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Analysis and Optimization of Process Parameter by using Taguchi DoE Technique for Closed Die Hot forging Process – A Case Study

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Abstract: From the reference paper we found that various forging defects occur that because high rejection rates in which unfilling defect has major contribution. The various process parameter such as workpiece temperature, die temperatures, coefficients of heat transfer between the dies and the billet, heating time, workpiece and die interface heat-transfer coefficient etc. affect the forming process differently, thus the optimization design of process parameters is necessary to obtain a good product. In this paper, an optimization method for forging process parameters is proposed in order to reduce the rejection rate due to unfilling defect and Taguchi method with single-objective design. The billet weight, heating temperature and heating time is considered as the optimal objectives. The optimal parameters combination is obtained through S/N analysis and the analysis of variance (ANOVA). The verified experimental result agrees with the predictive value well, which demonstrates the effectiveness of the proposed optimization method.

***Keywords* — Forging defects, Process Parameter, S/N ratio, ANOVA**

I. INTRODUCTION

Though forging process gives superior quality product compared to other manufacturing processes, there are some defects that are lightly to come if a proper care is not taken in forging process design. This article referred the data of research paper Soni et al. (2018) which was carried out in a forging industry. 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. The collected data indicates that the rejection rate in the company was more than 4% of the total productions made each month. 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.

This Paper recommended for statistical methods which are commonly used to improve the quality of a product or process. Hence, for the present data 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.

II. LITERATURE REVIEW

Soni, et.al [1] investigate and analyze the various forging defects that occur in forging industries which causes the huge percentage of rejection in the forged components. In this paper 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.

M.G.Rathi, N.A.Jakhade,et.al [2] discussed forging defects those repeatedly occurring along with their cause and remedies. The Process parameters considered were- billet weight, heating temperature, and heating time each at three levels. To obtain the optimal setting of these parameters, the S/N ratio analysis of Taguchi method (L9 OA) is used. ANOVA is carried out for determining the influence of given input parameters from a series of experimental results by Taguchi method. The optimum job weight is calculated by Regression equation.

Tomov et al. [3] studied the hot forging process under closed die condition in terms of flash formation. A number

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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. .

Satish et al. [4] uses FEM-based computer simulation to optimize the design parameters and input billet cross-section for front axle beam. By carrying out multiple number of forging experiments during simulation trials, input billet size has been optimized.

C.Y. Park and D.Y. Yang [5] analyzed the void-crushing process, including the bonding process by the finite-element method for three-dimensional forging at elevated temperature. The effects of the pre-cooling temperature, the rate of deformation and the change of the die-shape are discussed for obtaining the high crushing efficiency of a void, using the Taguchi method.

F.C. Lin et al. [6] presented an abdicative network in conjunction with Taguchi method to predict the minimum additional material volume of pre-form billet for an acceptable product without shape defect such as unfilling in closed-die forging process.

III. RESEARCH METHODOLOGY: TAGUCHI METHOD

Following are the steps followed according to the Taguchi method's single objective optimization:

1. Input Data Collection and Problem Identification: Input data has taken from paper Soni et al. (2018). On the basis of this input data further Taguchi's step is carried out.

2. Selection of Process Parameter levels and Response Factor

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. 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 1 shows the unfilling defect at job that can be found after machining operation in quality check.

Figure 1: Unfilling defect at job

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 – 1.

Table 1: Level wise process parameter

S.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)

3. Design of Experiments and selection of Orthogonal Array

The design of experiment is carried out by Taguchi methodology using Minitab 17 Software. In this technique the main objective is to optimize the job weight that is influenced by various process parameters. Since three controllable factors and three levels of each factor are considered L9 (3^3) Orthogonal Array is selected for this study. Table 2 shows the layout of experiments to be carried out according to Taguchi L9 Orthogonal Array.

Table 2: Layout of experiments

Trial Nos.	Parameters Combination		
	A	B	C
1	90	1210	90
2	90	1260	100
3	90	1310	110
4	95	1210	100
5	95	1260	110
6	95	1310	90
7	100	1210	110
8	100	1260	90
9	100	1310	100

IV. EXPERIMENTAL SET-UP

A Series of experiments are conducted to evaluate the influence of process parameters on job weight. The trials were carried out on 2 Ton Pneumatic Hammer. Electronic weighing machine is used for weight measurement. Figure 2 shows hammering operation on 2-Ton hammer during experimentation and figure 3 shows electronic weighing machine to be used for weight measurement purpose.

Figure 2 & 3: Hammering Operation & Electronic Weighing Machine respectively

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V. RESULTS AND DISCUSSION

5.1 S/N Ratio Analysis:

The S/N ratio for larger-the-better target of each experimental trial is calculated based on the following equation, and the values are listed in Table 3.

Larger-the-better characteristic: S/N = -10 log (MSD)

Where MSD= Mean Square Deviation for the Output Characteristic.

MSD = (1/Y12 + 1/Y22 + 1/Y32 + ……….. + 1/Yn2) / n

Where Y1, Y2, Y3 are the responses and 'n' is the number of tests in a trial.

The level of a factor with the highest S/N ratio is the optimum level for responses measured. The higher the signal to noise ratio, the more favorable is the effect of input variable on the output.

Table 3: Results of Experiments

Trial Nos.	Parameters Combination				
	A	B	C	Job wts.	S/N ratio
1	90	1210	90	84.89	38.5771
2	90	1260	100	84.87	38.5751
3	90	1310	110	84.94	38.5822
4	95	1210	100	84.95	38.5833
5	95	1260	110	84.92	38.5801
6	95	1310	90	84.91	38.5792
7	100	1210	110	84.94	38.5822
8	100	1260	90	84.98	38.5863
9	100	1310	100	84.96	38.5843

From Table 3 - It is clear that, the S/N ratio is higher for Trial No. 8, hence the optimum value levels of control factors for higher job weight, are at-Billet weight (100 Kg), heating temperature (1260 ^{0}C), and heating time (90 min.).

Hence, optimal settings of the process parameters, determined from the Analysis i.e. A3B2C1.

Table 4: Estimated Model Coefficients for S/N ratios

Term	**Coeff.**	**SE Coeff.**	**T**	**P**
Const.	38.5811	0.001503	25664.3	0.000
B wt. 90	-0.0030	0.002126	-1.39	0.299
B wt. 95	-0.0002	0.002126	-0.107	0.925
Temp 1210	-0.0002	0.002126	-0.107	0.925
Temp 1260	-0.0002	0.002126	-0.268	0.814
Time 90	-0.0002	0.002126	-0.107	0.925
Time 100	-0.0002	0.002126	-0.107	0.925

Table 4 shows the linear model for S/N ratios. Summary of Model- S = 0.004510 R-Sq = 59.9 % R-Sq (adj) = 0.00%

Larger is better

Table 5: Response for S/N ratios

Level	B wt	Temp.	Time
1	38.58	38.58	38.58
2	38.58	38.58	38.58
3	38.58	38.58	38.58
Delta	0.01	0.00	0.00
Rank	1	2	3

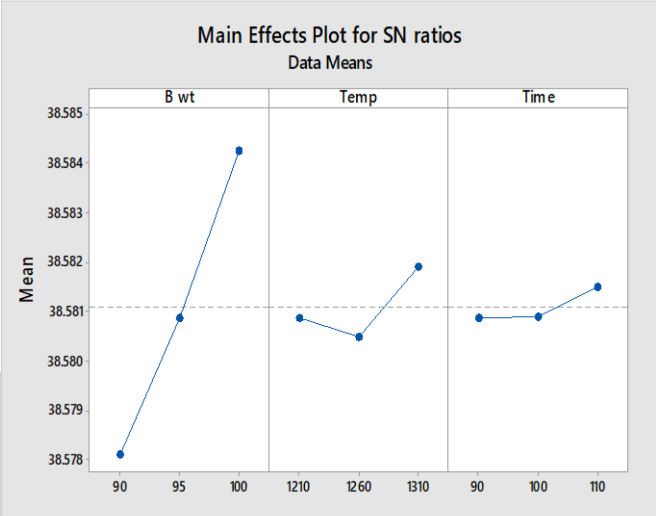

Fig. 4: Effect of process parameters on S/N Ratio

From Table 5 and Figure 4, it is clear that, larger the 'delta' value, greater the significance of the control factor. It means for higher job weight, the most significant factor is billet weight (A), followed by heating temperature (B) and heating time (C)

5.2. Analysis of Variance (ANOVA):

The purpose of ANOVA is to investigate which process parameters significantly affect the quality characteristic. The analysis of the experimental data is carried out using the software MINITAB 17 specially used for design of experiment applications.

Table 6: ANOVA for S/N ratios

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value
B wt	2	0.000057	0.000057	0.000002	1.39	0.0418
Tem	2	0.000003	0.000003	0.00000	0.07	0.931
Time	2	0.000001	0.000001	0.000020	0.02	0.978
Error	2	0.000041	0.000041			
Total	8	0.000101				

VI. CONFIRMATION EXPERIMENTS

In Order to test the predicted result, confirmation experiment has been conducted by running another three trials at the optimal settings of the process parameters, determined from the Analysis i.e. A3B2C1.

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Table 7: Results for confirmation experiments

Observation	Trial no.			Avg Job wt	S/N ratio
	1	2	3		
1	84.97	84.96	84.97	84.9666	38.5850

The results for confirmation experiments are shown in Table 9, and it is observed that the average Job weight i.e. 84.9666 and S/N Ratio 38.5850, falls within predicted 80% Confidence Interval

VII. Comparative Study Of Monthly Rejection Report

In this section, the rejection report of Jan. 2018, Feb. 2018 and March 2018 month is collected to compare with data collected before the implementation of Taguchi method. It was necessary to compare the data before implementation and after implementation so that the results obtained from Taguchi method get validated.

For comparative purpose the monthly defect wise rejection report in % vs types of defect was collected and shown in fig 5, 6 & 7 for the month of Jan. 2018, Feb. 2018 and March 2018 respectively.

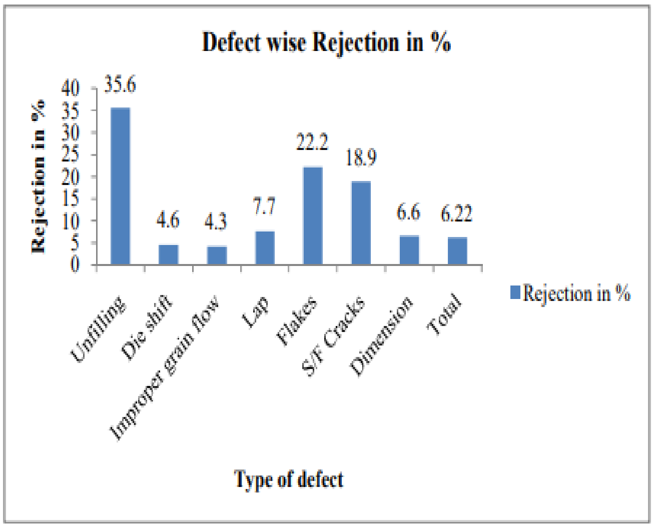

Fig5: Defect wise rejection in % (Jan. 2018)

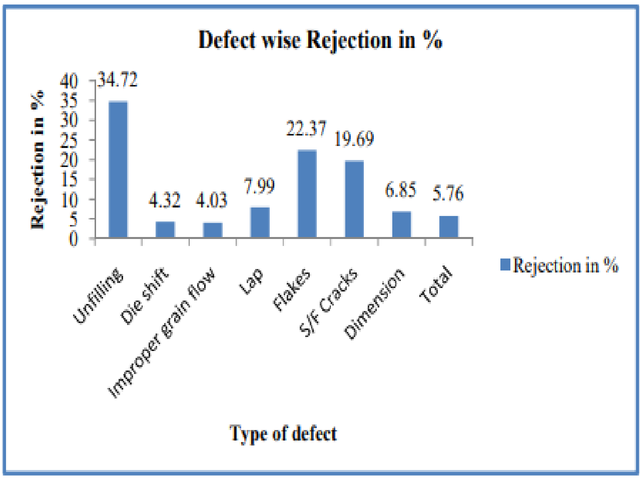

Fig6: Defect wise rejection in % (Feb. 2018)

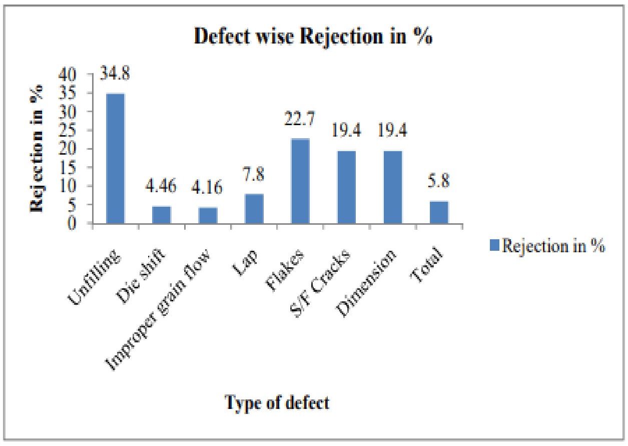

Fig7: Defect wise rejection in % (Mar. 2018)

Following figure 8 represent the month wise comparative study of production quantity and rejected quantity before (Nov. 2017 and Dec. 2017) and after (Jan. 2018, Feb. 2018 and Mar 2018) implementation of Taguchi method. From observation, it is clear that after applying Taguchi method there is significant reduction in rejection quantities.

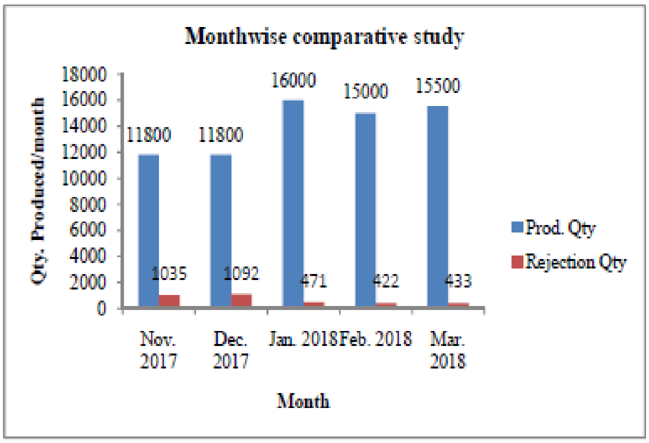

Figure 8: Month wise comparative study

Following figure 9 shows that the comparative study for the part no. 5122 for unfilling defect, which shows the % of reduction in unfilling defects.

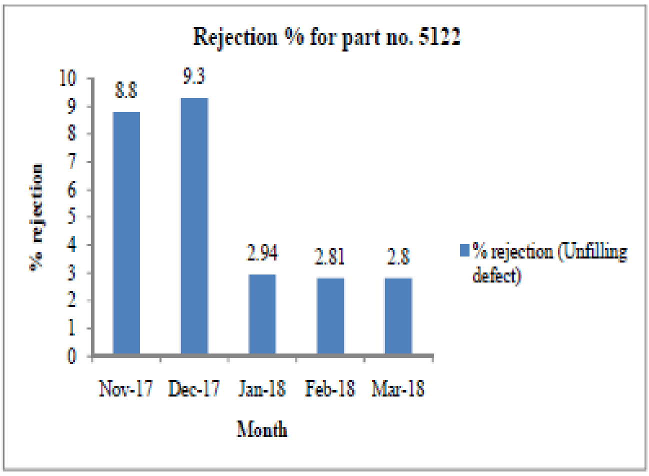

Figure 9: Comparison of rejection % for part no5122

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VIII. Comparative Analysis Of Measured Productivity

Productivity Calculation: Productivity is nothing but the maximum output with minimum inputs. It means lowering the rejection rate firm can increase the productivity of the system with utilization of fewer resources.

Measured productivity is the ratio of a **measure** of total outputs to a **measure** of inputs used in the production of goods and services.

Measured productivity in month of Nov. 2017 considering part no. 5122,

Measured productivity in month of Nov. 2017,

= (11800-1035)*100 / 11800 = **91.22%**

Productivity in month of Jan. 2018,

= (16000-471)*100/16000 = **97.05%**

Measured productivity comparison for part no. 5122 before implementation and after implementation is given in figure 10.

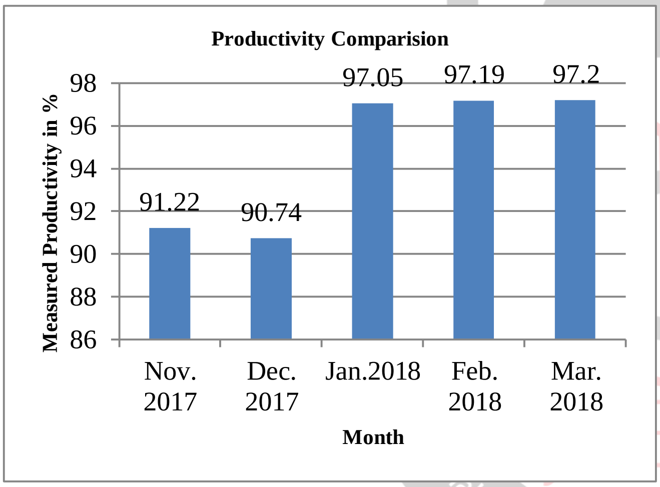

Figure 10: Measured Productivity Comparison

Above comparative analysis shows the effective improvement in productivity while reducing the % of unfilling defect in forging operation after application of Taguchi method which validates the results of the experiment.

VI. Conclusion

- Before implementing the Taguchi method in month of Nov. 2017, total rejection was 6.6% and that of part no. 5122 was 8.8%. Also in month of Dec. 2017, total rejection was 6.8% and for part no. 5122 was 9.3% which is huge and company can be tolerated this product loss.
- The experimental investigation of the defect analysis in forging component makes it possible to study the effects of process parameters such as billet weight, heating temperature, and heating time for that the Design of experiments (Taguchi Method) is used in order to obtain a better understanding of the process parameter.
- After applying the Taguchi method, the rejection percentage of unfilling defect has been decreases from 8.8% and 9.3% for the month of Nov. 2017 and Dec. 2017 to 2.94%, 2.81% and 2.8% for the month Jan. 2018, Feb. 2018 and March 2018 respectively. The output will give us the proper combination of these parameters so that the unfilling forging defect will be reduced and quality of product will increase.
- To obtain the optimal setting of these parameters, the S/N ratio analysis of Taguchi method (L9 OA) is used. ANOVA is carried out for determining the influence of given input parameters from a series of experimental results by Taguchi method.
- Hence, following conclusions are drawn from the present study:
  1. From the S/N ratio and ANOVA analyses, it is clear that the optimal combination of process parameters is A3B2C1.
  2. Thus, the use of Taguchi and ANOVA methods, were effective in studying the influence of selected process parameters on job weight.
  3. Among three process parameters, billet weight is the most significant parameter followed by heating time and heating temperature to get the higher job weight.
  4. The optimal level of process parameters that must be followed during the production process in order to reduce the rejection rate due to unfilling forging defect, are: Billet wt. 100 kg, Heating temp. 1260 ^{0}C., Heating time 90 min.
  5. The results of present study are valid within specified range of process parameters. Hence, the present study stands valid.
- By minimization of unfilling defects, quality of product is enhanced and finally the productivity is increased from 90.74 % to 97.20 %.

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