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Billet Sorting Mechanism for Reducing the Rejection Rate in Forging Operation

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Abstract: **In the forging process, defects cause high rejection rates so it is important to move any production process in the direction of eliminating all imperfections as a part of an effective continuous improvement program. During the process it is observed that the three process parameters having major responsibility to fill the job weight. These parameters are- billet weight, heating temperature, and heating time. The best combination of these process parameters must be followed during the production process in order to reduce the rejection rate due to unfilling forging defect. The range of heating process time is define to avoid the overheating process of billets. The homogeneity in microstructure and mechanical properties of forging products can highly affect the performance of the product during its service. So the billet was sorted according to the temperature to reduce the rejection rate and the die life. The accept reject system for sorting the billet according to its temperature using pneumatic actuation technique is developed to overcome the forging defects and increases the die life.**

Keywords: **UN filling defect, scale pits, pyrometer, billet sorting, rejection rate, pneumatic actuation, OVAT analysis.**

I. INTRODUCTION

Forging is defined as a metal working process in which the useful shape of work piece is obtained in solid state by compressive forces applied through the use of dies and tools. Forging process is accomplished by hammering or pressing the metal. Forging process produces parts of superior mechanical properties with minimum waste of material. In this process, the starting material has a relatively simple geometry; this material is plastically deformed in one or more operations into a product of relatively complex configuration.

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. Defects can be defined as 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. In this study, unfilling forging defect is focused. Unfilling defect can be defined as some section of die cavity not completely filled by the flowing metal, or 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. 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. 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, the 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.

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II. FORGING DEFECTS

When a forge shop begins to experience defects in their process, they should try to find the root cause of the problem, initiate corrective action and implement procedures to prevent its recurrence. A brief description of defects and their remedial methods is given below:

1) Incomplete forging penetration:

Dendrite ingot structure at the interior of forging is not broken. Actual forging takes place only at the surface.

Cause- Use of light rapid hammer blows

Remedy- To use forging press for full penetration.

2) Surface cracking:

Cause- Excessive working on the surface and too low temperature.

Remedy- To increase the work temperature

3) Cracking at the flash:

This crack penetrates into the interior after flash is trimmed off.

Cause- Very thin flash

Remedy - Increasing flash thickness, relocating the flash to a less critical region of the forging, hot trimming and stress relieving.

4) Cold shut (Fold): Two surfaces of metal fold against each other without welding completely.

Cause- Sharp corner (less fillet), excessive chilling, high friction

Remedy - Increase fillet radius on the die.

5) Unfilled Section (Unfilling/Under filling):

Fig.1 Unfilling defect

Some section of die cavity not completely filled by the flowing metal. Cause - Improper design of the forging die or using forging techniques, less raw material, poor heating.

Remedy - Proper die design, Proper raw material and Proper heating. Figure 2 shows the fish-bone diagram for root-cause analysis of under filling defect.

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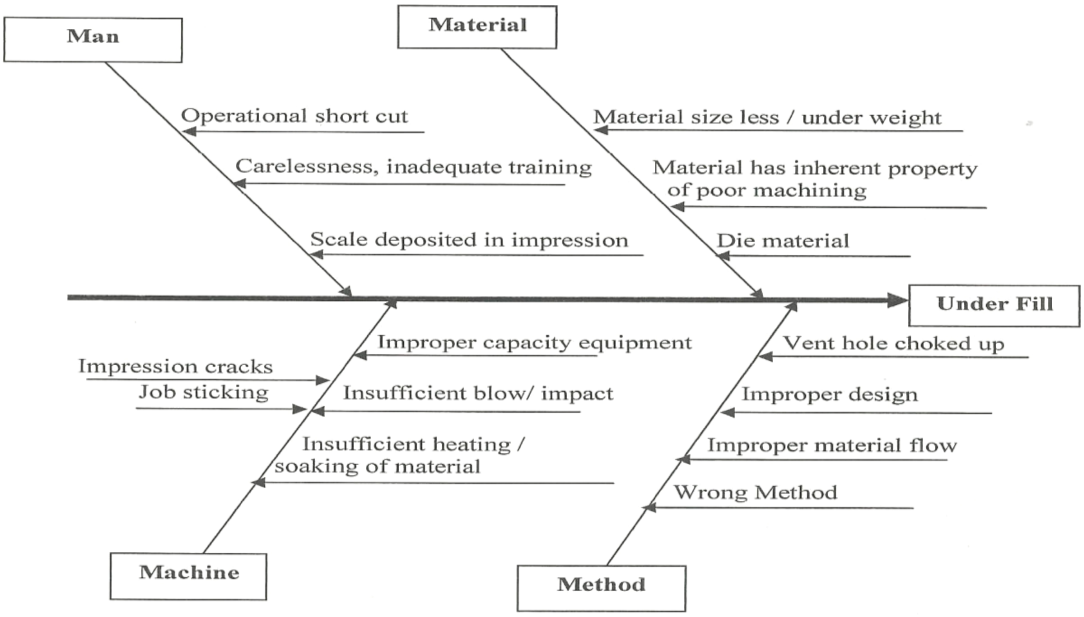

Fig.2 Fish bone diagram for root-cause analysis of under filling defect.

6) Die shift (Mismatch): Misalignment of forging at flash line.

Cause- Misalignment of the die halves.

Remedy - Proper alignment of die halves. Make mistake proofing for proper alignment for e.g. provide half notch on upper and lower die so that at the time of alignment notch will match each other. Figure 7- Shows the fish-bone diagram for root-cause analysis of mismatch defect.

7) Scale Pits (Pit marks): Irregular depurations on the surface of forging.

Cause - Improper cleaning of the stock used for forging. The oxide and scale gets embedded into the finish forging surface.

Remedy - Proper cleaning of the stock prior to forging.

Figure.3 shows the fish-bone diagram for root-cause analysis of Scale Pits defect.

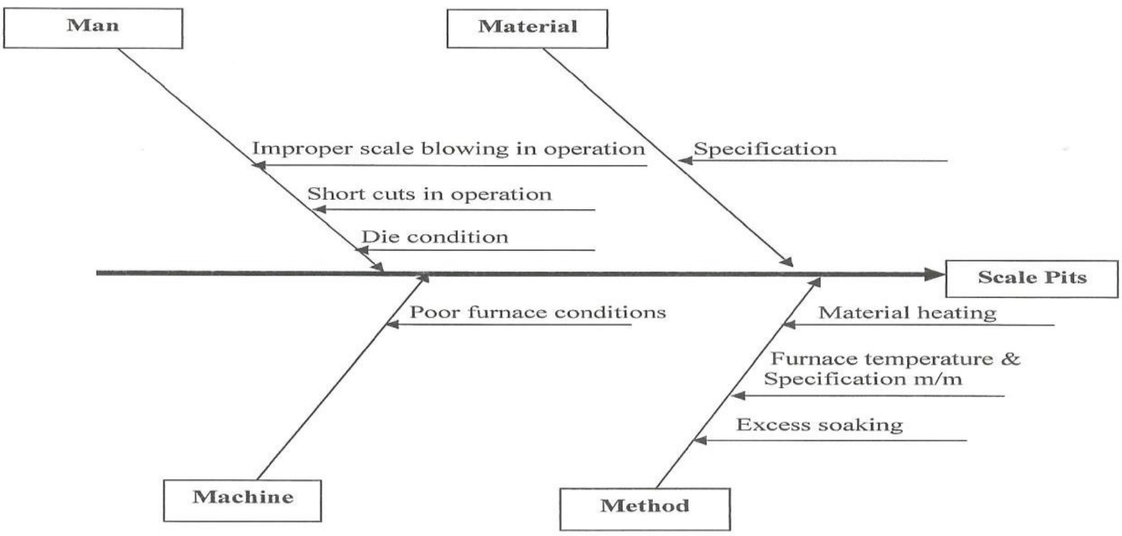

Fig.3 fish-bone diagram for root-cause analysis of Scale Pits defect

8) Flakes: These are basically internal ruptures.

Cause - Improper cooling of forging. Rapid cooling causes the exterior to cool quickly causing internal fractures.

Remedy - Follow proper cooling practices.

9) Improper grain flow:

Cause - Improper die design, which makes the metal not flowing in final interred direction.

Remedy- Proper die design.

10) Residual stresses in forging:

Cause - Inhomogeneous deformation and improper cooling (quenching) of forging.

Remedy- Slow cooling of the forging in a furnace or under ash cover over a period of time.

III. PROBLEMS WITH EXISTING SETUP

Company uses the conventional setup used in mass production system.

- First billets were filled in the vibrator.
- Then billets were sent to induction heater through conveyor line.
- Billets were heated and send to forging machine.

In existing setup billets were thrown in to the hopper which vibrates with the frequency of 80 Hz. Due to conical shape of hopper and vibration frequency billets send to the conveyor in a single line. Conveyor send billets into the induction heater and then heated billets with temperature ranges from 850 to 1100 ºC were directly send to forging machine. As per standard set for forging die, billets with temperature ranges from 950 to 1050 were only required. Due to this uneven temperature defects like unfilling, scale pits etc. were found in final product and it increases the rate of rejection. Therefore there is need to sort billets according to its temperature.

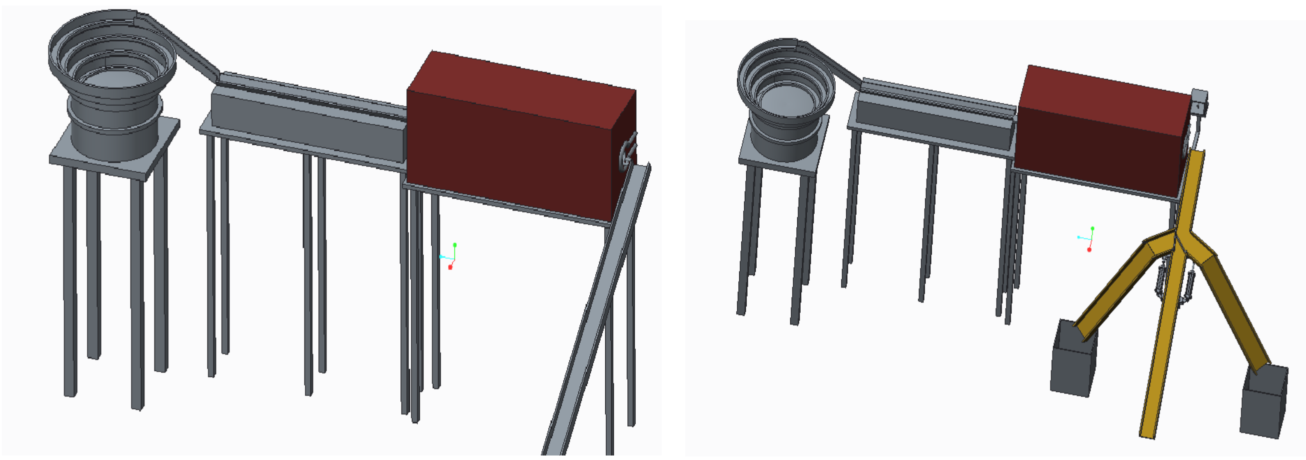

Fig.4 Existing Setup

Causes of Defects:

Since the defects causes high rejection rates, it is important to move any production process in the direction of eliminating all imperfections as a part of an effective continuous improvement program. In present study, the various forging defects that occur in the components during closed-die hot forging process are studied initially. The investigation is done with the help of Quality Assurance department in a forging industry. During study, the various defects that cause high rejection rates are identified and Unfilling defect which has major contribution in high rejection rate is selected. It is observed that the process parameters having major responsibility to fill the job weight. These parameters are- billet weight, heating

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temperature. The best combination of these process parameters must be followed during the production process in order to reduce the rejection rate due to Unfilling forging defect.

Design Principles:

The principles used in design of billet sorting system based on temperature are as follows: -

1. The designs of sorting system should allow easy and quick loading and unloading of work-piece. This reduces idle time to minimum.
2. The system should pass the billet of required temperature to the forging machine.
3. The system should reject the billet of incorrect temperature to the rejection bin.
4. To avoid any damage to billet during its travel.
5. Clearance should be provided to allow any variation in billet size and allow for hand movement wherever necessary.
6. Sorting system should be sufficiently rigid to preset accuracy.

IV. SOLUTION TO THE PROBLEM

A sorting mechanism for sorting of billet according to its temperature is developed to overcome the problems related to billet temperature. The mechanism is installed between the induction heater and forging machine as per space available.

The billets are sort by actuating the flappers mounted on the guide by pneumatic cylinder. According to the billet temperature, it is sorted as under heated and overheated billet. This sorting of billets results into less rejection rate of the final product.

Fig proposed setup

Design and selection:

Selection of pneumatic cylinder:

For fully retracted condition:

Smallest piston diameter available from festo catalogue = 25 mm.

Total weight considering all linkages, joints, bolts and friction =4 Kg.

$$= 4 \times 9.81 = 40 \text{ N.}$$

From relation,

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

$$P_{ex} = \frac{20}{\frac{\pi}{4} \times 25^2} = 0.08074 \text{ N/}mm^2$$

$$P_{ex} = 80.74 \times 10^3 \text{ N/}mm^2$$

$$P_{ex} = 0.8 \text{ Bar.}$$

For fully retracted condition:

$$P_R = \frac{40}{\frac{\pi}{4}\left(25^2 - 12^2\right)} = 0.10563 \text{ N/}mm^2$$

$= 105.35 \times 10^3 \; N/mm^2$

$P_R = 1.056$ Bar ≈ 1.05 Bar.

Considering the efficiency of the cylinder as 80%.

Thus,

$P_{max} = 1.9$ Bar ≈ 2 Bar.

Thus from Pneumatic application &reference handbook,

Pneumatic cylinder with 3 bar pressure is selected for our application because screw compressor with 3 to 6 bar pressure is available in the forging plant and it is the lowest pressure available in the festo catalogue.

For 2.5 pound = 1.13 Kg.

Available piston rod length = 60mm.

Velocity of pneumatic cylinder = 0.5 m/s

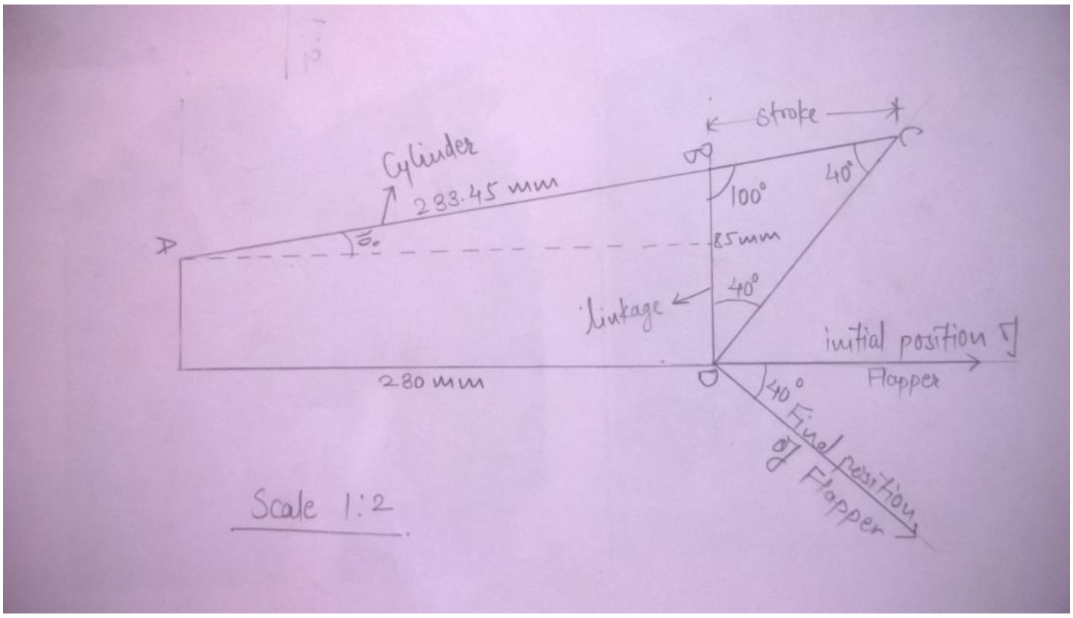

Fig.5 FBD of proposed setup

Force exerted by the pneumatic cylinder,

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

$$\frac{3\times10^5}{10^{-6}} = \frac{F}{\frac{\pi}{4}\times25^2}$$

F = 147.26 N

Considering the effect of friction as 10%

Thus,

$F_{max} = 132.5$ N

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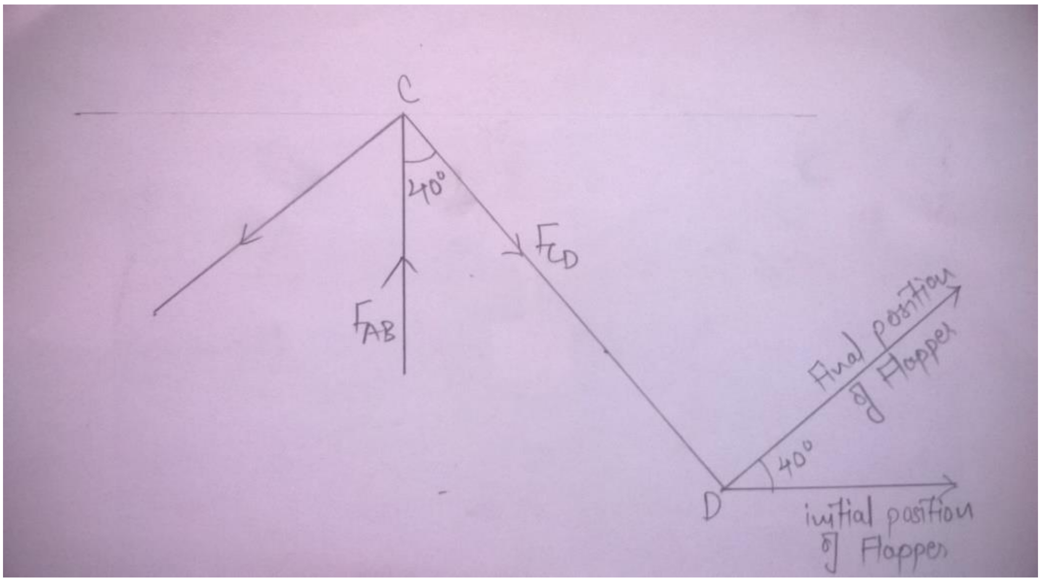

Fig.6 FBD of forces

Construction:

The main function of accept-reject mechanisms is to sort billet according to its temperature and for that it requires proper alignment. To achieve that it consists of the following:-

1. Bracket
2. Cylinder mounting
3. Pneumatic cylinder
4. Coupling
5. Flapper
6. Pyrometer

Assembly procedure:

Every product has certain procedure, guidelines, step to assemble or dissemble in specific manner which provides proper alignment, reduce error, and reduce damage of parts. So for this some precaution should be taken for its safety and maintenance.

1. Screw compressor was made to start and air gets compressed accordingly.
2. Place the sorting mechanism on the ground level considering the safety of the worker.
3. Clean the top surface.
4. Weld the bracket in the positing as per the drawing. Use oxy acetylene welding for superior strength.
5. Clamped the clevis mounting on the cylinder.
6. Cylinder with mounting has been placed in the position as per the drawing.
7. Flapper, coupling and bolts were fitted in their position with suitable tools.
8. Input and output connections were given to the cylinder.
9. Pyrometer is placed nearer to induction heater to sense the heated billet temperature.
10. After all electrical connections, set up have been mounted on machine for working and analysis.

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Precautions:

1. Keep all parts neat and clean like linkage, guide way etc. And handle all parts gently.
2. Tighten bolts in threaded joints with 15 N-m torque.
3. Lubricate all reciprocating parts like coupling, bolts etc. with grease. And clean all parts using Feryyl 101 Anticorrosive oil.
4. Maintain pneumatic air pressure of 3 bar for efficient working of the system.

Sequence of operation:

1. First cut the long bar into small billets.
2. Then the billets were fed into the hopper.
3. Then one by one all billets move over the conveyor line towards the induction heater.
4. In induction heater billets are heated to a temperature (ranges from 850 to 1050 degree).
5. Pyrometer is placed near the exit of the induction heater so that the temperature of heated billet is recorded.
6. If the temperature sensed by the pyrometer is within the range then there is no actuation of the pneumatic cylinder and the billet is made available at the forging machine.
7. If temperature of the billet sensed by the pyrometer is lower than given range i.e.950 to 1050, then PLC sends signal to solenoid valve that actuates the pneumatic cylinder and flapper 1 rotates through 40^0 which rejects the billet by sending it to left side of the setup.
8. If the temperature of billet was higher than the given range then a signal is send to cylinder 2, that actuates flapper 2 and billet goes to the right side of setup.

V. ANALYSIS

During the analysis done with the help of Quality Assurance department, it is clear from the monthly rejection report (Table 1) for the month of March 2015, company has manufactured 3 types of components. In the total production of 90000 jobs, 3840 jobs got rejected. It means the plant has a rejection rate of 4.26% in that month. This much rejection rate cannot be tolerated by the company, this lead to undergo detail study in the company about the defects that caused such high rejection rate and the remedial actions suitable to reduce the rejection rate. From the information of Table 1 two graphs are plotted.

Table no.1 Reading taken before implementing the sorting system

Sr. No	Component	Production Quantity	Defect wise rejected quantity					Total rejected Quantity	Rejection Rate (%)
			U/F	S/P	M/M	C/R	D/M		
1	Claw pole	30000	869	366	56	111	38	1440	4.8
2	Lug gear	30000	643	351	43	99	34	1170	3.90
3	Drive shaft	30000	684	354	49	104	39	1230	4.1
TOTAL		90000	2220	1056	154	315	95	3840	4.26

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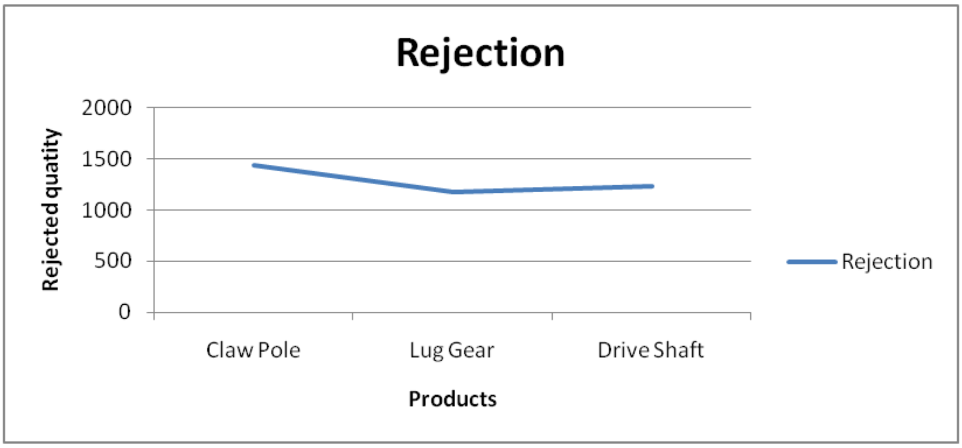
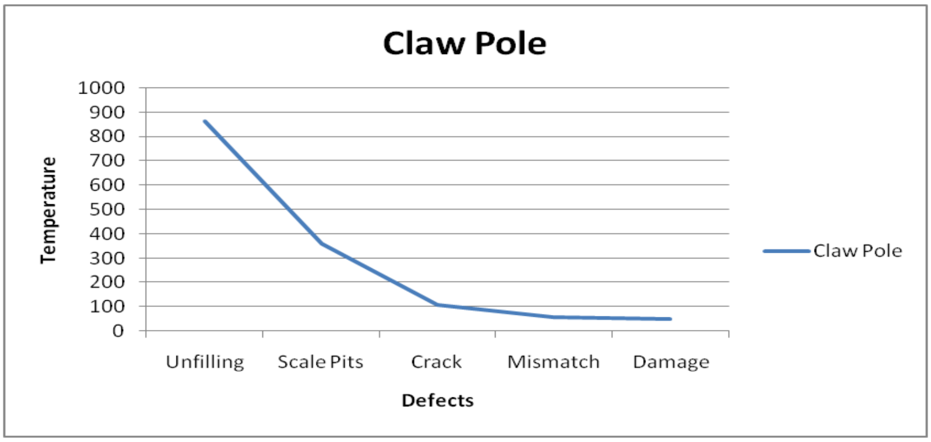


Graph 1 Part wise rejected quantity

Graph 1 shows that Claw Pole has maximum rejection. Therefore, Claw Pole is selected here for study purpose.



Graph 2 Defect wise rejection rate.

Graph8.2 shows that 'Unfilling' defect has major contribution in rejection of Claw Pole. Therefore, Claw Pole is selected here for study purpose and trying to attack on unfilling defect in that product.

Data collection after trials:

During the study it is observed that the main cause of rejection is the unfilling defect in the job which can be reduced by maintaining correct temperature and weight of the billet. So after implementing the sorting system, the results obtained are as follows:

Table no.2 Reading taken after implementing the sorting system

Sr. No.	Batch	Production Quantity	Defect wise rejected quantity					Total rejected Quantity	Rejection Rate (%)
			U/F	S/P	M/M	C/R	D/M		
1	Claw pole	30000	331	152	54	87	36	660	2.2
2	Lug gear	30000	358	190	42	78	37	705	2.35
3	Drive shaft	30000	374	236	47	83	40	780	2.6
TOTAL		90000	1063	578	143	248	113	2145	2.38

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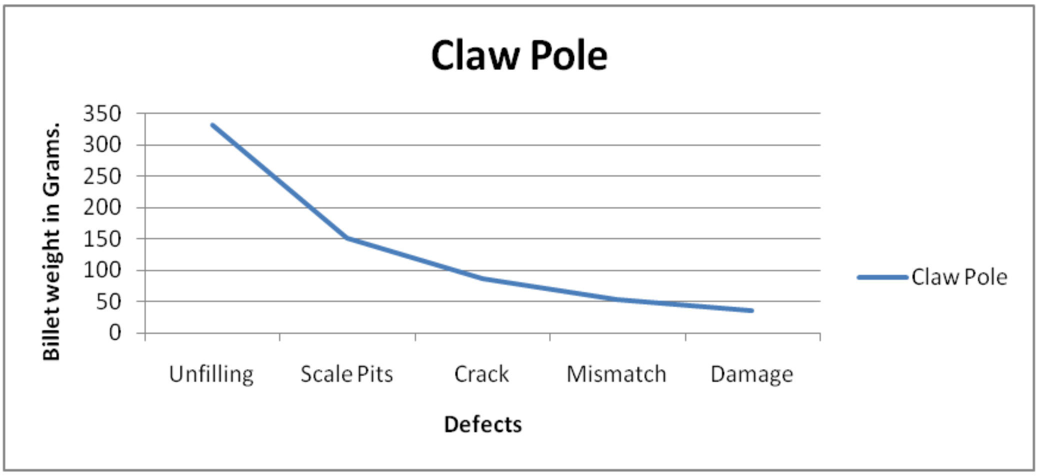

Graph. 3 Readings plotted for Claw Pole after implementation of sorting system

After conducting the trails it was observed that the defects due to unfilling of jobs and scale pits are reduced thus reducing the rejection rate.

VI. RESULTS AND DISCUSSION

After analyzing the defects, it is observed that billet weight and temperature plays an important role in the final weight of the product. According to the company standard, the final weight of the product should be within 180 to 185 grams.

After the conduction of trials, the results for job weight are collected and they are analyzed by means of OVAT (one variable at a time) analysis. In this analysis, we keep one variable constant and take reading of other variable and observe the variation. Table shows the results of trials for OVAT analysis.

Table 3 Results of OVAT Analysis

TRIAL NO.	PARAMETERS COMBINATION		JOB WEIGHT (grams)
	Billet Weight (grams)	Heating Temperature (Celsius)	
1	180	1000	168
2	200	1000	182
3	220	1000	202
4	200	800	170
5	200	950	181
6	200	1150	201

Analysis of billet weight:

Results for Billet Weight analysis:

The selected levels of billet weight are 180,200,220gm. Heating temperature is kept constant at 1000 degree Celsius and trials are taken. From table and chart, it is observed that, in Trial No. 1, as billet weight is at lower side of limits, there is heating loss. Due to this, there is material loss and resulted into unfilled job. In Trial No. 2, billet weight is increased by 20 gm. as compared to trial No. 1, so there is compensation of heating loss. Therefore, there is optimum job weight. In Trial No. 3, as billet weight is at higher side of limits there is minimum heating loss, hence there is no unfilling of job. Due to higher job weight there is die crack resulting in its failure.

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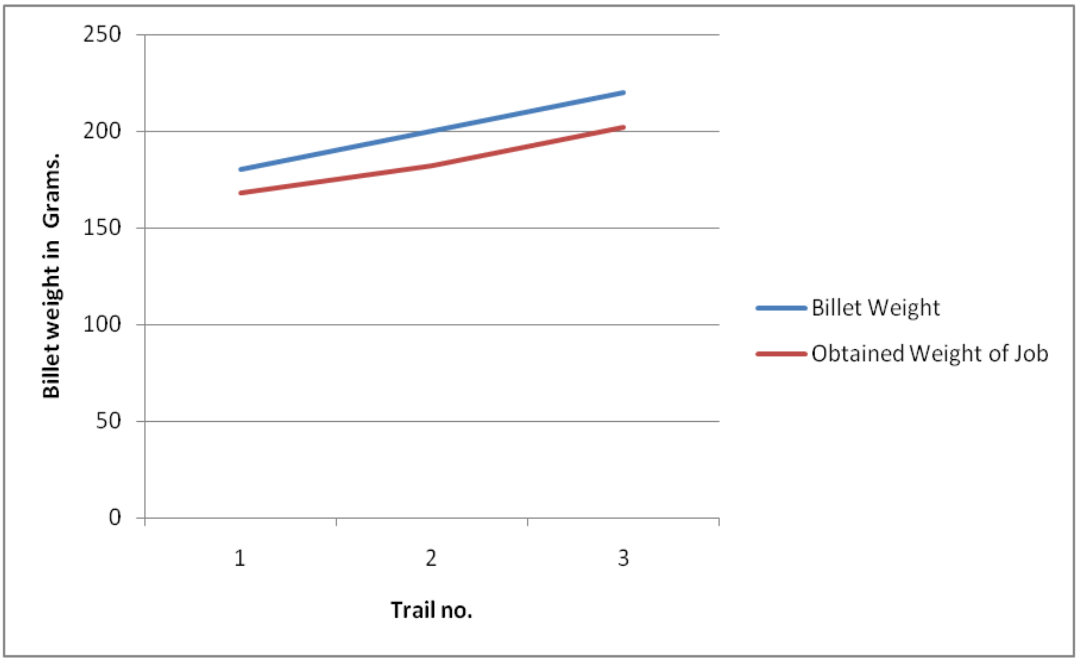
Table 4 Results of Billet Weight Analysis

Trial No	Billet Weight (Grams.)	Obtained Weight of Job
1	180	168
2	200	182
3	220	202



Graph 4 Plot for Job Weight

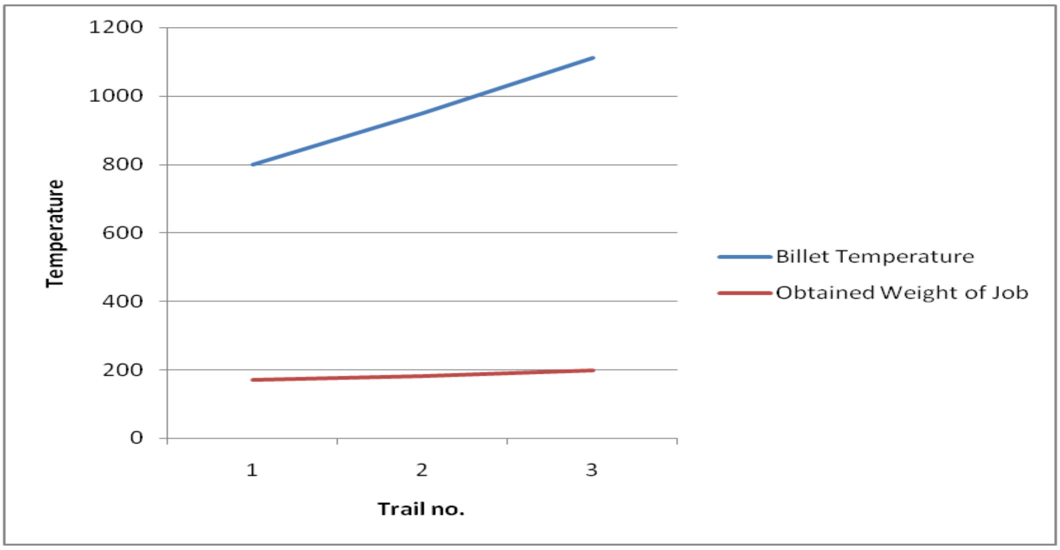
Analysis of heating temperature:

Results for Heating Temperature analysis

Table 5 Results for Heating Temperature Analysis

Trial no.	Temperature	Obtained weight of job
1	800	170
2	950	181
3	1110	201

The selected levels of heating temperature are 800, 950, and 1110 degree. Billet weight is kept constant at 200 grams and trials are taken. From table and graph, it is observed that, in Trial No. 1, as heating temperature is at lower side of limits, there is improper material flow, resulted in unfilled job. In Trial No. 2, heating temperature is increased by 150 degrees as compared to trial No. 1, so there is proper material flow, resulted into optimum job weight. In Trial No. 3, as heating temperature is at higher side of limits, there are more scale losses. So material loss is more, resulted into unfilled job. Hence, heating temperature is influencing factor on job weight.



Graph 5 Plot for Job weight

VII. CONCLUSION

After conducting the trails and analyzing the process it is observed that less billet weight resulted into unfilled job. As well as due to high heating temperature and time, there is excessive scale loss, resulted into unfilled job.

Due to high heating temperature and excessive heating time, there will be improper microstructure and hardness of job. Low heating temperature and time resulted into forging rupture and improper microstructure of job.

When heating losses (scale losses) are more, job is getting rejected due to unfilling. Heating loss is more when the heating temperature and duration of heating the billets is more.

From trails conducting on Claw pole it is found out that heating temperature 950 to 1000 degree would be better for 180 gm. Hence, the selections of process parameters with their levels are proper and they are having the influence on filling the job weight.

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