International Journal of Advance Research in Science and Engineering
Volume No. 14, Issue No. 04, April 2025
www.ijarse.com
IJARSE
ISSN 2319 - 8354

Defect analysis and remedies of Flange forging component to improve overall productivity by using quality tools

Rohan Desai[1], Prof. Mahesh A. Sutar[2], Prof. S S Petkar[3]

[1]Student, Department of Mechanical Engineering, Shri Balasaheb Mane Shikshan Prasarak Mandal's Ashokrao Mane Group of Institutions, Wathar, MH, India

[2-3]Assistant Professor, Department of Mechanical Engineering, Shri Balasaheb Mane Shikshan Prasarak Mandal's Ashokrao Mane Group of Institutions, Wathar, MH, India

ABSTRACT

Forging is an essential manufacturing process used to produce strong and durable components. However, defects in forged parts can lead to high rejection rates, production delays, and increased costs. This study focuses on identifying defects in Flange forging components, analyzing their root causes, and implementing solutions using quality improvement tools. Common forging defects such as mismatch, underfill, scale pits, flash extension, excess grinding, and cracks are examined. Among these, underfill and cracks are found to be the most frequent defects in Flange forgings. Their root causes are analyzed using Ishikawa diagrams and why - why analysis to identify key problem areas. To reduce defects and improve product quality, process parameters are optimized. Corrective actions such as die modifications, process adjustments, and improved material selection are explored. The study also highlights how small but crucial changes in heating methods, billet positioning, and forging pressure can significantly minimize defects. Additionally, regular maintenance of dies and quality control checks play a key role in achieving better forging results. The findings show that structured defect analysis and corrective measures lead to a significant reduction in scrap and rework, ultimately improving productivity and efficiency in the forging industry. This research provides valuable insights for manufacturers aiming to enhance the reliability, performance, and cost-effectiveness of forged components.

Keywords— *Forging defects, Flange forging, Quality tools, Defect analysis, Process optimization, Productivity improvement, Forging industry.*

I. INTRODUCTION

Forging is a dynamic three-dimensional manufacturing process where compressive and bending stresses play a major role. This process is broadly classified into three types: open die forging, closed die forging with flash, and closed die forging without flash. Due to its ability to produce components with superior mechanical properties and high productivity, forging remains a crucial method for manufacturing various shapes and sizes using different metals. It is widely used in industries that require parts capable of withstanding high dynamic loads and stresses, such as engine components (e.g., crankshafts and connecting rods), turbine blades, structural elements, and agricultural machinery. However, forging is not limited to high-load applications, many less demanding components are also effectively produced through this process [1]. One of the most critical aspects of hot forging is die life, as the forming die endures significant loads and high temperatures while shaping the workpiece into its final form. The longevity and efficiency of the dies directly impact the overall forging process, making their design and durability key considerations. With advancements in tooling, materials, and high-capacity machines, the focus of modern forging technology has shifted toward achieving high precision and efficiency in production [2]. The goal is to manufacture defect-free forged components while minimizing material waste, reducing scrap rates, and optimizing production time.

The quality of a forged component depends on multiple factors, including the initial billet shape, the starting temperature of the material and dies, forming speed, friction conditions, and the number and design of intermediate dies. By carefully controlling these parameters, manufacturers can enhance the quality and reliability of forged products, ensuring better performance and cost efficiency [3].

International Journal of Advance Research in Science and Engineering
Volume No. 14, Issue No. 04, April 2025
www.ijarse.com
IJARSE
ISSN 2319 - 8354

II. DATA COLLECTION AND COMPONENT SELECTION

2.1. Selection of Component

The Sponsored industry is a big manufacturer of forging components. There are nearly 138 components which are manufactured in this industry.

Table 1: Rejection percentage components in October 2024

Sr No	Item Name	Wt of each item (Kg)	Qty of forging / m	Rej. Qty	Rej. Wt (Kg)	Rej. %
1	Flange B	0.416	112367	9653	4015.6	8.6
2	Flange Pump	0.6	25034	1534	920.4	6.1
3	Cap Con Rod	1.388	11203	675	936.9	6.0
4	Lug Shift	0.551	5320	290	159.8	5.5
5	Cap Con Rod	1.388	12520	642	891.4	5.1
6	Selector Shaft	0.620	32300	1524	944.9	4.7
7	Clamp Enjector	0.250	8200	356	88.9	4.3
8	Pawl Park Lock	0.265	6124	265	70.2	4.3
9	Butterfly valve	0.181	1636	68	12.3	4.2

These components are produced in the different production batches and shifts. Selection of the components is our basic objective to complete. To select the appropriate component we need to check all the forging components in the industry. We need to check the components which are having maximum rejection. After studying all the components in the industry we have selected the 9 components with maximum rejection of month October 2024. The rejection percentage components in October 2024 are tabulated in table 1.

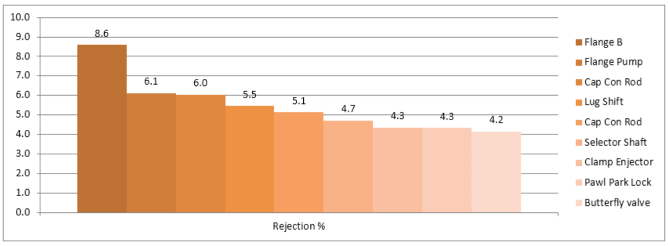


Figure 1: Pareto analysis of Forging components

After doing above Pareto analysis we can conclude that the rejection percentage of Flange B is more. The percentage of rejection for Flange B is 8.6%. The graphical representation of the rejection analysis is shown in figure 1.

Figure 2: Flange B Forging component

2.2. Parameters for Defect Analysis

After selecting components for study, the actual rejection analysis will start. Next step is to know the various parameters required for defect analysis of the forging component. The Major parameters responsible for the introduction of the defects in the system are temperature, cut weight, cut length, power pot, speed pot, etc. This all parameters are mentioned as below. This type of data will be recorded for each month (2-4 months) until the quantity of those major defects come down to required rejection percentage.

Table 2: Responsible parameters for defects

Cut Weight	0.245 Kg
Section Diameter	Dia 22 mm
Cut Length	83 mm
Temperature	1180 degree Celsius
Power pot	245 W
Speed Pot	45 %
Die coat	White graphite with 1:15 Ratio

III. REJECTION ANALYSIS

This chapter includes the core portion of rejection analysis. The rejection is 8.6%, which is more in the forging. The quality tools like Ishikawa diagram and why why analysis will be used to reduce the defects.

3.1. Rejection Analysis and Process Improvement

After selection of component next step is analysis of the Frange B. The collected data for the first month of each component shows that the rejection percentage is not in acceptable limits. The rejection is 8.6%. The improvements needed in process to control the rejection percentage. The improvements will be done with the help of rejection analysis. Following table shows defect wise rejected quantity of the forging.

Table 3: Defectwise quantity of Flange B (Oct 2024)

Defects	Rejection qty
Underfill	4521
Crack	1720
Mismatch	1342
Scale pit	980
Excess Grinding	640
Dent	450

3.2. Analysis of Defects by using Ishikawa Diagram

3.2.1. Ishikawa diagram for underfill defect

The Ishikawa diagram for underfill defect is mentioned below:

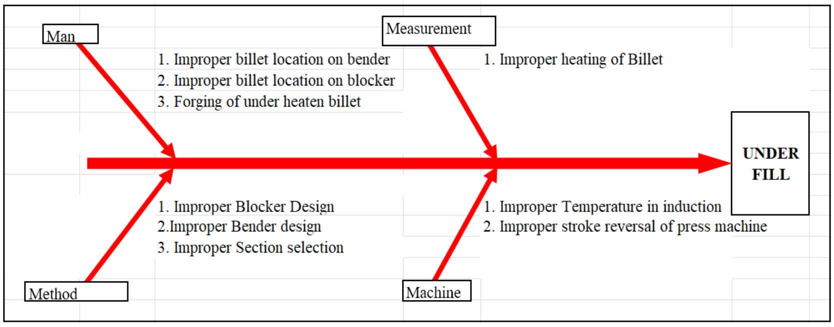


Figure 3: Ishikawa diagram for Underfill Defect

Causes and Remedies for Underfill Defect in Forging

1. Billet Size & Shape

- **Cause:** Incorrect billet dimensions (undersized or irregular shape).
- **Remedies:**
  - Ensure accurate billet sizing as per design specifications. The required billet size should be 83 mm and diameter of billet should be Dia 22 mm.
  - The Billet should be made flat to 18 mm for better material distribution.

2. Billet Heating

- **Cause:** Inadequate heating or uneven temperature distribution.
- **Remedies:**
  - Maintain optimal billet heating temperature based on material type. The heating temperature should be from

1150 degree to 1180 degrees Celsius.

- Use infrared thermometers or thermal cameras to measure the temperature.

3. Die Design

- **Cause:** Insufficient flash land or improper cavity design.
- **Remedies:**
  - Modify die design to improve metal flow. The Upsetter, Blocker and Finisher should be designed as per standards of die design.

4. Insufficient Forging Load

- **Cause:** Low press tonnage or insufficient hammering force.
- **Remedies:**
  - Increase forging load to ensure complete die filling.
  - Use a properly rated press/hammer for required force.

5. Improper Die Alignment

- **Cause:** Misalignment of upper and lower dies affecting material flow.
- **Remedies:**
  - Regularly inspect and align dies to prevent improper metal flow.
  - Use dowel pins or guides for precise alignment.

6. Friction & Lubrication

- **Cause:** Excessive friction preventing proper material flow.
- **Remedies:**
  - Apply appropriate die lubrication to reduce friction.
  - Use graphite-based lubricants for hot forging with ratio of 1:15 should be used.

7. Preforming Issues

- **Cause:** Inadequate material distribution in preform stage.
- **Remedies:**
  - Optimize preform design for better material distribution.
  - Use closed-die preforming to minimize material loss.

8. Forging Speed

- **Cause:** Too high or too low deformation speed affecting material flow.
- **Remedies:**
  - Adjust stroke speed of forging press based on material type.
  - Conduct trials to determine the optimal forging speed.

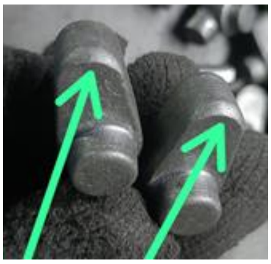


Figure 4: Underfill defect of Flange B

3.2.2. Ishikawa diagram for Crack defect

The Ishikawa diagram for Crack defect is mentioned below:

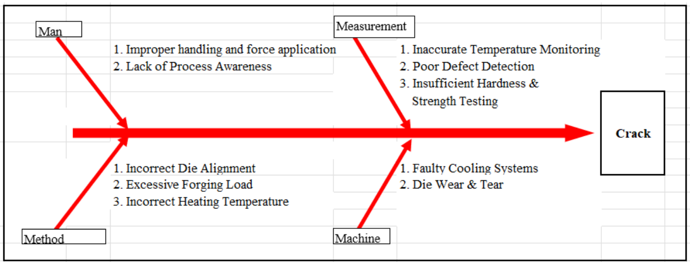


Figure 5: Ishikawa diagram for Crack Defect

Causes and Remedies for Crack Defect in Forging

1. Improper Material Selection

- **Cause:** Use of material with low ductility or poor forgeability.
- **Remedies:**
  - Choose materials with high toughness and good forgeability.
  - Use preheated billets for improved plasticity.

2. Excessive Forging Load

- **Cause:** Applying excessive force beyond the material's ductility limit.
- **Remedies:**
  - Optimize forging force based on material properties.
  - Use controlled deformation techniques to prevent overstressing.

3. Inadequate Billet Heating

- **Cause:** Insufficient or uneven heating leading to low ductility.
- **Remedies:**
  - Maintain proper billet heating temperature using infrared thermometers.
  - Ensure uniform heating through controlled induction or furnace settings.

4. Die Misalignment

- **Cause:** Poor alignment of upper and lower dies causing stress concentration.
- **Remedies:**
  - Regularly inspect and align dies before production.
  - Use precision guide pins or automated die alignment systems.

5. Sharp Corners in Die Design

- **Cause:** Sharp edges in die cavities cause stress concentration.
- **Remedies:**
  - Modify die design with fillets and smooth transitions.
  - Use CAD simulations (QForm, DEFORM) to analyze stress points.

6. Rapid Cooling of Forged Component

- **Cause:** Sudden cooling causes thermal stresses leading to cracks.
- **Remedies:**
  - Use controlled cooling methods such as furnace cooling.
  - Avoid direct water quenching unless required for hardening.

7. Poor Lubrication

- **Cause:** High friction leading to non-uniform material flow and cracking.
- **Remedies:**
  - Apply proper die lubrication to reduce stress concentration.
  - Use graphite-based lubricants for hot forging and oil-based for cold forging.

8. Inadequate Preforming

- **Cause:** Poor material distribution leading to localized stress.
- **Remedies:**
  - Optimize preform shape to distribute material evenly.
  - Use multi-step preforming techniques to reduce stress points.

9. Inclusion or Impurities in Material

- **Cause:** Presence of non-metallic inclusions weakening the structure.
- **Remedies:**
  - Use high-quality, defect-free billets from reliable suppliers.
  - Implement strict material inspection and ultrasonic testing (UT).

10. Incorrect Die Temperature

- **Cause:** Cold dies cause rapid cooling and induce cracks.
- **Remedies:**
  - Preheat dies to the recommended temperature before forging.

o Use temperature-controlled die heating systems.

Figure 6: Crack Defect in Flange

3.3. Corrective actions (Phase I)

The Ishikawa diagram analysis highlights the primary cause of rejection is due to the improper billet cutting. While other factors, such as improper die heating, improper lubrication and excess force on the die, also contribute to the defects. Temperature, however, is considered a separate factor. As a result, the first priority is to address issues related to the billet cutting.

Corrective Actions for Underfill and Crack Defects with Respect to Billet Cutting

1. Accurate Billet Length & Weight

- Ensure precise billet length and weight to provide adequate material for complete die filling.
- Use automated cutting machines to maintain consistency in billet dimensions.

Figure 7: Billet Size

Figure 8: Automatic cutting machine

2. Proper Cutting Method

- Use shearing or sawing methods that produce clean, burr-free edges to prevent stress concentration.
- Avoid excessive cutting force, which may induce microcracks in the billet edges.

3. Regular Blade/Machine Maintenance

- Maintain sharp cutting blades to prevent uneven or rough cuts that may cause defects.
- Periodically calibrate billet-cutting machines to ensure accuracy in dimensions.

4. Minimize Material Wastage & Variation

- Standardize the cutting tolerance to ensure uniform billet size and volume.
- Monitor billet dimensions using inspection tools like calipers and micrometers.

5. Proper Handling After Cutting

- Avoid dropping or stacking billets improperly, as this may create surface cracks.
- Store billets in a controlled environment to prevent oxidation and contamination before forging.

By implementing these corrective actions, **underfill defects (due to insufficient material) and crack defects (due to improper cutting stress)** can be significantly reduced, leading to improved forging quality and productivity.

3.4. Defect-wise analysis of Flange B in November 2024

After first remedial action, we have collected the defect wise data in month of **November 2024** and it is tabulated as below. The rejection is decreased from 8.6% to 5.7% after application of remedial actions. The defects like excess grinding are man made defects, which will be reduced after proper training to persons. Table 4 shows the Defect-wise analysis of Flange B (November 2024).

Table 4: Defectwise quantity of Flange B

Defects	Rejection qty
Underfill	3200
Crack	1100
Mismatch	800
Scale pit	432
Excess Grinding	520
Dent	344

The above table shows the rejection quantity of major defects.

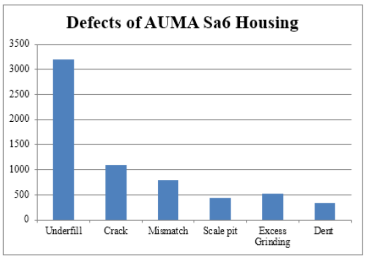


Figure 9: Defects in month of November 2024

The percentage of the defects is decreased compare to previous month but still the overall percentage is more in the forging. Thus, we will go for why why analysis of the defects mentioned above.

3.5. Analysis of Defects by using Why Why analysis

3.5.1. Why Why analysis of Underfill Defects:

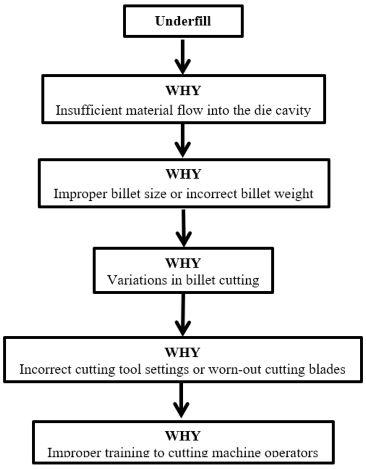


Figure 10: Why why analysis of Underfill defect

Remedial Actions

Optimized Billet Size & Weight:

- Ensure precise billet cutting with calibrated cutting tools
- Regular inspection and replacement of worn-out cutting blades

Improved Heating Process:

- Standardize heating temperature and soaking time. Its is mentioned in table 2.
- Implement infrared thermometers for accurate temperature monitoring
- Use automated temperature control systems to avoid overheating/underheating

Enhanced Die Design & Process Parameters:

- Ensure proper preform design for better material flow. The upsetter gap should be reduced to 17 mm.
- Optimize press force and forging temperature. The flash gap is kept 2 mm for finisher and 2.5 mm for blocker.
- Increase die lubrication to reduce friction and allow smooth material flow

Preventive Maintenance & Quality Checks:

- Conduct regular die inspections to detect wear and misalignment
- Train operators to ensure process consistency and minimize errors

3.5.2. Why Why analysis of Crack Defects:

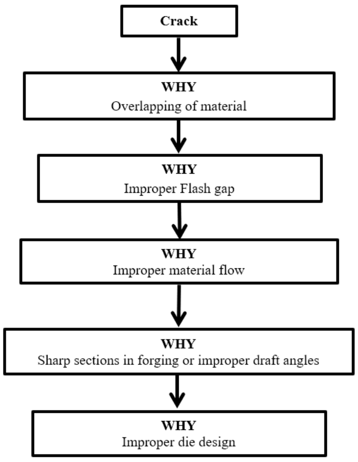


Figure 11: Why why analysis of Underfill defect

Remedial Actions

Die Design Improvements

- Increase fillet radii in die design to reduce stress concentration.
- Use computer-aided simulations (FEA) to predict crack-prone areas.

Material Selection & Handling

- Use high-quality raw materials with good ductility and toughness.
- Ensure proper grain structure through controlled cooling.

Optimized Heating & Cooling

- Maintain correct billet temperature during forging to avoid thermal stress.
- Use thermocouples for accurate temperature monitoring.

Process Control & Maintenance

- Conduct regular inspections of dies and tools for wear and tear.
- Implement strict quality control measures at each forging stage.

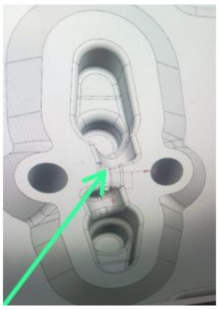
Training & Awareness

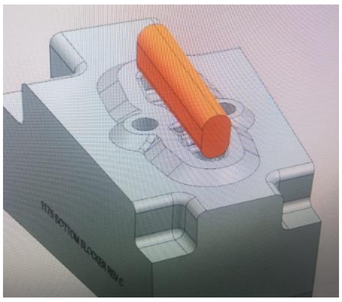
- Train operators on optimal forging techniques to minimize crack defects.
- Conduct root cause analysis regularly to prevent reoccurrence.

3.6. Corrective actions:

1. Die Design Improvements

- Ensure smooth die contours to avoid sharp edges and stress concentration.
- Increase fillet radii in die cavities to reduce crack formation.
- Make provision for location of buster to avoid crack
- Top die groove making to avoid stuck up at bottom





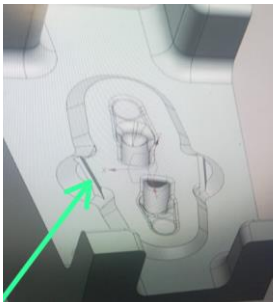


Figure 12: Improvement in Die **Figure 13:** Billet location on blocker **Figure 14:** Groove in top die to reduce

International Journal of Advance Research in Science and Engineering
Volume No. 14, Issue No. 04, April 2025
www.ijarse.com
IJARSE
ISSN 2319 - 8354

2. Proper Material Selection & Handling

- Use high-quality raw materials with sufficient ductility and strength.
- Ensure proper grain structure by controlling the cooling rate after forging.
- Avoid contaminated or substandard materials that can weaken the final product.

3. Optimized Heating & Temperature Control

- Maintain correct billet heating temperature to ensure proper metal flow. The details of the
- Use thermocouples and infrared sensors to monitor heating uniformity.
- Avoid overheating (which leads to cracks) and underheating (which causes underfill).

4. Process Control & Forging Parameters

- Ensure proper forging pressure and hammering force to prevent cracks.
- Use gradual deformation techniques instead of excessive force application.
- Maintain controlled lubrication to reduce friction and ensure even metal flow.

5. Regular Maintenance & Inspection

- Perform periodic die inspections to check for wear, misalignment, or damage.
- Replace or repair worn-out dies to maintain quality and consistency.
- Ensure proper die lubrication to prevent material sticking and flow issues.

6. Operator Training & Awareness

- Train workers on correct heating, positioning, and hammering techniques.
- Conduct regular defect analysis using tools like Ishikawa diagrams and Why-Why analysis.
- Promote a culture of quality control to identify and address defects early.

3.7. Defect-wise analysis of Flange B in December 2024

After first remedial action, we have collected the defect wise data in month of December 2024 and it is tabulated as below. The rejection is decreased from 8.6% to 2.8% after application of remedial actions. The excess grinding defect is reduced by training the workers. The other defects decreased once we tried to maintain the other parameters. Table 5 shows the Defect-wise analysis of Flange B (December 2024).

Table 5: Defectwise quantity of Flange B

Defects	Rejection qty
Underfill	1100
Crack	800
Mismatch	735
Scale pit	322
Excess Grinding	59
Dent	135

The above table shows the rejection quantity of major defects.

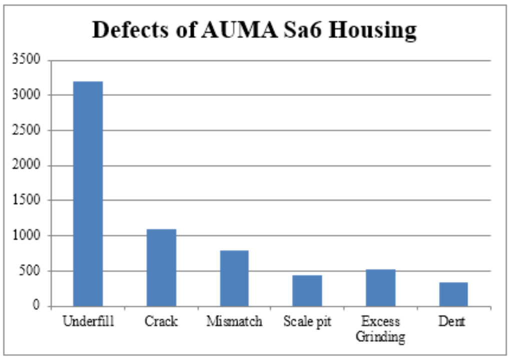


Figure 15: Defects in month of December 2024

The percentage of the defects is decreased compare to previous month but still the overall percentage is more in the forging. Thus, we will go for why why analysis of the defects mentioned above.

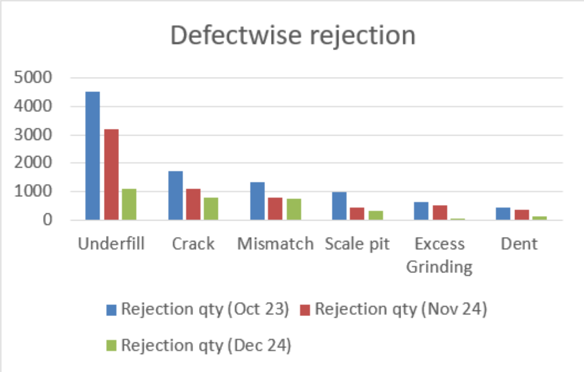


Figure 16: Defectwise rejection in month of Oct, Nov and Dec 2024

IV. CONCLUSION

The rejection analysis was conducted in Industry on Flange B forging component. The different quality tools were used to find the root causes for major defects. Flange B was studied and analysed for almost three months. the conclusions are as follow,

a) The final quality of forging depends on different process parameters throughout the whole process of the Forging. The parameters like temperature, billet size, die coat spraying time, etc are responsible parameters in Forging.

b) To identify root cause is a difficult task especially in forging process. Two quality tools, Ishikawa diagram and Why why analysis was used in this work to find root cause for major defects. The corrective actions are suggested for each defect.

c) The Most contribution in rejection was of Underfill and Crack defect. After applying the remedies suggested the rejection was reduced.

d) The total rejection of the all the defects was 8.6 %, in which contribution of Underfill was 4%, and Crack was Crack 1.5 %, and remaining was other defects. After applying the corrective actions on the root cause of defect analysed by Ishikawa tool, it was reduced upto 5.7 %, in which the contribution of Underfill was 2.8 % and crack was 1%. Overall all rejection was below reduced by 2.9% hence this analysis and corrective actions taken were correct.

e) To reduce the defects more the Why why analysis tool was used. The defects reduced upto 2.8%, in which the contribution of Underfill was 1% and crack was 0.7%. Overall all rejection was below reduced by 2.9% hence this analysis and corrective actions taken were correct.

REFERENCE:

[1] Miroslav Plančak1, Dejan Movrin, Igor Kačmarčik, Milentije Stefanović, Plavka Skakun , Dragiša Vilotić, "Comparative Analysis of Classical Forging and Orbital Forging of Cross Joint Component", Journal for Technology of Plasticity, Vol. 40 (2015), Number 2

[2] Chanin Tavichaiyuth and Yingyot Aue-u-Lan, "Evaluation of Forging Die Defect by Considering Plastic Deformation and Abrasive Wear in a Hot Forged Axle Shaft", Applied Science and Engineering Progress, Vol. 14, No. 1, pp. 60-71, 2021

[3] Hawryluk M, Kondracki P, Krawczyk J, Rychlik M, Ziemba J. "Analysis of the impact of forging and trimming tools wear on the dimension-shape precision of forgings obtained in the process of manufacturing components for the automotive industry" Eksploatacja Niezawodnosc – Maintenance and Reliability 2019; 21 (3): 476–484.

[4] Pankaj Chandna, Arunesh Chandra, "Quality Tools to Reduce Crankshaft Forging Defects: An Industrial Case Study", Journal of Industrial and Systems Engineering, Vol. 3, No. 1, pp 27-37 Spring 2009

[5] Sanjay Kumar, Kharat Anand Babasaeb, Khotkar Saurabh Dipak, "An Overview of Forging Process and Defects in Hot and Cold Forging", International Research Journal of Engineering and Technology (IRJET), Volume: 09 Issue: 07 | July 2022

[6] Shivlal Mewada, Anil Saroliya, N. Chandramouli, T. Rajasanthosh Kumar, M. Lakshmi, S. Suma Christal Mary, and Mani Jayakumar, "Smart Diagnostic Expert System for Defect in Forging Process by Using Machine Learning Process", Journal of Nanomaterials Volume 2022, Article ID 2567194, 8 pages https://doi.org/10.1155/2022/2567194

[7] Tejal Dinkar Raut, "The Improvement of Manufacturing Process by Using Quality Tools", International Journal of Engineering Research & Science (IJOER) ISBN:[978-93-5391-287-1] ISSN: [2395-6992] [Vol-5, Issue-3, March- 2020]

[8] Dana STANČEKOVÁ, Andrej CZÁN, Michal DERBAS, "Investigation of Defects in Forging Tools by Nondestructive Detection Method", University of Zilina, Zilina, Slovak Republic, EU, 15. - 17. 5. 2013, Brno, Czech Republic, EU

[9] Mr. Jadhav Vijay B., Prof. Mundhe V.L., Mr. Sabale Amol Dnyandeo, Mr. Walunj Abhimanyu Arjun, "Forging Defects Analysis in Suspension Arm and Product Development", GRD Journals- Global Research and Development Journal for Engineering | Volume 3 | Issue 1 | December 2017 ISSN: 2455-5703

[10] M. A. Khatode, S. V. Badnale, Y.N. Chate H. S. Deshmukh, Prof. M. N. Vaidya, "Design and Analysis of Forging Component and Die", IOSR Journal of Engineering (IOSR JEN) ISSN (e): 2250-3021, ISSN (p): 2278-8719 PP 58-65

[11] Jasleen Kaur, BS Pabla & SS Dhami, "A Parametric Analysis Of Deformation Of Workpiece, In Closed Die Forging", International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) ISSN (P): 2249-6890; ISSN (E): 2249-8001 Vol. 7, Issue 6, Dec 2017, 147-154

[12] Rohan K. Soyaliya, V. Parmar, Jayendra B. Kanani, "A Review on Unfilling Defect Found in Forging Process", IJSRD - International Journal for Scientific Research & Development| Vol. 3, Issue 10, 2015 | ISSN (online): 2321-0613

[13] Mahendra G. Rathi, Nilesh A. Jakhade, "An Effect of Forging Process Parameters on Filling the Job Weight: An Industrial Case Study", International Journal of Scientific and Research Publications, Volume 4, Issue 6, June 2014 ISSN 2250-3153

[14] Mahendra G. Rathi, Nilesh A. Jakhade, "An Overview of Forging Processes with Their Defects", International Journal of Scientific and Research Publications, Volume 4, Issue 6, June 2014 1 ISSN 2250-3153

[15] Marek R. Hawryluk, Marcin Rychlik, Sławomir Polak, Maciej Zwierzchowski, Łukasz Dudkiewicz , Jan Marzec , Paweł Jabłoński, "Analysis and Improvement of an Industrial Process of Hot Die Forging of an Elongated Forging Tipped with a Joggle with the Use of Numerical Simulation Results", Advances in Science and Technology Research Journal 2023, 17(2), 192–205 https://doi.org/10.12913/22998624/162158 ISSN 2299–8624, License CC-BY 4.0

[16] Mr. Praveena R, Mr. Mujebur Rehaman, Mr. Abhishek C R, Mr. Bharath Gowda G, "Study on Development of an Automated Open Die Forging Machine", International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181

[17] Mr. Bhavesh V Patel, Dr. Hemant R Thakkar, Prof. Shruti B. Mehta, " Review of Analysis on Forging Defects for Quality Improvement in Forging Industries", Journal of Emerging Technologies and Innovative Research (JETIR), Dec 2014 (Volume 1 Issue 7) JETIR (ISSN-2349-5162)

[18] F. Deschaux- Beaumea, F. Schmidta, N. FreÂtyb, T. Cutarda, J.C. Boyerc, C. Levaillant, "Numerical simulation of failure prediction for ceramic tools: comparison with forging test results", Journal of Materials Processing Technology 92±93 (1999) 502±507.

[19] Bhoop Singh, "Study of Various Factors Related to Quality in Forging Industry", International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181",

[20] Neta Łukaszek-Sołek, Sylwia Bednarek, Łukasz Lisiecki, Piotr Skubisz, "The Numerical Analysis Of Selected Defects In Forging Processes", Computer Methods in Material Science, Vol 19, 2019 No 3. ISSN 1641-8581, 89 – 99.

[21] P. Ruban and J. Jayaprakash, "Implementation of design for manufacturing in hot forging", Materials Science and Engineering 992 (2020) 012011 doi:10.1088/1757-899X/992/1/012011