



Process Parameter Optimization of Flange Rollers in Sand Casting Using the Taguchi Approach

Shashank S, Dr. Rajath H G

¹PG Student, Department of Mechanical Engineering, GMIT,
Bharathi Nagar, Mandya, India

²Associate professor, Department of Mechanical Engineering, GMIT
Bharathi Nagar, Mandya, India

Abstract : Metal casting is an earliest and known process however, most of the industries are facing problems in producing defect free products due to involvement of numerous parameters in the process. Likewise, Satish Industries & Foundry, metal manufacturing industry is also suffering from rejections due to defects. According to the annual report from 2021-2024, flange roller which had a rejection rate of about 17.73% was the foremost rejected product in the company due to the severity of gas porosity on it. The reason for the existence of the defect on the product was involvement of faulty process parameters while production. Therefore, an attempt was done to locate the optimum combination of parameters which minimizes the rate of gas porosity as well as improves hardness and compressive strength by applying Taguchi's DoE method. Based on the four years annual report three parameters which primarily affect the quality of the product were selected and studied within three levels..

INTRODUCTION

Casting process is one of the oldest metal shaping processes used by human beings. It is a process of pouring molten metal into a mold cavity and allowing it to cool and solidify. The object which is solidified in the mold is removed either by breaking or taking the mold apart. This process is called casting process and the part which is made is called as casting. The discovery of casting process dates back to 3500 BC in Mesopotamia. During that time, wood cutting tools such as copper axes and other flat objects were made in open molds using baked clay. All of them were made in a single piece. In 2000 BC in its name the Bronze Age, more modifications in the casting process were seen. For example, core for making hollow sockets in the cast objects was invented for the first time. This core was made from baked sand. During 1500 BC, the technology of casting shows a great improvement due to casting activity found in China. They made highly intricate jobs using multi piece molds [1]. Now a days, castings are widely used in every sector of economy. Almost 90 percent of all manufactured products have one or more metal castings. The present application of cast metal product includes different automotive parts, mining and oil field equipment, recreational equipment, surgical equipment, compressors, pumps, pipes, fittings and many other components

PROBLEM STATEMENT

Satish Industries and Foundry, based in Bengaluru, operates with a commitment to delivering a premium range of cast components manufacturing through sand casting process. Our expertise in manufacturing and supplying these components has enabled us to establish a strong presence in the Indian market. Despite the critical role that the foundry shop plays in the company's production process, it continues to face challenges related to poor product quality during casting operations. Defects such as porosity, shrinkage, scab, inclusion, mismatch, under-dimension, misrun and hot tears are commonly observed in the foundry. Among the most defective products produced by the company are pulleys, scraper plates, trash plates, flange rollers, mill rollers, pinion gears and sprockets. According to the annual report from 2021 to 2024, the flange roller has consistently been the most defective product, with a rejection rate of approximately 17.73%. Of these rejected flange rollers, 49.62% were discarded solely due to the gas porosity defect. The main causes identified for the occurrence of this defect are faulty process parameters, including moisture content (ranging from 0.5% to 0.8%), pouring temperature (ranging from 1430°C to 1460°C), and an improper grain fineness number (ranging from 48 to 52 AFS) used during production. The presence of gas porosity in the flange rollers significantly impacts their mechanical properties, particularly hardness and compressive strength. For instance, the expected hardness value for the flange rollers, as per the DIN EN 1561 standard, should range from 114-175 HB (72-95 HRC). However, the defective flange rollers have an average hardness of only 62.74 HRC. Similarly, the expected compressive strength for these rollers should range from 510-768 MPa, but the average compressive strength of the defective units is only 403.49 MPa, which is considerably lower than the standard. The report identifies the primary causes for these defects as excess moisture content, uncontrolled pouring temperature, and improper sand size. As a result, moisture content (%), pouring temperature (°C), and grain fineness number (AFS) have been identified as the key parameters that need to be optimized to reduce the defect rate and improve the flange rollers quality.

RESEARCH METHODOLOGY

The present study was carried out on flange rollers which were made from grey cast iron in Satish Industries & Foundry. The main objective of the study was to find out optimum parameters which can minimize the rate of gas porosity existed on the flange rollers. To achieve this goal Taguchi's DoE method was applied. The parameters selected for the study were moisture content (%), pouring temperature (°C) and grain fineness number (AFS).

3.1 Materials/Equipment

Materials and equipment which were used during sand preparation, mold making, melting & pouring, solidification & shakeout and finally while testing are given in the Table 3.1.

Table 3.1 List of materials and equipment/tools used while experimentation

Materials	Equipment	Equipment/Tools
• New silica sand (SiO₂) • Reclaimed silica sand • Furfuran alcohol (resin) • Sulfonic acid (Catalyst) • Dolomite powder • Iron cover • Pig iron • Metal scraps • Slag remover • Iron ore • Couplant oil		• Flask • Wooden pattern of flange roller • Sprue and sprue base maker • Rammer • Vent wire • Sieve • Sieve shaker • Digital weighing scale • Induction furnace • Ladle • Non-contact infrared thermometer • Grinder • Lathe machine • Magnet • Electromagnetic yoke • Field indicator • Magnifying glass • Universal ultrasonic flaw detector • Rockwell hardness tester • Milling machine • Saw • Vernier caliper • Universal testing machine • Computer

3.2 Methods

The following methods were implemented in this research.

3.2.1 Data Collection

To get a useful data regarding casting defects of the industry both of primary data and secondary data collection methods were used and are discussed as follows.

✓ **Examining annual reports:** the four years annual reports from 2021 to 2024 were examined in order to get necessary data such as: frequently produced products of the company, quantities that were ordered, produced and inspected, types & frequencies of defects, causes for those defects, rejection rates, money losses and customer complaints for each products.

✓ **Direct observation:** To make a cross check on the existence of the defects which were recorded on the annual reports, direct physical observation on the rejected products was performed. Then defects such as porosity, shrinkage, sand inclusion, scab, mismatch and misrun were seen. While observing, it was identified that the rate of gas porosity on the rejected products was higher than the other defects.

✓ **Referring documents about Satish Industries & Foundry and literature review:** To have enough information about the background, products, capacity and main customers of the company etc., recorded documents on the case company were referred. In this study, various literatures on casting defects were also reviewed to understand the methods, approaches and tools which are helpful to solve defect related problems.

✓ **Experimental analysis:** involves the following:- testing the size and moisture content of the sand, preparing nine molds, melting, measuring the temperature and then pouring, solidification and shakeout, finishing, magnetic particle testing, ultrasonic testing, Rockwell hardness testing and preparing samples & testing compressive strength. Experiment ultimate goal was to find out the optimum parameters combination which gives lesser defects as well as improved mechanical properties particularly for flange rollers.

3.2.2 Data Analysis

To analyze the defects quality control tools such as bar graph, Pareto chart and Ishikawa's cause and effect diagram were used. The vertical bar graph was just to compare rejection percentages of different products in the last four years and then to choose the product with the worst rejection percentage for a detail investigation. On the other hand, Pareto chart was used to recognize the major defect which contributed more on the product rejections. After identifying the major defect, the next step was finding out the root causes for that defect through Ishikawa's cause and effect diagram. Process parameters which were related to those major causes were selected and their optimum values were found using Taguchi's DoE method. The results of the experimental data was

analyzed using S/N ratio and ANOVA analysis through a Minitab 17 statistical software. Finally, to validate the result of the experiment simulation was done using a Pro-Cast simulation software.

3.3 Experimental Setup

The following procedures were followed while doing the experiment.

- ✓ First, take sands which were dried by the sun for 3-4 days, 5-6 days and 7-8 days after wash.
- ✓ Then, measure their grain fineness number using a sieve shaker machine by taking 100grams of sand samples from each.
- ✓ Check the moisture content of the sands by taking 200grams of samples from each and heat the samples by an induction furnace. Then, calculate the difference on percentage.
- ✓ Prepare nine molds according to the orthogonal array given by Taguchi's DoE method.
- ✓ Melt pig irons and scraps with a temperature of 1500°C-1650°C using an induction furnace. Then, measure the temperature of melt before pouring it into each molds. The following are information regarding the device used for measuring the pouring temperature.

Equipment: Non-contact infrared thermometer

Model: AS892

Manufacturer: SMARTSENSOR, China

Capacity: 200~2200°C ±2°C



Figure 3.1 Non-contact infrared thermometer

- ✓ After pouring, leave it for 24hrs for proper solidification.
- ✓ Then, perform machining operation for all of the nine castings.
- ✓ Finally, execute the following tests for each castings.

Magnetic particle test

- ✓ Check whether the material is ferromagnetic or not by using a magnet.
- ✓ If the material is ferromagnetic then, magnetize it using an Electromagnetic yoke. The following are information regarding an Electromagnetic yoke used while experimentation:

Equipment: Electromagnetic Yoke

Model: Y6

Manufacturer: MAGNAFLUX, UK



Figure 3.2 Electromagnetic Yoke

- ✓ Check whether the material is properly magnetized or not by using a field indicator.
- ✓ Spray magnetic particle inspection ink (iron ore) on the material surface.
- ✓ Then, demagnetize the material again with the help of electromagnetic yoke.
- ✓ Finally, count each and every gas porosity defects on the surface of the material. For defects which are very tiny to be seen by naked eyes, use a magnifying glass.

Ultrasonic test

- ✓ Properly clean the material to be tested.
- ✓ Adjust the range of values in which the test is going to be done on the ultrasonic flaw detector. The following are information regarding the ultrasonic flaw detector used while studying.

Equipment: Universal ultrasonic flaw detector

Model: USM 20

Manufacturer: Sonatest Plc, England



Figure 3.3 Universal ultrasonic flaw detector

- ✓ Apply a couplant oil on the material surface to be tested in order to avoid air gap between the probe and the surface.
- ✓ Finally, move the probe on the material surface and record all readings displayed on the ultrasonic flaw detector.

Hardness test

The following are information regarding the machine used to test the hardness of the experimented products.

Equipment: Rockwell hardness testing machine

Model: 4150 LK

Manufacturer: Indentec Hardness Testing Machines Limited, England

Capacity: Minor load = 10kgf

Major load = 150kgf



Figure 3.4 Rockwell hardness testing machine

- ✓ Adjust scale, load, indenter type and dwell time on the machine.
- ✓ Place the material to be tested on the platform of a machine.
- ✓ Raise the platform using an elevating screw to bring the material in contact with the indenter.
- ✓ Apply a load until the machine reads the position of the pointer on the scale, which gives the hardness value.
- ✓ Repeat the procedure five times and take the average to know the exact value of hardness for that particular product.

Compressive strength test

The following are information regarding the machine used while testing the compressive strength of the experimented products.

Equipment: Universal material tester, hydraulically operated

Model: WP310

Manufacturer: G.U.N.T Gerätebau GmbH, Germany

Capacity: 50kN



Figure 3.5 Universal material tester

- ✓ Prepare three specimens from each of the materials to be tested according to DIN 50106: 2016-11 standard.
- ✓ Mount a specimen on the universal testing machine between a fixed and movable jaws.
- ✓ Adjust the load range to 50kN.
- ✓ Switched on the computer and adjust type of test, material type and dimensions.
- ✓ Switch on the machine and apply a compressive load up to the ultimate value.
- ✓ Print out the values recorded by the computer.

3.4 Conceptual Framework for the Methodology

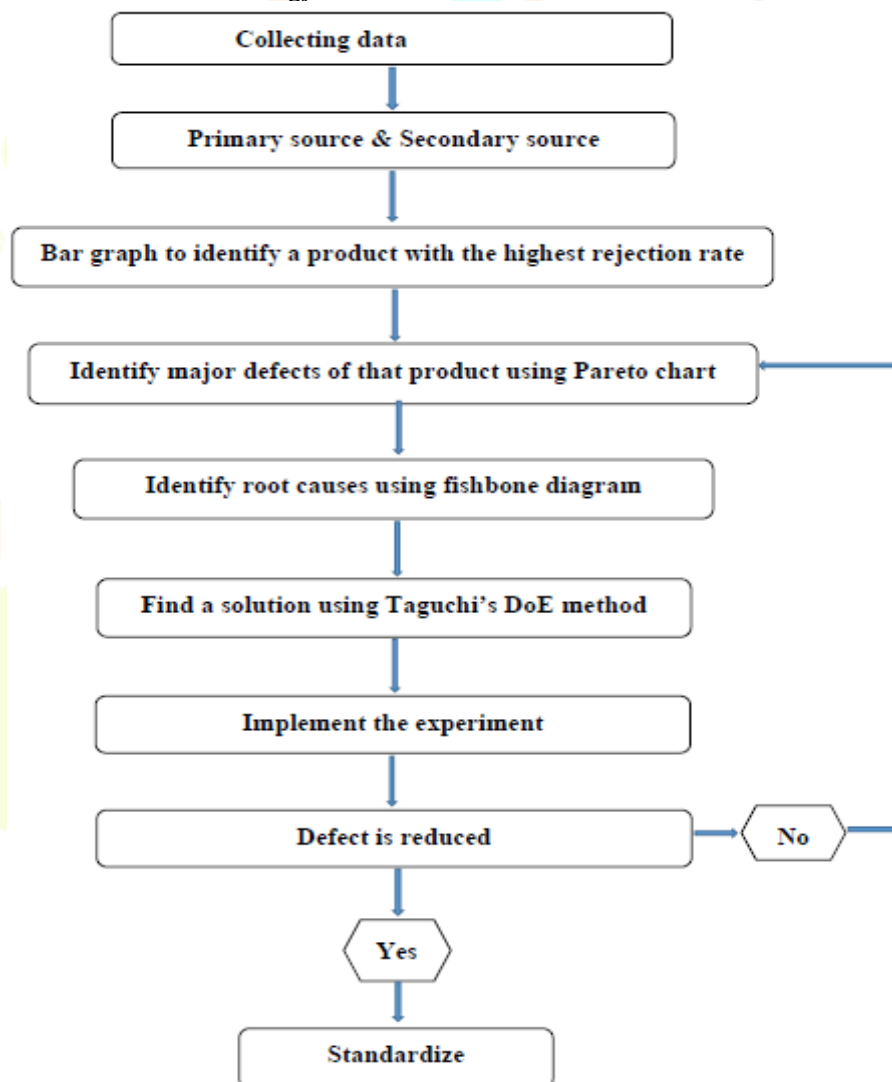


Figure 3.6 Conceptual framework for the methodology

RESULTS AND DISCUSSIONS

In this research, an experimental study was conducted on the foundry of Satish Industries & Foundry. Annual reports from 2021 to 2024 were examined in order to get relevant information regarding casting defects, rejection rates and root causes. To select a specific product for a case study, careful analysis on rejection percentages of every defective products was done. Quality control tools such as bar graph, Pareto chart and cause and effect diagram were implemented for the analysis purpose

4.1 Product Selection

Four years annual reports (2021-2024) on rejection rates of defective castings were collected from the industry's quality department. The frequencies of rejections on each defective castings were shown as follows using a bar graph:

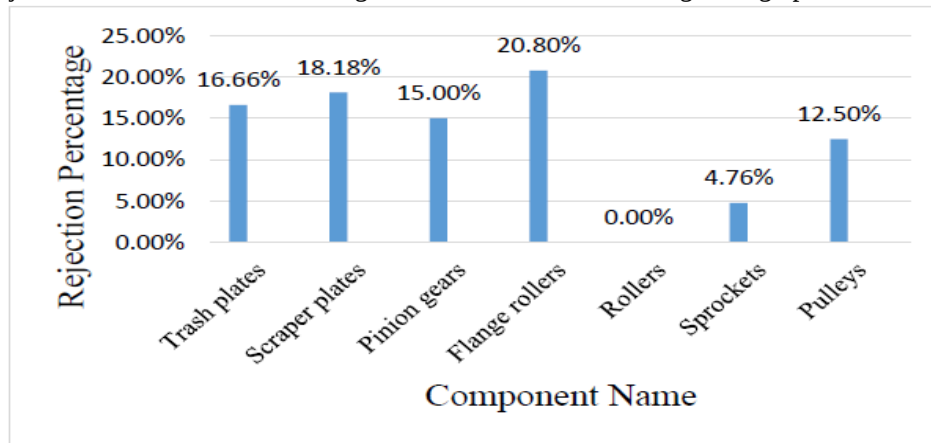


Figure 4.1 Bar graph on rejection rates of different products in 2021.

From Figure 4.1 it was identified that, in 2021 flange roller was the primary rejected product which had about 20.80 rejection percentage. Next to it, scraper plate and trash plate were the most rejected ones with rejection percentages of 18.18 and 16.66 respectively.

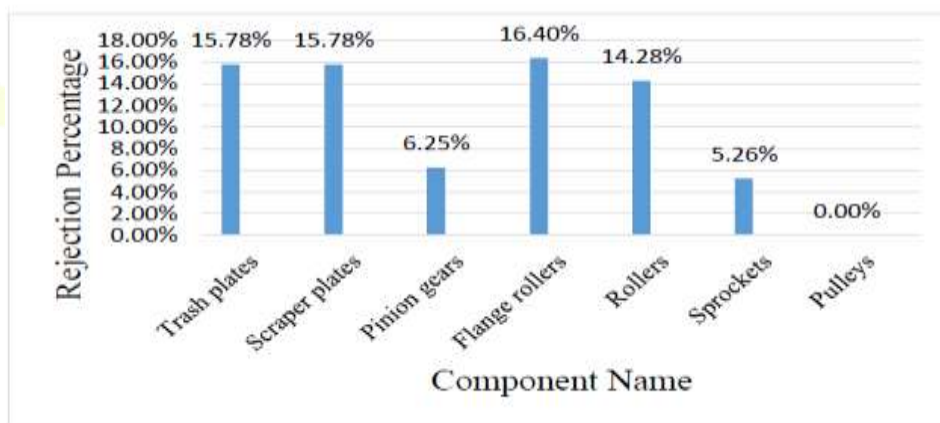


Figure 4.2 Bar graph on rejection rates of different products in 2022.

In 2022, the data on rejection rates of different products showed that, flange roller was the most rejected product with 16.40 rejection percentage and is followed by products such as scraper plate and trash plate which had rejection percentages of about 15.78%.

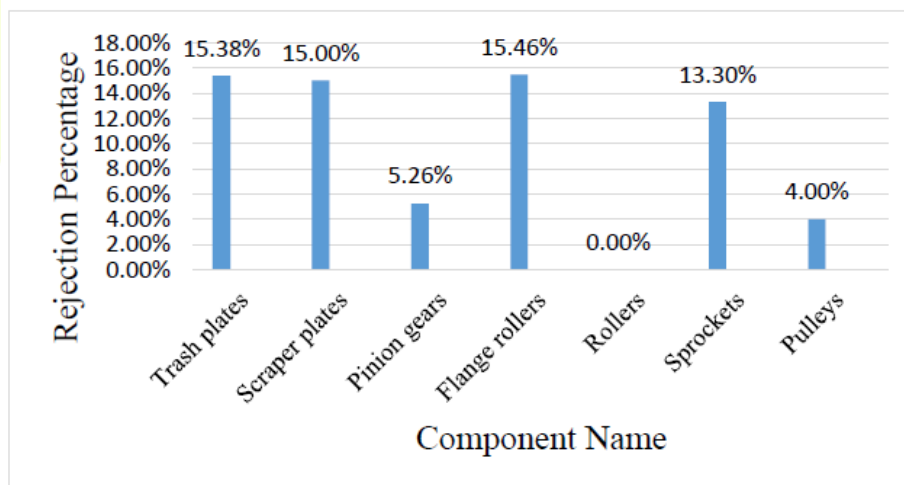


Figure 4.3 Bar graph on rejection rates of different products in 2023.

From Figure 4.3 it was observed that in 2023, flange rollers faced largest rate of rejection which was about 15.46% and is followed by a trash plate which had a rejection percentage of 15.38. Thirdly, scraper plates had high rejections which was about 15%.

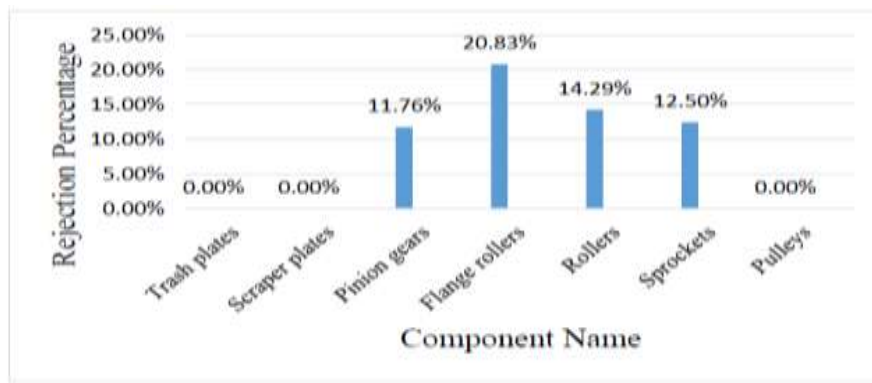


Figure 4.4 Bar graph on rejection rates of different products in 2024.

As shown on Figure 4.4 in 2024, the worst product which had largest rate of rejection was flange roller with a rejection rate of 20.83%. Secondly, roller was the next most rejected product with a rejection percentage of 14.29%.

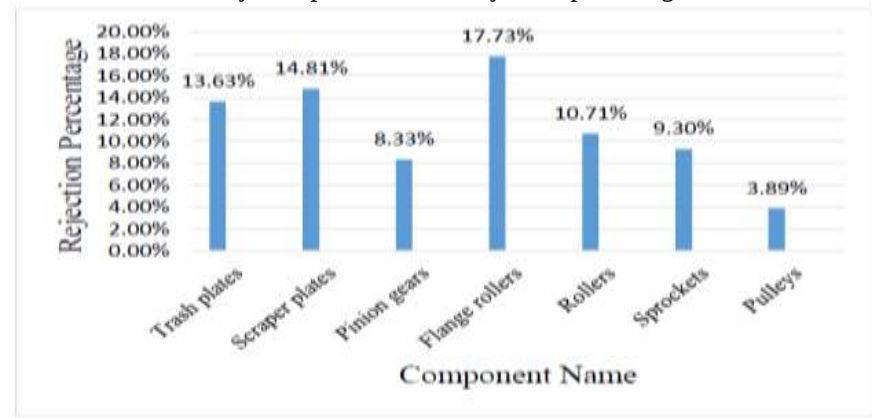


Figure 4.5 Bar graph on rejection rates of different products from 2021-2024.

Totally, within the last four years about 17.73% of flange rollers were rejected hence, is selected as the primary rejected product as it had largest rejection percentage when it is compared to the other ones. Therefore, according to the available cost and time, a detail investigation was carried out on this most rejected product, flange roller. The figure below shows the image of a flange



Figure 4.6 Flange roller

4.2 Product Description

A product selected for this study was a one sided flange roller made out of grey cast iron to provide as a wheel for industrial carts by being mounted on a roller shaft. It was mainly produced for Metehara sugar factory. The primary ingredient for the product was pig iron and other elements such as C, Si and Mn were also added. The composition of the material is given as follows:

Table 4.1 Composition of a flange roller at Satish Industries & Foundry.

Chemical compositions	C	Si	Mn
	3.5%	2.5%	0.6%

Table 4.2 Standard Parameters for the flange roller at Satish Industries & Foundry.

Material	Grey cast iron
Average mass of the product	7kg
Shrinkage allowance	1%
Draft angle	20
Sand	New silica sand mixed with reclaimed sand
Sand grain size	40-60AFS
Resin (binder)	Furfuran alcohol, 1.2%
Catalyst	Sulfonic acid, 0.6%
Melting temp	1500-1650°C
Material	Grey cast iron
Average mass of the product	7kg
Shrinkage allowance	1%

4.3 Defects on Flange Rollers

The following were frequencies of defects and percentage of rejections on flange rollers from 2021-2024 (Annual Report).

Table 4.3 Defects and percentage of rejections on flange rollers

Year	Inspected Qty	Total rejection	Porosity	Cracks	Inclusion	scab	Mis- run	Mis-match	% of rejection
2021	234	47	17	8	4	0	7	11	20.8%
2022	250	41	28	3	2	0	4	4	16.4%
2023	194	30	12	0	1	2	8	7	15.46%
2024	72	15	9	1	2	0	1	2	20.83%
Total	750	133	66	12	9	2	20	24	17.73%

4.4 Pareto Analysis

To identify a major defect which contributed more on the rejections of flange rollers, a Pareto analysis was applied. It works on 80/20 principle which stated that 80% of rejection occurs only due to 20% defects [42]. The figures below show the rate of defects on the product within the last four years.

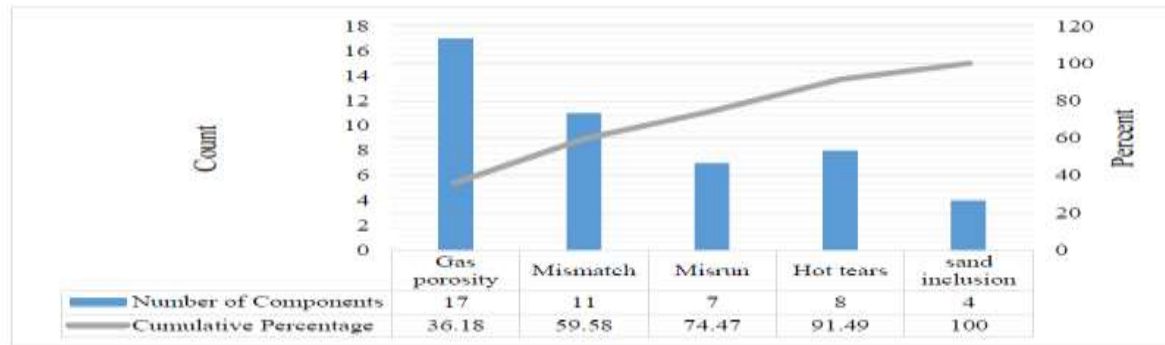


Figure 4.7 Pareto chart for the defects of the flange rollers in 2021.

From Figure 4.7 it was observed that, in 2021, the main cause for the rejections of the product was gas porosity. Among 234 flanges, 36.18% were rejected only due to gas porosity. Other defects such as mismatch, misrun, hot tears and sand inclusion had contribution of about 23.40%, 14.89%, 17.02% and 8.51% respectively.

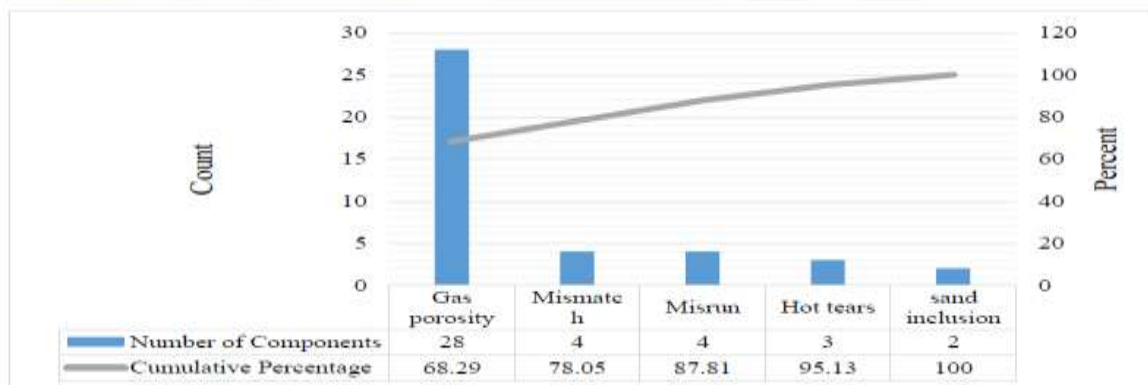


Figure 4.8 Pareto chart for the defects of the flange rollers in 2022.

From Figure 4.8 it was identified that, in 2022, the main cause for the rejections of the product was gas porosity. From 250 flanges, 68.29% flanges were rejected due to gas porosity. Other defects such as mismatch, misrun, hot tears and sand inclusion had contribution of about 9.76%, 9.76%, 7.32% and 4.87% respectively.

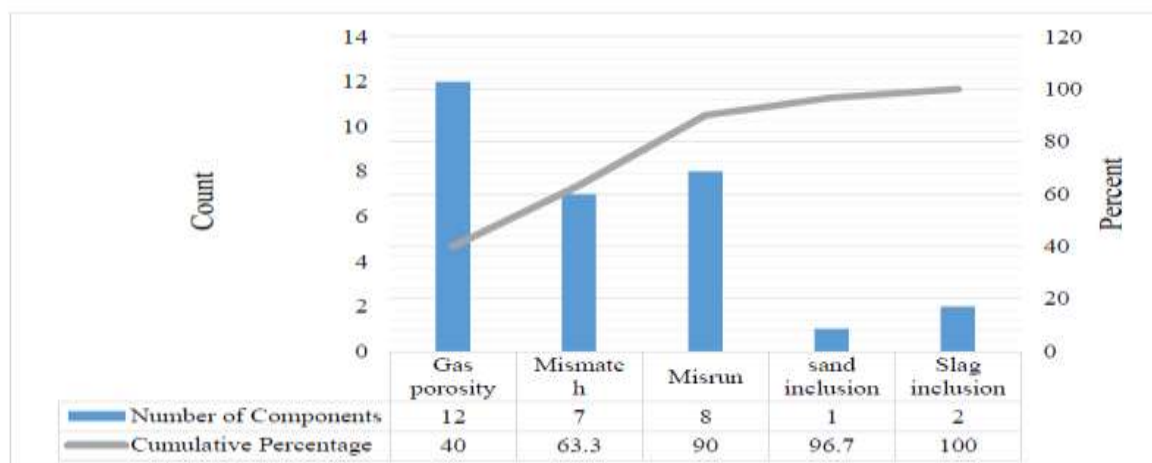


Figure 4.9 Pareto chart for the defects of the flange rollers in 2023.

From Figure 4.9 it was observed that, in 2023, the main cause for the rejections of the product was gas porosity. Among 194 flanges, 40% were rejected due to gas porosity. Other defects such as mismatch, misrun, sand inclusion and slag inclusion had contribution of about 23.3%, 26.7%, 3.3% and 6.7% respectively.

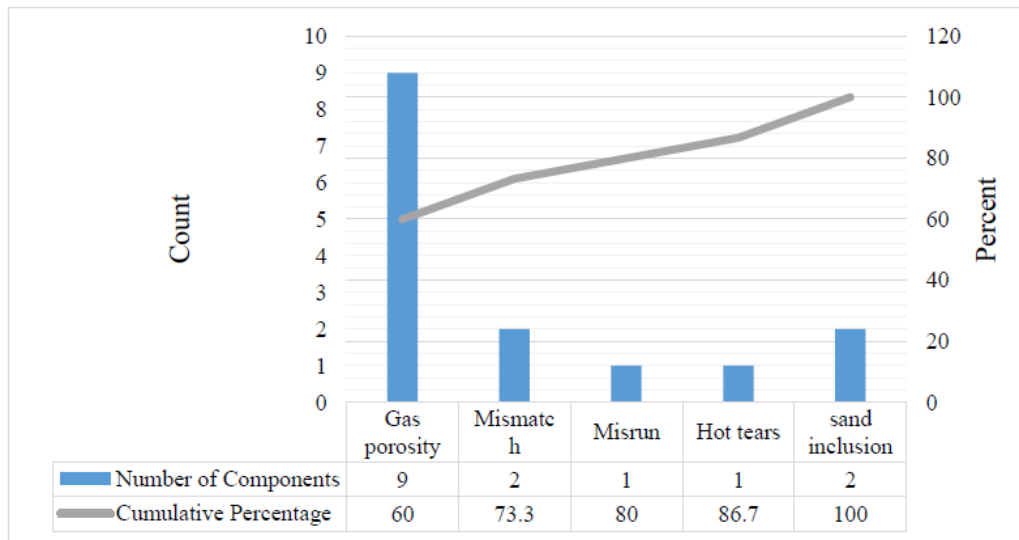


Figure 4.10 Pareto chart for the defects of the flange rollers in 2024.

From Figure 4.10 it was known that, in 2024, the main cause for the rejections of the product was gas porosity. From 72 flanges, 60% flanges were rejected due to gas porosity. Other defects such as mismatch, misrun, hot tears and sand inclusion had contribution of about 13.3%, 6.7%, 6.7% and 13.3% respectively.

EXPERIMENTAL WORK RESULTS

In the case company, the casting process used while producing parts was a sand casting process. In the sand casting, to have a certain product, general procedures such as pattern making, mold and core preparation, melting and pouring, solidification and shake out should be carried out [7].

According to the selected orthogonal array, to achieve a desired goal, it was compulsory to perform at least nine experiments. Therefore, here in this study, nine experiments were carried out. Before starting to prepare each molds, grain size and moisture content of the sand were tested and the following results were gained from the mentioned tests.

Future Scope of the Study

The quality of a product in sand casting operation can be affected by a number of parameters involved in the process. Therefore, it is necessary to optimize all parameters as much as possible to get a tremendous product. Hence, for a better improvement, other important parameters such as gating system design, sand permeability, scrap quality, pouring speed and solidification time should be studied in the future in order to obtain their optimum values.

REFERENCES

- [1] S. Rajender, *Introduction to basic manufacturing process*, Second edition. New Delhi: New Age International Publisher, 2006.
- [2] T. Aleksander, "Overview of foundry processes and technologies." USITC, 2005.
- [3] T. Beza, "Minimization of sand cast defect through integration of Failure Mode Effect Analysis (FMEA) with casting simulation," MSc., Adama Science and Technology, Adama, 2017.
- [4] D. M. Netsanet, "Porosity Effect Analysis on the Dimension of Cast Pinion Gear, Drive Disc and Head Stock Components of Manganese Steel," MSc., University of Addis Ababa, Addis Ababa, 2016.
- [5] M. Narasimha, R. Rejickumar, and K. Sridhar, "Statistical Methods to Optimize Process Parameters to Minimize Casting Defects," *Int. J. Mech. Eng. Technol.*, vol. 4, no. 3, pp. 11–23, 2013.
- [6] A. Samuel, F. Samuel, Doty H, and Valtierra S., "Porosity formation in Al – Si sand mold castings." Elsevier B.V, 2017. [Online]. Available: <http://dx.doi.org/10.1007/s40962-016-0129-0>
- [7] C.W Ammen, *Metalcasting*, illustrated, reprint, revised ed. McGraw Hill Professional, 1999.
- [8] M. M. Viqar, A. Krishnaiah, and H. S. Ferhathullah, "Optimization of Sand Mould Type and Melting Parameters to Reduce Porosity in Al-Si Alloy Castings," *Leonardo Electron. J. Pract. Technol.*, vol. 3, no. 28, pp. 93–106, 2016.
- [9] S. Sumaiya, Md. Tariquzzaman, R. Md. Habibur, Md. Al Amin, and R. Md. Abdur, "Optimization of Molding Sand Composition for Casting Al Alloy," *Int. J. Mech. Eng. Appl.*, vol. 5, no. 3, pp. 155–161, 2017.
- [10] P.R. Carey and M. Lott, "Sand binder systems." ASKCHEMICALS L.P, USA, 2011.
- [11] M. Dalgobind, "Casting and casting processes," *Int. Res. J. Eng. Technol.*, vol. 2, no. 5, pp. 2–28, 2015.
- [12] T. P. Rahul, S. M. Veena, and S. T. Shubhangi, "Causes of Casting Defects with Remedies," *Int. J. Eng. Res. Technol.*, vol. 4, no. 11, pp. 639–644, 2015.
- [13] Kumar. M. Saravana and Prakash. K. Jeya, "Optimization of Casting Process Parameters using Taguchi Analysis," *Int. J. Mech. Eng. Res.*, vol. 5, no. 1, pp. 134–136, 2015.
- [14] Siddalingswami, S. Hiremath, and S. R. Dulange, "Advanced Techniques in Casting Defects and Rejection Analysis: A Study in an Industry," *Int. J. Innov. Eng. Res. Technol.*, vol. 2, no. 9, pp. 1–9, 2015.