

Quality circle implementation to reduce defects in cast steel products in the heavy equipment industry

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Abstract. *Steel products produced from the metal casting process or commonly called cast steel are still very much needed in the industrial world, as components for production machines, power plants, automotives, heavy equipment and other needs. PT KX is a company that produces cast steel products, the products produced are targeted to be able to meet customer needs both for domestic needs and for export needs abroad. One of the problems currently faced by this company is the high defect ratio in several products currently produced. The defects that occur are porosity, gas holes, sand inclusions, cracks, and misruns. This company's good culture in implementing continuous improvement is well developed in all lines and all members of the organization so that this company continuously makes efforts to reduce defects that occur in products. The aim of this research is to analyze the causes of problems and make improvements to reduce the defect ratio. The method used by Quality Circle (QC) is as a method for making continuous improvements in reducing defects. One of the ways in which the verification process is carried out is by utilizing Electron Probe Micro Analyzer (EPMA) machine technology. This aims to make the analysis results more in-depth so that ultimately the defects that occur in a product can be reduced significantly.*

Keywords: *Quality Circle, Improvement, EPMA Technology, Reduce Defect*

1. Introduction

PT KX is a company engaged in metal casting which was founded in Indonesia more than thirty years ago, the products produced are cast steel products for industrial needs. At the beginning of this fiscal year, the management of this company planned to be more "*Competitive & Productive*" in order to become one of the companies that is sustainable and useful for the nation and state. To realize this, many things must be done and improved, one of which is to reduce costs, increase productivity and improve product quality.

Cast steel products at this company are produced from metal smelting processes using induction furnaces and arc furnaces. The melted or molten metal is then poured into the mold cavity which is formed according to the desired product (Chelladurai et al., 2020). The molding media is made from silica sand (Si) which has been mixed with resin as a binder and *catalyst*. The temperature of the molten steel casting is higher than the threshold for the ability of silica sand to retain heat from the molten steel, so that the molding sand silica (is) able to withstand the temperature of the molten steel during the pouring process, this mold requires additional material as a coating with a raw materials that are stronger in resisting the pouring temperature of the molten steel (Nwaogu & Tiedje, 2011), one of which is a coating material whose main raw material is *Zircon* (Zr) sand.

The work process of each work station has been made and standardized, raw materials and other supporting materials used for production needs have also been selected with careful consideration. Even so, the products produced are not entirely as expected, there are still defects that occur in several types of products. These defects are sometimes unavoidable, some of which are caused by errors in the design, processing or inaccuracy in the selection of main materials and supporting materials in the manufacture of cast steel products (Hodbe & Shinde, 2018). The high percentage of defects experienced by the product results in several problems that arise which are currently being faced, namely the need for a repair process for the product, whether repairs are carried out by grinding or adding meat by welding or, sometimes, defects with a high level of severity. causing the product to be rejected/scrap.

There are several types of defects that occur in certain cast steel products in this company that cause the product to be rejected/scrap, including porosity, gas-holes, sand inclusion, cracks, and misruns. Of course, this creates a lot of waste and inefficiencies in time and costs. Various efforts and corrective actions have been carried out by the company to improve product quality by reducing defects occurring in several products. This company has a good culture of making continuous improvements, especially by using the Quality Circle (QC) method. Improvements are made in all lines and in all members of the organization so that this company has been able to reduce defects in several types of products, although currently it has not been completely resolved. With the good spirit and culture that is currently owned to carry out continuous improvements, the company feels confident that all defect problems will be resolved.

For several reasons and defects that occur, the author determines that the purpose of writing this time is to carry out a repair process for defects that are dominant in current products by implementing the "Quality Circle (QC)" improvement method (Goyal et al., 2022). The tools used in identifying, analyzing and evaluating the results of improvements are several tools from 7 tools improvements including pareto diagrams, brainstorming, root-cause analysis Fishbone (Barot et al., 2019), In the process of defect analysis, verification is carried out on each assumption possible cause of the defect. Among the ways in the verification process that is carried out is by utilizing the Electron Probe Micro Analyzer (EPMA) machine technology. Through this improvement method, it is expected that the percentage of defects in products will decrease significantly, which means that products that are rejected/ scrapped will decrease so that production costs will decrease and what the company plans to do in this fiscal year is to become a more "Competitive & Competitive" company. Productive" can be supported and realized. The aim of this research is to analyze the causes of problems and make improvements to reduce the defect ratio

2. Method

The method used in this study is research using quantitative methods and also qualitative analysis. Data for research were taken from several sources, to collect the required data it was carried out in several ways, namely first by direct observation in the field, the second was carried out by conducting several direct interviews with several relevant employees from the operator level to the manager. The next method used is to hold brainstorming with leaders, foreman, production supervisors, related engineers, even managers, both production managers and engineering managers in the company. The collected data is then used according to the steps in the improvement process with the "Quality Circle" method to reduce or eliminate defects in cast steel products. The research framework can be seen in Figure 1.

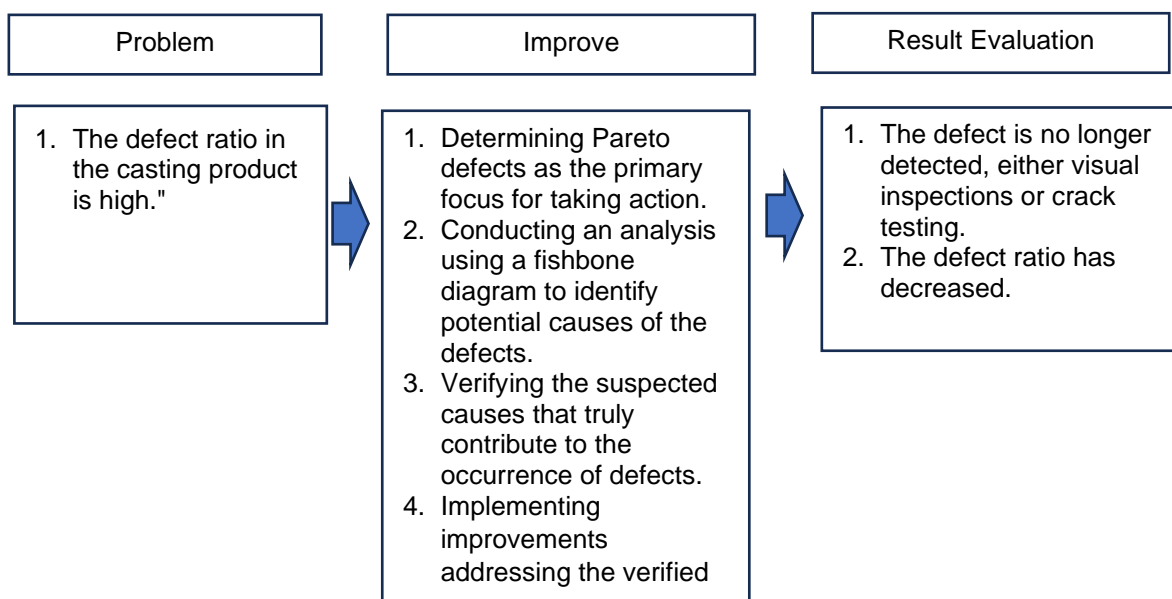


Figure 1. Research framework

The first step taken by researchers in implementing the Quality Circle method is to collect data. The data is used to be able to identify problems that occur at this time, from problems that are legible and which can already be identified then identified, grouped, arranged and outlined in a diagram that is used as one of the tools, namely the Pareto diagram. From this Pareto diagram, it will visually illustrate what problem/problem is the dominant defect that is currently happening (Ahmed & Ahmad, 2011), the problem that appears most dominant will be taken as the author's main focus to be addressed immediately.

The problems that occurred have been obtained and the most dominant problems have been visualized after that. The next step that must be taken is to set targets, the targets set in a minimum value are the values that follow the achievement targets that have been announced by the company's management at the beginning of the fiscal year. However, as a challenge for the improvement team, the target (internal target) set is the challenging target, namely the value that is sought to reduce defects is zero.

The next step is an analysis of the problems that occur. Analysis of dominant defects was carried out by researchers by inviting members of the improvement team to discuss actual problems and possible causes of these problems through brainstorming (Guleria et al., 2021). In this discussion, leaders, foreman, production and engineering supervisors were involved. In the brainstorming process, all participants were asked and had to express their opinion about what they think is one of the possible factors that causes defects to occur in the product. In the brainstorming process, all opinions expressed by members cannot be rejected, all are recorded and poured into the improvement tool. The improvement tool used in this study is the root-cause analysis-Ishikawa diagram or better known as the fish-bone diagram. The opinions of the brainstorming participants that have been recorded and poured into a fishbone diagram (Xu et al., 2022) are then confirmed for each opinion according to the suitability of the opinion with the facts that occur in the defective product or in the environment and work station where the product is made. Opinions that have been confirmed by the facts and the results are inconsistent, then the opinion is declared disqualified/not continued to the next step and for certain opinions whose suitability when confirmed is appropriate then the opinion (likely to be the cause of the problem) is then followed up for the process of seeking improvement ideas and the process of implementing improvements. The conformity confirmation process between the alleged probable cause of the problem and the facts in the field is carried out in two ways, namely the direct or visual confirmation process on the product that has a defect or to the environment/workstation where the product is being worked on. Both confirmation processes between opinions and facts are carried out using a technological analysis tool/machine, namely the Electron Probe Micro Analyzer (EPMA), which is for the process of confirming opinions that cannot be easily proven visually. In this confirmation process, it is necessary to prepare the product directly to be tested (if the product size is still within the machine specifications) or by using a test sample. For the testing process using test samples, the sample preparation process is carried out in a destructive way on defective products. Then the product or the cut sample is tested using an EPMA machine. The test results obtained from this testing machine are the elements or elements contained in the defect test product/sample (Grover et al., 2006).

Opinions that have been confirmed for suitability both visually and by using the EPMA machine, are used as the root cause of the defects that occur. Henceforth, the root of the problem that has been obtained is sought for suggestions for corrective action. How to get suggestions for improvement is done in the same way as the analysis process, namely by brainstorming. However, to enrich the number and quality of these proposals, the brainstorming participants did not only involve participants during the analysis process, but also involved managers, both production and engineering managers, for their opinions and suggestions.

From the collection of proposals or ideas that have been obtained, select the best proposal or idea that is logical, easy and safe which is taken as the first idea or proposal to be implemented/implemented. After the proposal is executed, observe the process of implementing the repair in the field, monitor the product, make sure the product being repaired is not confused with a similar product currently in the field which is still being worked on/processed as it was before the repair.

3. Results and Discussion

Case study

The discussion on the handling of defects that occur in this company begins with making improvements to a "case study" of one of the products that is currently experiencing defects, namely bracket bottom. The defect problems experienced by this product are porosity, gas-holes, sand inclusions, cracks, and misruns (Skryabin & Likhanov, 2019). as illustrated in the pareto diagram in Figure 2.

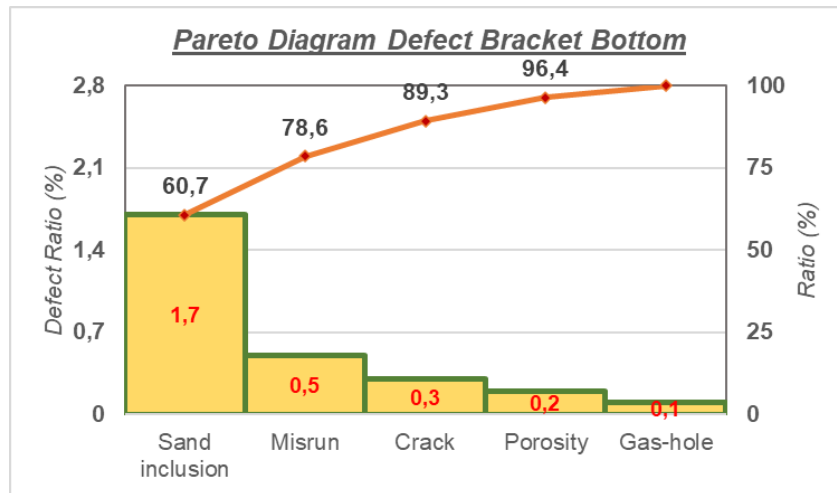


Figure 2. Pareto defect diagram for bracket bottom products

Based on the results of the depiction using a pareto diagram it is visualized that the most dominant defect is sand inclusion with a percentage of 1.7%, misrun 0.5%, crack 0.3%, porosity 0.2% and gashole 0.1%. Henceforth, sand inclusion defects are the focus for handling and repairing in this study.

Before carrying out the corrective steps using the Quality Circle method for sand inclusion defects, we will briefly explain what is meant by defect sand inclusion. Defect sand inclusion occurs due to the presence of a certain amount of sand, either molding sand or sand from other material sources, such as sand contained in coatings that enters the existing mold cavity or is carried into the molten metal that is poured to form cavities around the surface or inside. casting products (López et al., 2021). Defect sand inclusion on bracket bottom products is visualized in Figure 3.



Figure 3. Defect sand inclusion on bracket products

In the above illustration, sand inclusion defects occur under the surface layer of the product, visually these sand inclusion defects are detected as hair cracks on the surface of the product after the crack check process is carried out, but after these small cracks the operator tries to remove them by grinding the surface of the product. the cracks, it turns out that below the surface of the

cracked product there are cavities filled with sand inclusions so it is certain that the defect that actually occurs is sand inclusion (Li et al., 2021). Furthermore, after it was clearly identified that the defect that occurred was sand inclusion, then a search/analysis of the factors that made it possible for the sand to enter the mold cavity/ into the metal fluid was started, causing defects. To find out the possible causes of sand inclusion or sand getting into the metal liquid, a brainstorming was carried out with members of the improvement team, namely leaders, foreman, production supervisors, engineers involved to get some opinions on the causes of defects sand inclusion. From the brainstorming process, there are those who argue that the compressive strength of the molded sand may be low, there are also those who think that the cleanliness of the mold before the assembling process is not given enough attention, the molding sand erodes during the process of pouring molten metal or there are also those who argue that impurity sand (inclusions) is produced by the material. others that are not from molding sand, namely sand that comes from coating material (Kandpal et al., 2021). Opinions regarding the analysis of possible causes of sand inclusion defects are set forth in the improvement tool in the form of a fishbone diagram as shown in Figure 4.

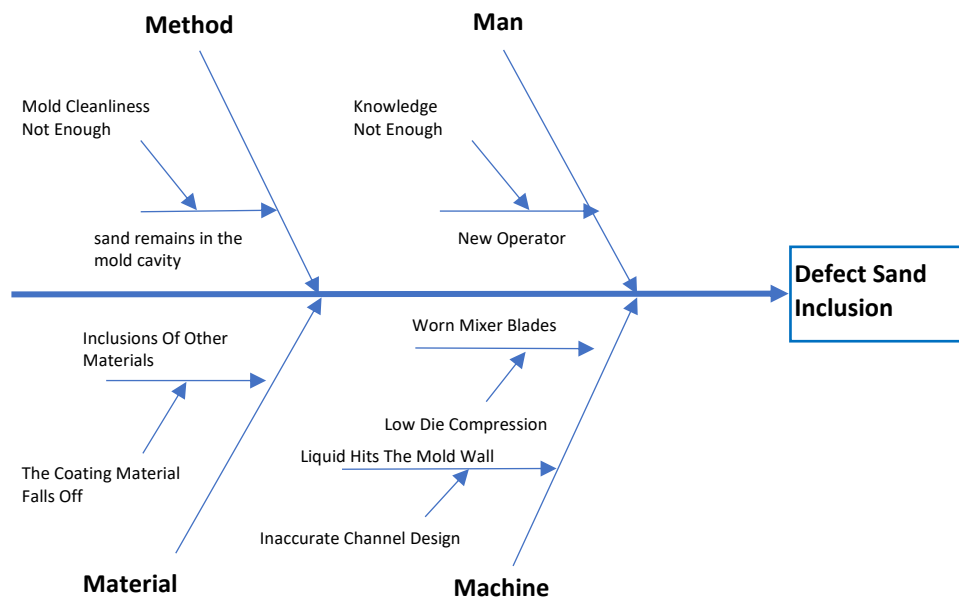


Figure 4. Fishbone diagram of analysis defect sand inclusion

Based on several opinions, one by one each opinion is confirmed for suitability Analysis of possible causes with the facts in the field and in product defects. From the opinions put forward whose confirmation is sufficient with visuals, all of them have been proven that the allegations regarding the possible causes of the problem turned out to be inappropriate/unproven. Next, there is only one more opinion that cannot be confirmed for its suitability, namely the opinion which states that the sand that is an inclusion in the product is sand that comes from the coating material. This opinion means that a proof is needed if the sand that includes the product is an inclusion where most of the content is zircon (Zr) and a small part is silica (Si), this condition causes confirmation of conformity not to be visual, so as a way to carry out the process the proof is with an elemental analysis tool/machine, namely by using an Electron Probe Micro Analyzer (EPMA) machine.

The EPMA tool (Electron Probe Micro Analyzer) is a tool that has modern technology that can be used to assist researchers in viewing the microstructure of a material being examined. The EPMA machine design is a machine that combines a combination of two tools, X-Ray Fluorescence (XRF) and Scanning Electron Microscope (SEM). With this tool, qualitative and quantitative analysis can be carried out. The next advantage of this electron probe micro analyzer is that this tool has the ability to to analyze the test object quickly, accurately and non-destructively. In the field of metallurgical engineering, the properties of a material are largely determined by the constituent elements and the microstructure it contains.

The working principle of this EPMA machine/tool is to utilize the signals/light emission captured from the effects of collisions between electrons. The advantages of EPMA analysis are:

1. Materials/test objects with relatively small dimensions can be analyzed relatively quickly and accurately without being destructive to the test objects/products being tested if the size of the product matches the space in the machine (non-destructive analysis).
 2. By using the X-Ray spectrum obtained, the elements/elements that are composed of a material in the test object can be read qualitatively (Dybowski et al., 2023; Lal et al., 2023).
 3. With the X-Ray generated during testing, the results of the distribution of various elements in a certain area of the test object being tested can be identified and the composition or microelements of a single object can be known (Yu et al., 2020).
- The next step is to prepare test samples taken from defects in the product by means of destructive/cutting of the product. The samples that have been prepared are then tested using an EPMA machine with the test results as shown in Figure 5.

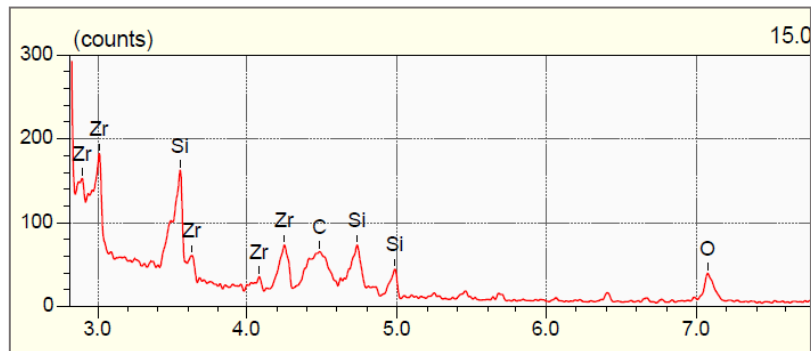


Figure 5. The results of the EPMA test on the defect sand inclusion sample

From the test results, it was found that the content of inclusions (impurities) in the bottom bracket product was Zircon (Zr) and Silica (Si) elements. Furthermore, the data from this test is very valuable for finding materials containing Zr and Si which cause inclusions in the product. After searching for various materials used in the process of making cast steel, we finally got one type of material that contains the Zr element, namely the material in the mold coating, namely coating material, meaning that one opinion regarding the origin of the inclusions is appropriate/proven. Then further analysis is carried out related to the coating material (Grover et al., 2006). Currently there are two types of coatings used for coating prints, namely coatings with the ISXXXX-8X and ISXXXX-33X types. In this company, the use of coating type ISXXXX-8X is widely used for medium to low products, including being used as a mold coating for bracket bottom products which is currently problematic, while coating type ISXXXX-33X is used for large products. For this incident, testing of the coatings was carried out by visually comparing the absorption to find out how strong and in the absorption capacity of each type of coating into the printing sand (Calderón et al., 2020). The test results and coating comparisons were carried out with the results shown in Figure 6.

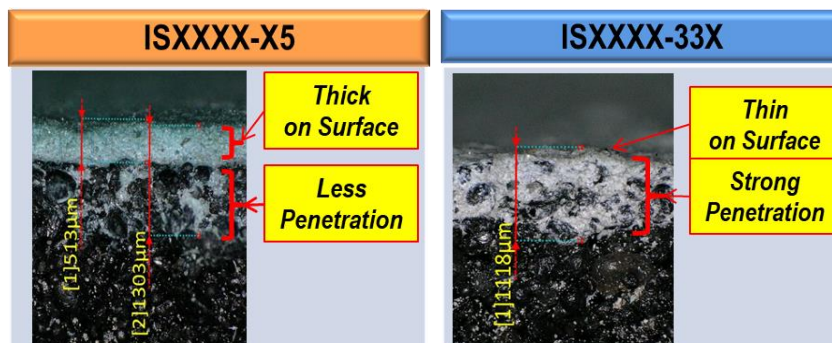


Figure 6. Comparison test results of the two types of coatings

With the condition that the ISXXXX-33X type coating has better performance than the ISXXXX-8X type coating, it is subsequently agreed to propose changing the current coating to ISXXXX-33X type coating. The next step is to conduct an experiment to implement the proposal, the mold is prepared for coating using ISXXXX-33X type coating. The mold is poured using molten steel, the next process is to check the resulting product, observe the results of the product. And the results can be seen in Figure 7.



Figure 7. Surface of the bracket product after repair

Looking at the surface condition of the bracket bottom product after the repair, the defects caused by sand inclusion were no longer visible, so a change was immediately determined in the use of coating using the ISXXX-33X type. From the observed results, the defect in the current bracket product has decreased drastically from XX% to zero defect (sand inclusion).

4. Conclusions and Recommendations

Based on the research conducted, the process of repairing defects that occur in current products has been carried out and has succeeded in reducing defects experienced by bracket products by implementing Quality Circle. Through this improvement, the percentage of defects in products has decreased, which means that the process of working on repairs to products has been reduced or even disappeared so that production costs have decreased and what the company has planned in this fiscal year to become a more Competitive & Productive company can be supported and realized. As a suggestion from the author, the achievement of this positive improvement should also be implemented for products with similar problems in this company, so that the culture of continuous improvement on all lines and in every member of the organization in this company can be maintained and even improved. For this reason, continuous Quality Circle training is needed for every member of the organization who has just joined this company so that this capability and culture can be sustainable.

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