammed moulding sand must resist these pressures created by the liquid metal against the mould. Moreover when the section size of the casting increases, the contact time between the mould surface and metal is also gets increased. This increased exposure leads to rough surface on the castings. Metal can penetrate into the mould wall easily when the metallostatic head pressure is higher and it causes rough surface on the casting. Hence the metal is poured at lower metallostatic head to get good surface finish on the casting.

7. PREVENTION OF THE DEFECTS

Generally trial and error method is used to identify and control the casting defect. This method is not suitable to discover the hidden cause of a defect. The initial step in the defect prevention is to identify the defect based on the appearance and shape. The second step is to find out the reasons and root causes for the occurrence of the defect by using quality control tools. Finally, casting defects can be prevented by the use of standard recommended procedures, by conducting review meeting in the shop floor involving people concerned, providing skill based training and knowledge based training. Hence a systematic approach is required to diagnose a casting defect and to find an appropriate corrective as well as preventive action. By using quality control tools and implementing the proper solution, defect can be minimized quickly saving time and money.

8. CONCLUSION

The correct identification of the casting defect in the inspection stage is important for further analysis. Most of the casting defects are occurring repeatedly due to incomplete knowledge and wrong selection of the root cause. Identification of the defect and determination of possible causes are the first step in the defect analysis. In this paper identification, mechanism and major factors causing the rough surface on sand casting are presented as cause and effect diagram. Subsequently the root cause for this defect can be identified easily and necessary remedial steps can be implemented to eliminate this defect occurring on castings

Acknowledgement
The authors wish to thank the Management and Principal of Sri Ramakrishna Institute of Technology, Coimbatore, India for providing the facilities and support to complete this work.

References:

Alagarsamy, A. (2003, October). Casting defect analysis procedure and a case history. In *PT Keith Millis Symposium on Ductile Iron Castings, Citation Corporation, Birmingham, Alabama, October* (pp. 20-23).

Beeley, P. (2001). *Foundry technology*. Elsevier.

Bryant, N., & Thiel, J. (2018). Critical characteristics affecting the surface finish of castings. *International Journal of Metalcasting*, *12*(1), 186-195.

Chokkalingam, B., Raja, V., Anburaj, J., Immanual, R., & Dhineshkumar, M. (2017). Investigation of Shrinkage Defect in Castings by Quantitative Ishikawa Diagram. *Archives of Foundry Engineering*, *17*(1), 174-178.

Gartlehner, G., Schultes, M. T., Titscher, V., Morgan, L. C., Bobashev, G. V., Williams, P., & West, S. L. (2017). User testing of an adaptation of fishbone diagrams to depict results of systematic reviews. *BMC medical research methodology*, *17*(1), 169.

Gawdzińska, K. (2011). Application of the Pareto chart and Ishikawa diagram for the Identification of Major Defects in Metal Composite Castings. *ISSN (1897-3310)*, *11*(2).

Gwiazda, A. (2006). Quality tools in a process of technical project management. *Journal of Achievements in Materials and Manufacturing Engineering*, *18*(1-2), 439-442.

Heine, R. W., Loper, C. R., & Rosenthal, P. C. (1996).*Principles of metal casting*. Tata McGraw-Hill Education.

Imerys (2002). *Manual of casting defects*. Imerys metallurgy division, http://www.imerys-additivesformetallurgy.com.

Ishikawa, K. (1982). *Guide to quality control* (No. TS156. I3713 1994.).

Jain, P. L. (2003). *Principles of foundry technology*. Tata McGraw-Hill Education.

Mariajayaprakash, A., Senthilvelan, T., & Vivekananthan, K. P. (2013). Optimisation of shock absorber process parameters using failure mode and effect analysis and genetic algorithm. *Journal of Industrial Engineering International*, *9*(1), 18.

Plaines, D. (1966). Casting Defects Handbook. *American Foundrymen's society training and research institute, USA*.

Przystupa, K. (2019). The methods analysis of hazards and product defects in food processing. *Czech Journal of Food Sciences*, *37*(1), 44-50.

Rao, T. R. (2007). *Metal casting: Principles and practice*. New Age International.

Senthilkumar, B., Ponnambalam, S. G., & Jawahar, N. (2009). Process factor optimization for controlling pull-down defects in iron castings. *Journal of materials processing technology*,*209*(1), 554-560.

Siekanski, K., & Borkowski, S. (2003). Analysis of foundry defects and preventive activities for quality improvement of castings. *Metalurgija-sisak then zagreb-*, *42*(1), 57-60.

Slameto, S. (2016). The Application of Fishbone Diagram Analisis to Improve School Quality. *Dinamika Ilmu*, *16*(1), 59-74.

Stefanescu, D. M., Davis, J. R., & Destefani, J. D. (1988). Metals Handbook, Vol. 15--Casting. *ASM International, 1988*, 937.

Tegegne, A., & Argu, T. (2014). Experimental development of bio-based polymer matrix building material and fish bone diagram for material effect on quality. *International Journal for Quality Research*, *8*(2).

Tegegne, A., & Singh, A. P. (2013). Experimental analysis and ishikawa diagram for burn on effect on manganese silicon alloy medium carbon steel shaft. *International Journal for quality research*, *7*(4).

Vijayaram, T. R., Sulaiman, S., Hamouda, A. M. S., & Ahmad, M. H. M. (2006). Foundry quality control aspects and prospects to reduce scrap rework and rejection in metal casting manufacturing industries. *Journal of materials processing technology*, *178*(1-3), 39-43.

Voelker, M. M. (2016). Quantitative surface inspection methods for metal castings.

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