Analysis of Forging Defects and Identification of Process Control Parameters – A Case Study

[1]Soni Jaiswal, [2]Prof. M. B. Sorte
[1]PG Student, [2]Associate Professor & HOD
[1, 2]Mechanical Engineering Department,
[1]Saraswati College of Engineering, Navi Mumbai, India

Abstract: **Due to the competitiveness and global pressure on manufacturing industry, each firm is trying to improve quality and reduce cost of the products. The objective of this paper is to investigate and analyze the various forging defects that occur in forging industries that causes the huge percentage of rejection in the forged components. Forging analysis is done to demonstrate how the forging defects occur and how to prevent them by selecting different process parameters. A case study approach is applied to investigate and analyze the forging defects that cause the rejection in forged components. Finally, the research is concluded that how several industries are able to control forging defects by improving optimum selection of process parameters.**

***Index Terms* – Forging defects, Process parameters, Quality control tools.**

I. INTRODUCTION

Forging is a metal working process in which useful shape of work piece is obtained by compressive force through the use of dies and tools. It is oldest metal working process originated thousands of years back.

In modern times, industrial forging is done either with press machines or with hammers powered by compressed air, electricity, hydraulics. Some examples of forged components are - Crane hook, connecting rod of an IC engine, spanner, gear blanks, crown wheel, pinion etc. Forging process produces parts of superior mechanical properties with minimum waste of material.

Forging defects are the imperfections that exceed certain limits. There are many imperfections that can be considered as being defects, ranging from those traceable to the starting materials to those caused by one of the forging processes or by post forging operations. In forging process, defects like unfilling, mismatch, scale pits, surface cracking, fold and lap, improper grain flow etc. are responsible for high rejection rates (Aju Pius, Sijo, et.al 2013). Sometime unfilling defects occurs due to metal does not fill the recesses of the die cavity completely during the forging process. It causes due to improper design of the forging die, die wear, improper use of forging techniques, less raw material, poor heating of raw material inside the furnace, etc. Christry Mathew et.al (2013) studied the forging analysis to explain how the defects occur and how to prevent them.

It can be avoided by proper die design, using proper raw material and proper heating of billets inside the furnace to get the desired forge ability of raw material. The effect of unfilling defect is that the job dimensions cannot be filled; ultimately the required final job weight cannot be filled completely as per the requirements of company standards (Rathi et. al, 2014). Due to presence of this defect, there will be insufficient material stock on forged component for subsequent machining operations, hence the job gets rejected.

In order to increase the product quality and to reduce the rejection rate due to defects, design activities need to systematically consider various designs and process related parameters and finally come out with the best parameters combination for better process performance (Sekhon et al. 2014).

1.1 Problem definition: In forging industry most of the rejection take place due to process defects that occurs due to improper process parameters i.e. billet weight, heating temperature, heating time etc. and remedial measures that can reduce these defects in the hot forging process.

1.2 Objective: The main objective of the study is through the process parameter identification improves the quality of the forging components by identifying and reducing the source of defects so that automatically the cost of the product will decrease.

II. LITERATURE REVIEW

Before the experimental part of the paper was stated a literature search was conducted to determine the state-of-the-art with respect to types and characteristics of defects in closed die forgings process. Although there have been some studies to examine internal forging defects reported in the technical literature, the number of articles is not large.

Vamsi (2002) discussed the phenomena of centre burst cracking, relating the changes the defect undergoes during the many stages of hot forging. The overall conclusion of the study was that the defects originated in the bar stock of the material and propagated during each phase. The center bursts were formed by a large concentration of "non metallic intrusions", providing an interesting argument of examining initial meta quality before industrial processing. The process parameters include input temperature of billet and die, interface friction, speed of deformation etc. These have been studied in a number of publications; some of the major ones would be dealt with.

Tomov et al. (2004) studied the hot forging process under closed die condition in terms of flash formation. A number of expressions proposed by earlier researchers for flash land calculation were compared using both analytical and numerical approaches. The best expression among the comparative work was identified so that it can be used as a first step for die design.
Saniee and Hosseini (2006) in their study showed that, input billet size and the flash dimension exercise a significant effect on both forging load and metal flow in the die. In a comparative experiment between two parts, it was observed that the die filling characteristic is more sensitive to size of billet, in case of component shapes having a horizontal axis of symmetry.
Aju Pius, Sijo et.al (2013) studied and investigate the various forging defects that occur in a forging industry that causes high rejection rates in the components and remedial measures that can reduce these defects in the hot forging. The investigation was done with the help of quality assurance department within the industry. The result indicates that the rejection rate in the company was more than five percent of the total productions made each month. The defects in the forged components includes the lapping, mismatch, scales, quench cracks, under filling etc. The remedial actions includes the proper use of anti-scale coating, venting process to prevent the under filling, the simulation software for determining the material flow, proper lubricant instead of furnace oil etc.
M.G. Rathi, N.A. Jakhade, et.al (2014) discussed forging defects those repeatedly occurring along with their cause and remedies. Then the fish-bone diagram are used to explore the possible causes of defect like unfilling, misma/tch and scale pit through a brainstorming session and to determine the cause which may have greatest effect.
M. Sekhon, Dr. G. Brar,et. al (2014) studied and investigate the various forging defects that occur in a forging industry. An analysis was done using six sigma technique and seven quality tools like Flow chart, Pareto diagram, Check sheet, Control chart, Histogram, Scatter plot, Cause and effect diagram. The major defects are cracks, scaling and low hardness. The remedial action includes the proper use of anti-scale coating, proper lubricant in the forging process.

III. METHODOLOGY

Methodology adopted for this project is a case study approach in forging industry in which optimization of the process parameters via three steps approach: system design, parameter design and tolerance design has come in picture. Initially, the process data was collected for the analysis of defects after that using quality tools like fishbone diagram, Pareto chart, Bar charts etc. the data has been plotted so that main source of occurrence for the particular defect has been find out.
To get the best process parameters combination, design of experiments (DOE) technique (like Taguchi method) is the most powerful approach. But before that, one important step is to determine the effect/influence of selected process parameters on final output. It is a method of designing experiments involving the testing of factors or causes, one at a time instead of all simultaneously. It involves:

- Moving one input variable, keeping others constant at their baseline (nominal) values, then,
- Returning the variable to its nominal value, and repeating for each of the other inputs in the same way.

IV. DATA COLLECTION AND ANALYSIS

The data have been collected from a forging industry "XYZ Limited" which is the manufacturer of stainless steel long products and stainless steel flanges. These flanges have major application in Pipeline engineering such as: Oil & gas – upstream & downstream, Mechanical & plant engineering, Ship building, Boiler and Pressure Vessels, Fertilizer industry, Waste water, Chemical & petrochemical, Power industries (nuclear, natural gas, wind, solar), Aerospace, Food processing industries.
With the help from QA department, we found that there has been huge rejection of material which leads to more production of material and more adding on cost. As to find corrective action, we investigated with last 2 month production vs rejection data from the month of Nov'17 and Dec'17.
We found that company is manufactured 17 types of Stainless steel flanges. In month of Nov'17, the total production of 238950 numbers in which 15795 numbers got rejected. It means the plant has a rejection rate of 6.6% in that month. In month of Dec'17, the total production of 226350 numbers in which 15310 numbers got rejected. It means the plant has a rejection rate of 6.8% in that month.
Below mentioned table 1 and 2 is the monthly rejection report for the Nov'17 and Dec'17 which is described in Defect wise rejection and it has been observed from the table that the rejection is more due to un-filling defects which contribute to high rejection in production quantity.

Table 1. Monthly Rejection Report (Nov. 2017)

			Defect wise rejected Qty. (in Nos.)								
S.No.	**Part No.**	**Prod. Qty (in Nos.)**	**Unfilling**	**Die shift**	**Improper grain flow**	**Lap**	**Flakes/ internal Crack**	**Surface crack**	**Dimension**	**Total Rejected Qty. (in Nos.)**	**Part Rejection (in %)**
1	2141	15000	450	45	40	80	210	156	45	986	6.6
2	2142	18000	380	40	45	75	205	165	40	905	5.0
3	2143	16000	410	35	38	68	256	145	35	949	5.9
4	2144	12550	305	49	35	74	175	202	45	850	6.8
5	3121	13650	288	36	42	89	258	207	56	934	6.8
6	3122	14700	212	32	36	91	278	198	65	876	6.0
7	3133	12800	298	45	39	78	196	178	56	851	6.6
8	3144	16500	480	54	41	65	203	189	69	1060	6.4
9	3155	12500	375	29	42	56	165	202	74	901	7.2
10	4142	14700	432	65	44	82	184	204	58	1025	7.0
11	4143	13500	285	54	45	87	195	213	66	900	6.7
12	4144	15600	198	51	45	78	165	188	74	754	4.8
13	4145	14300	175	56	39	69	206	122	78	706	4.9
14	5121	12200	453	55	37	66	212	147	77	1010	8.3
15	5122	11800	468	49	49	74	207	155	82	1035	8.8
16	5123	12600	388	48	54	77	274	189	84	1060	8.4
17	5124	12550	392	42	51	61	222	187	89	993	7.9
Total		**238950**	**5989**	**785**	**722**	**1270**	**3611**	**3047**	**1093**	**15795**	**6.6**
Defect wise % Rejection			**37.9**	**4.97**	**4.57**	**8.04**	**22.86**	**19.29**	**6.92**		

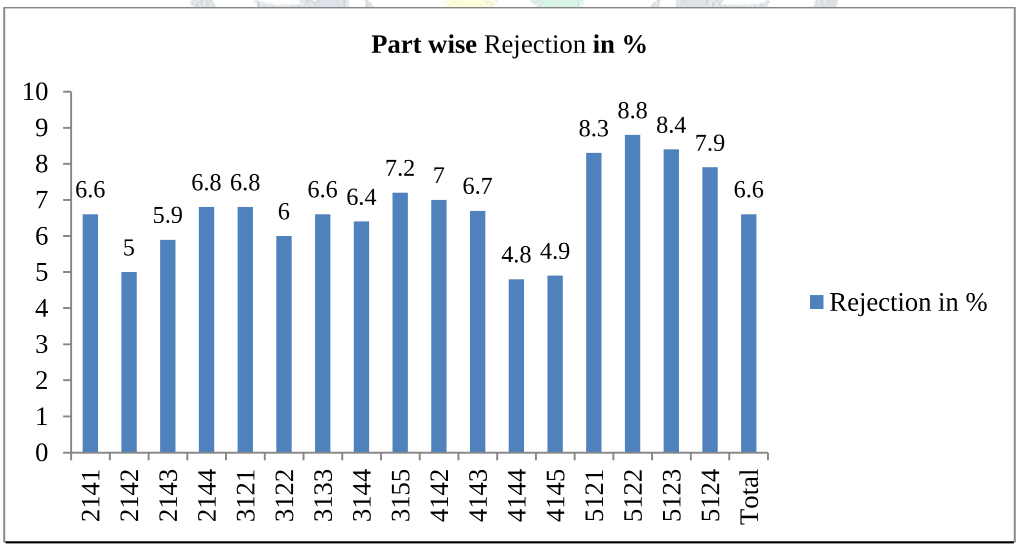

Figure 1: Part number wise rejected Quantity in % (Nov. 2017)

Figure 1 represent, part number wise rejected quantity in % which observe that the highest rejection of % found in part no. 5122 (8.8%) followed by part no. 5123 (8.4%) and part no. 5121 (8.3%) respectively. It mean part no. 5122 should be selected for analysis.

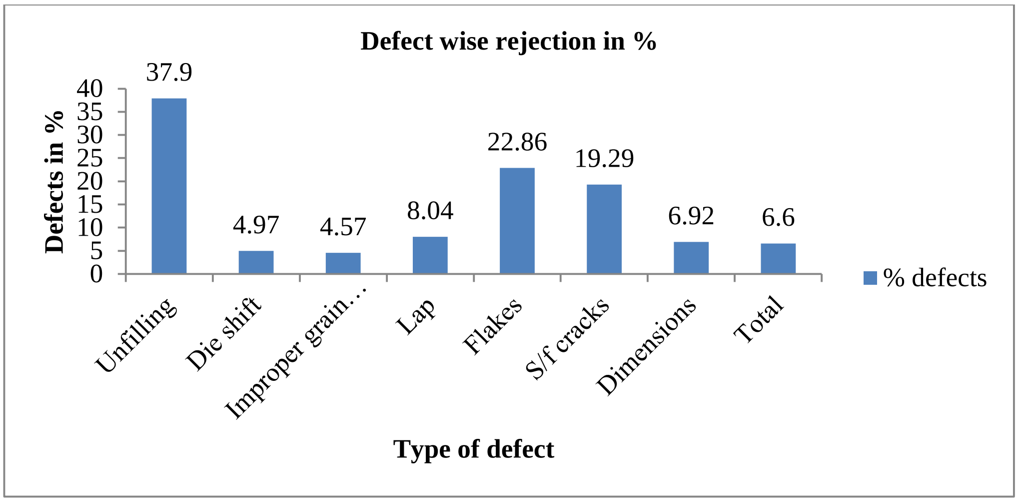

Figure 2: Defect wise rejected Quantity in % (Nov. 2017)

In figure 2, defect wise rejected quantity are shown for analysis purpose it's defect wise rejection are shown which shows that the 37.9% defects found due to unfilling followed by 22.86% flakes and 19.29% surface cracks throughout production of November 2017.

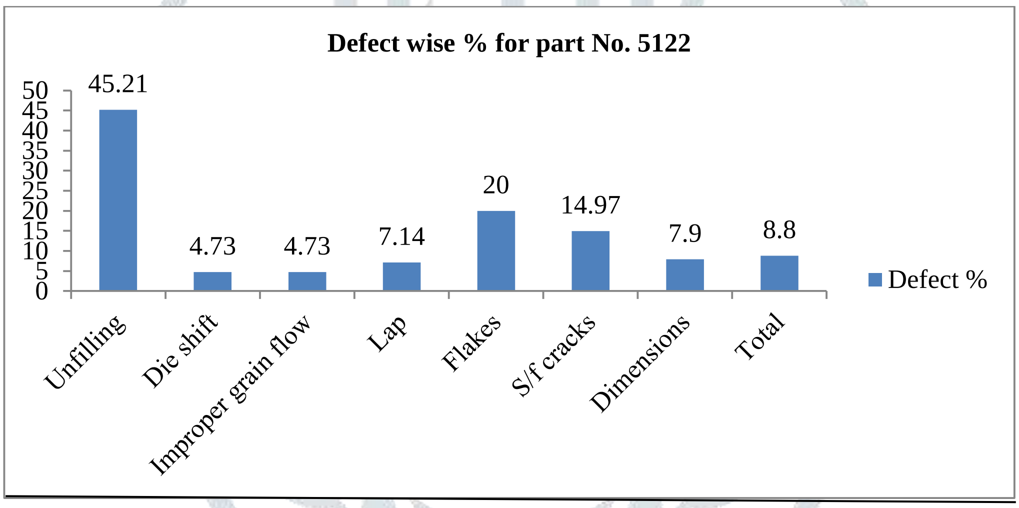

Figure 3 Defect wise rejection % for part No. 5122 (Nov. 2017)

After collecting and analysing the data for the month of November 2017, it has been observed that the part no. 5122 (8.8%), 5123 (8.4%) and 5121(8.3%) has more numbers of % defectives with respective to its production quantity. Hence before carrying out experiment it has been decided to observe and analyse the data for the month of December 2017. Table 2 shows the part number wise rejected quantity for the month of December 2017.

Table 2 Monthly Rejection Report (Dec. 2017)

			Defect wise rejected Qty. (in Nos.)								
S.No.	**Part No.**	**Prod. Qty (in Nos.)**	**Unfilling**	**Die shift**	**Improper grain flow**	**Lap**	**Flakes/ internal Crack**	**Surface crack**	**Dimension**	**Total Rejected Qty. (in Nos.)**	**Rejection (in %)**
1	2141	15000	440	45	40	75	215	160	42	1017	6.8
2	2142	18000	375	40	40	80	210	160	44	949	5.3
3	2143	16000	415	35	42	70	250	140	35	987	6.2
4	2144	12550	300	45	30	70	168	195	40	848	6.8
5	3121	13650	280	32	40	90	261	210	54	967	7.1
6	3122	14700	215	30	34	90	275	195	60	899	6.1
7	3133	12800	290	40	42	80	190	180	54	876	6.8
8	3144	16500	475	57	45	60	210	192	71	1110	6.7
9	3155	12500	381	32	40	50	160	198	78	939	7.5
10	4142	14700	430	62	46	80	180	200	50	1048	7.1
11	4143	13500	280	60	45	87	190	217	70	949	7
12	4144	15600	192	51	50	80	160	185	71	789	5.1
13	4145	14300	176	57	40	70	200	120	80	743	5.2
14	5121	12200	450	54	38	64	215	148	79	1048	8.6
15	5122	11800	470	52	50	75	200	160	85	1092	9.3
16	5124	12550	390	45	50	63	220	190	91	1049	8.4
Total		**226350**	**5559**	**737**	**672**	**1184**	**3304**	**2850**	**1004**	**15310**	**6.8**
Defect wise rejection %			**36.31**	**4.81**	**4.38**	**7.73**	**21.58**	**18.61**	**6.55**		

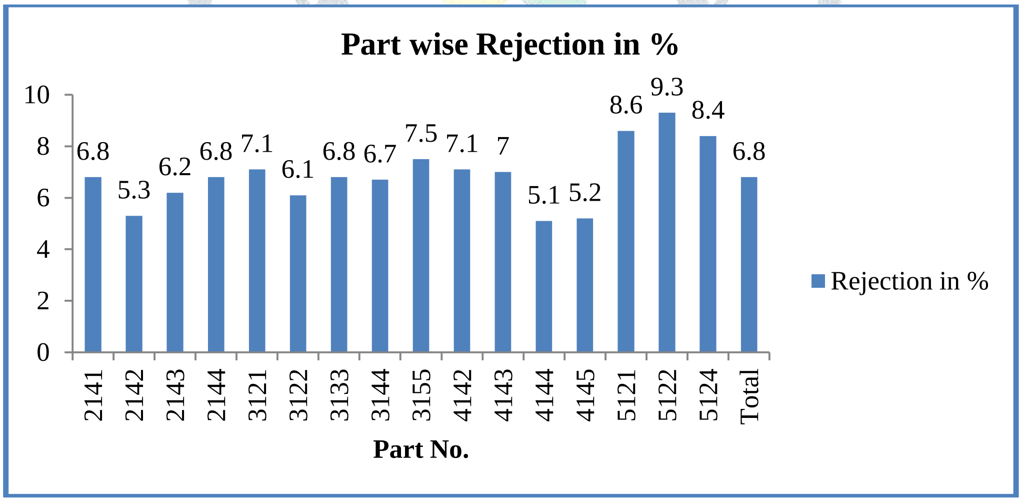

Figure 4 Part wise rejection in % (Dec. 2017)

Figure 4. Shows the part wise rejection % for the month of December 2017 in which part no. 5122 has rejection rate (9.3%) followed by part no. 5121 (8.6%) and part no. 5124 (8.4%).

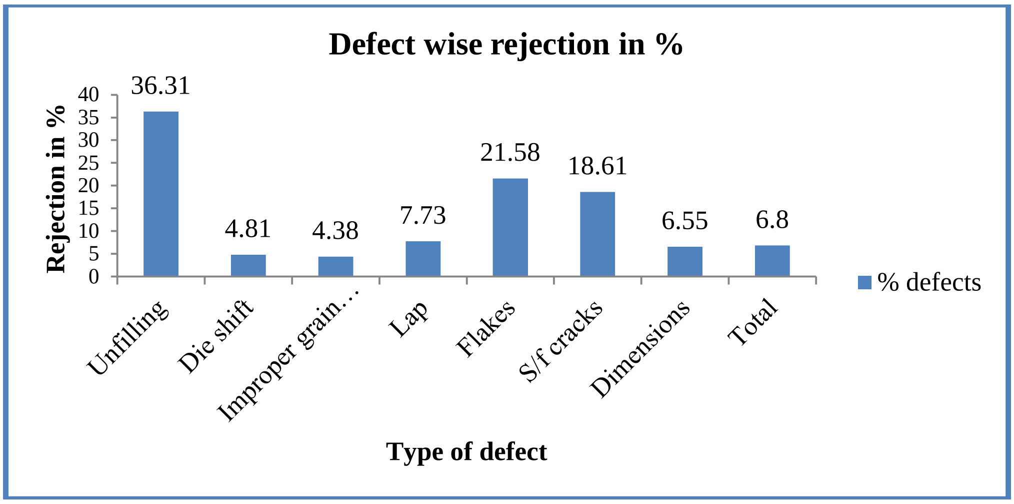

Figure 5 Defect wise rejection in % (Dec. 2017)

In figure 5 defect wise rejection % shown throughout total production rate for the month of December 2017. Rejection 36.3% are due to unfilling defect followed by flakes (21.58%) and surface cracks (18.61%) respectively.

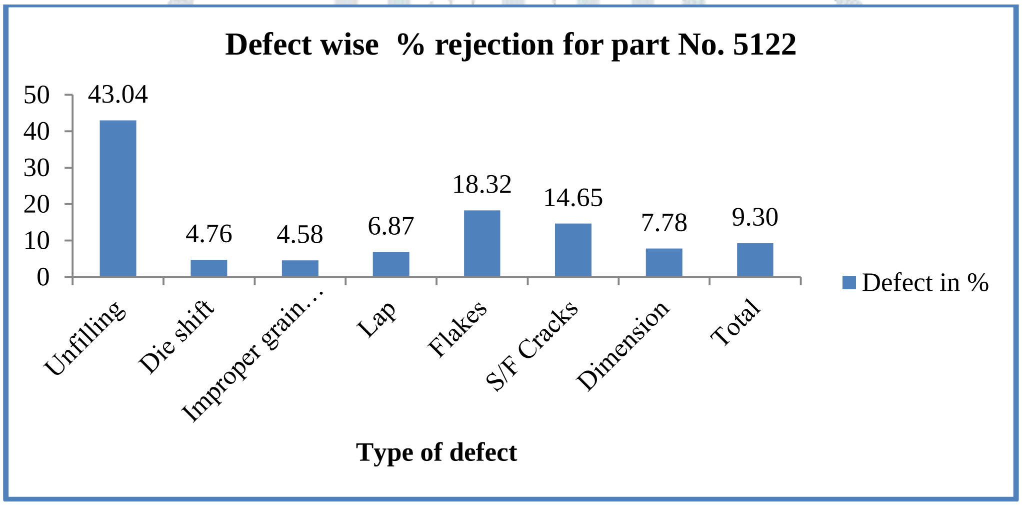

Figure 6 Defect wise % rejection for part No. 5122 (Dec. 2017)

After analyzing the data for the month of December 2017 (Figure 6), it concluded that rejection % in part no. 5122 (9.3%), part no. 5121 (8.6%) and part no. 5124 (8.4%).

This much rejection rate cannot be tolerated by the M/s XYZ Limited, this lead to undergo detail study in the XYZ about the defects for the part no. 5122 that caused this much rejection rate and the remedial actions suitable for that to reduce the rejection rate.

Defects Analysis by using Pareto chart:

Fig. 7 Pareto chart shows the defect wise rejected quantity for the part number 5122 whose total rejection percentage 9.3%.Highest rejection found due to the un-filling defects (43 %) whose contribution is more as compared to the other defects. Therefore Part No. 5122 is selected here for study purpose and trying to attack on un-filling defect in that product.

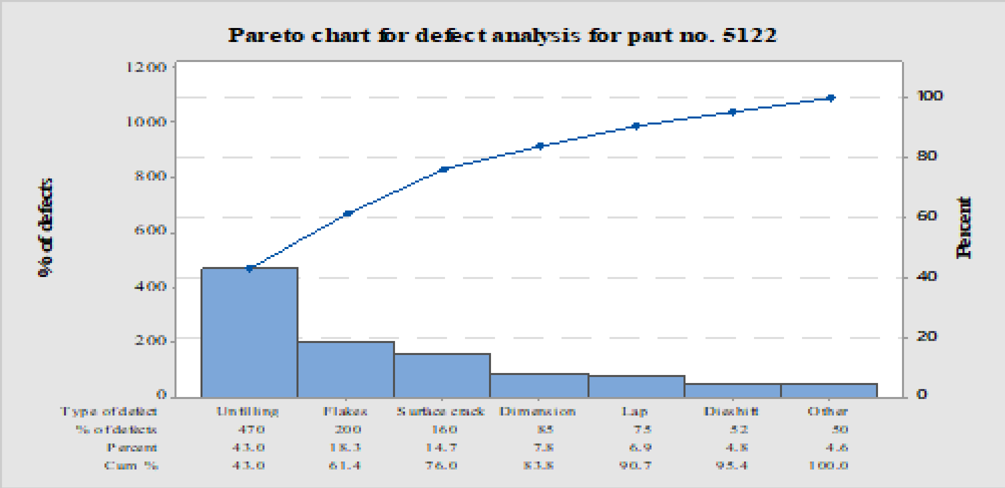

Figure 7 Pareto chart for defect wise analysis for part No. 5122

V. IDENTIFICATION OF PROCESS CONTROL PARAMETER

The quality of the closed-die forging depends on several controlling parameters such as die design parameters and process parameters. Design parameters represent the geometrical aspect of the die such as flash thickness, flash land width, fillet radii, corner radii and draft. Die design also consists of die wear analysis, since die wear is also responsible for unfilling defect.

Process parameters are variable related to the forging process. During the brainstorming session, it is observed that the three process parameters (billet weight, heating temperature of furnace, and heating/soaking time of raw material/billet inside the furnace) have major influence on filling the die cavity. Therefore these three process parameters are selected for trial purpose. The purpose of conducting trials is to determine the best combination of these process parameters.

Unfilling defect is as shown in figure 8. It is very difficult to predict the occurrence of this defect at a particular place on a job, but this defect directly affects the required final job weight. So, the selected response parameter/factor for this study is required final job weight.

As per the Company standard, the required final job weight for Part No. 5122 is 5.50 Kg +/- 0.05 Kg.

Figure 8: Unfilling defect at job

Figure 8 shows the unfilling defect at job that can be found after machining operation in quality check. After analysing the data and company standard the following process parameters are selected for optimizing the results such that rejection rate has to be decreases.

There are three input controlling parameters selected with their three levels. Details of parameters and their levels used in this study are as shown in Table - 3

Table 3: Level wise process parameter

Sr. No.	Process Parameter	Level 1	Level 2	Level 3
A	Billet Wt. (in Kg)	90 (A1)	95 (A2)	100 (A3)
B	Heating Temp. (in ^{0}C)	1210 (B1)	1260 (B2)	1310 (B3)
C	Heating Time (in min.)	90 (C1)	100 (C2)	110 (C3)

VI. CONCLUSIONS

Investigations have identified forging defects like unfilling, die shift, improper grain flow, lap, cracks/flakes, surface cracks, dimensions etc. Majority from these defects, forging industries experiencing unfilling and flakes are major defects in their processes.

Few investigations shows that by using quality control tools some extent forging defects can be control and improvement in rejection rate is possible. Dimension defect can be control by taking care during the manufacturing process. The collected data indicates that the rejection rate in the company was more than 4% of the total productions made each month. The defects in the forged components/ parts includes the lapping, mismatch, scales, cracks, under filling etc. The remedial actions includes the proper use of anti scale coating, venting process to prevent the under filling, the simulation software for determining the material flow, proper lubricant instead of furnace oil etc.

Forging process can be optimized to minimize the defects by proper selection of parameters like forging temperature, heating time, and billet weight.

VII. RECOMMENDATION

Now a day statistical methods are commonly used to improve the quality of a product or process. Such methods facilitate the user to define and study the outcome of every single condition possible in an experiment where several factors are involved. Defect analysis is such a process in which a number of control factors communally determine the performance output i.e. the defect percentage. Hence, in the present work a statistical technique called Taguchi method will be suitable to optimize the process parameters leading to minimum defect during forging process of stainless steel flange under study. It is a powerful tool for design of high quality systems based on orthogonal array experiments that provide much-reduced variance for the experiments with an optimum setting of process control parameters. It introduces an incorporated loom that is simple and efficient to find the best range of designs for quality, performance and cost.

REFERENCES

[1] Aju Pius Thottungal, Sijo. M.T, (2013). “Controlling Measures to Reduce Rejection Rate due to Forging Defects”, International Journal of Scientific and Research Publications, Vol.3, Issue 3.

[2] B. Tomov, R. Radev and V. Gagov (2004) Influence of flash design upon process parameters of hot die forging, *Journal of Materials Processing Technology*, Vol. 157–158, pp. 620-623.

[3] Chandna, P. and Chandra,A.(2009), “Quality tools to reduce crank shaft forging defects: an industrial case study”, Journal of Industrial and Systems Engineering,Vol.3, No.1, pp. 27-37.

[4] F. Fereshteh-Saniee and A.H. Hosseini (2006) The effects of flash allowance and bar size on forming load and metal flow in closed die forging, *Journal of Materials Processing Technology*, Vol. 177, pp. 261-265.

[5] K. B. Vamsi and R.K. Sidu, (2002). "Analysis of Center Burst During Hot Forging", Practical Failure Analysis, Vol. 2, 2002, p. 61-66.

[6] M.S. Sekhon, G.S. Barr and Sukhrajsingh.(2014),“A six sigma approach to detect forging defects in a small scale industry: A case study” ,International Journal of Engineering and Technical Research Publications,Vol.2No8, pp.33– 40.

[7] M.G. Rathi and N.A. Jakhade (2014), “An Overview of Forging Processes with their defects”, International Journal of scientific and Research Publications, Vol.4, No. 6.

[8] M.G. Rathi and N.A. Jakhade (2014), “An Effect of forging process parameters on filling the job weight::An industrial case study”, International Journal of scientific and Research Publications, Vol.4, No. 6.

[9] Mathew, C.,Koshy, J.and Verma, D.(2013), “Study of Forging Defects in Integral Axle Arms”, International Journal of Engineering and Innovative Technology, Vol.2. No. 7, pp. 322-326.

[10] Thottungal ,A. P.and Sijo,M.T. (2013),“Controlling Measures to Reduce Rejection Rate due to Forging Defects”, International Journal of Scientific and Research Publications,Vol.3No3, pp. 238– 243.

[11] V. Chand, S.S. Sen and M.S. Sethi (2014), “Taguchi analysis of forging defects for gears”, International Journal of Advance Technology and science Publications, Vol.2, No. 8.