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A six sigma approach to detect forging defects in a small scale industry: A case study

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***Abstract*— Through this research paper a case study conducted at a small forging unit in Ludhiana, is presented. Through this study, it was observed that the defect rate was more than 6%. In the second phase the collected data was validated by collecting sampling during production hours, which helped in representing a true picture of defects, occurred during manufacturing. Finally an analysis was done using Six Sigma technique. Pareto diagram was used to identify the major defects; 83% of total defects were due to cracks, scaling and low hardness. These all defects were occurred during forging operation. Then, the cause and effect diagram was used to explore possible causes of defects through a brainstorming session and to determine the causes which had major effect. Some corrective measures are also suggested to overcome these defects. In end, it is concluded that the after proper use of forging lubricants and lubrication methods such as spray lubrication and mixture of polymer and water if used as quenching medium may reduce the present defect rate.**

***Index Terms*—Forging, Pareto Analysis, Six Sigma, Small and Medium Enterprises.**

I. INTRODUCTION

Small and Medium Enterprises (SME's) constitute towards the 7% of the GDP growth in India. As per survey conducted by all India Census of Small Scale Industries in 2004; the number of SME's has increased from about 80,000 units in the 1940's to about 10.52 million units.

According to small and medium business development chamber of India, Enterprises in the manufacturing sector are defined in terms of investment in plant and machinery (excluding land & buildings) and further classified as follows:-

1. Micro Enterprise (with investment up to Rs 25 Lacs)
2. Small Enterprise (with investment range from Rs 25 Lacs to Rs 5 Crores)
3. Medium Enterprise (with investment range from Rs 5 Crores to Rs 10 Crores)

Indian SME's are not the exception in global quality levels instead they are trying new innovative measures and techniques to improve quality. These strategies and tools include Total Quality Management (TQM), Statistical Process Control (SPC), Quality Awards, Total Preventive Maintenance (TPM), Lean Manufacturing and Six Sigma.

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A. Six-Sigma

Six-Sigma, a set of techniques and tools for process improvement, was developed by Motorola in 1986.

Six-Sigma addresses the major root causes and guarantees the desired results, both in terms of improvement and time span. This enhancement approach delivers results of productivity, profitability and quality improvements based on its highly valuable approach [2]. Six-Sigma is adopted by many industries because of its proven benefits in increased profitability and reduction in cost especially for medium scale industries. Manufacturing sector is on the top in implementing Six Sigma with 69% contribution followed by IT (Information Technology) industries [3].

Sigma (σ) is a Greek letter that represents the standard deviation of a sample population in statistics. When measuring process capability, the standard deviations between the process mean and the nearest specification limit is designated in sigma units. The greater the sigma value, more number of standard deviations fit between the mean and the nearest specification limit.

- "One Sigma" is a very high degree of variability (i.e. 7 "mistakes" out of 10 opportunities)
- "Six Sigma" is a very low degree of variability (i.e. 3.4 "mistakes" out of one million opportunities). This translates into 99.99966% perfection.

B. Commonly Used Quality Control (QC) Tools in Six Sigma.

Significant number of quality assurance and quality management tools are available and selecting an appropriate tool is not always an easy task. Seven basic quality tools used in Six-Sigma methodologies are:

1. Flow chart
2. Pareto diagram
3. Check sheet
4. Control chart
5. Histogram
6. Scatter plot
7. Cause-and-effect diagram.

According to EOQ (European Organization for Quality) the process of data acquisitions includes three tools (Check sheet, Histogram and Control chart), and for the process of analysis another four tools (Pareto diagram, Cause and effect diagram, Scatter plot, and Flow chart) are used [25].

C. Forging

Forging is one of the oldest metal forming technique by which a desired shape is achieved by holding the raw material in die and then suitable load is applied by means of hammers. Forging can be classified as shown in figure 1.

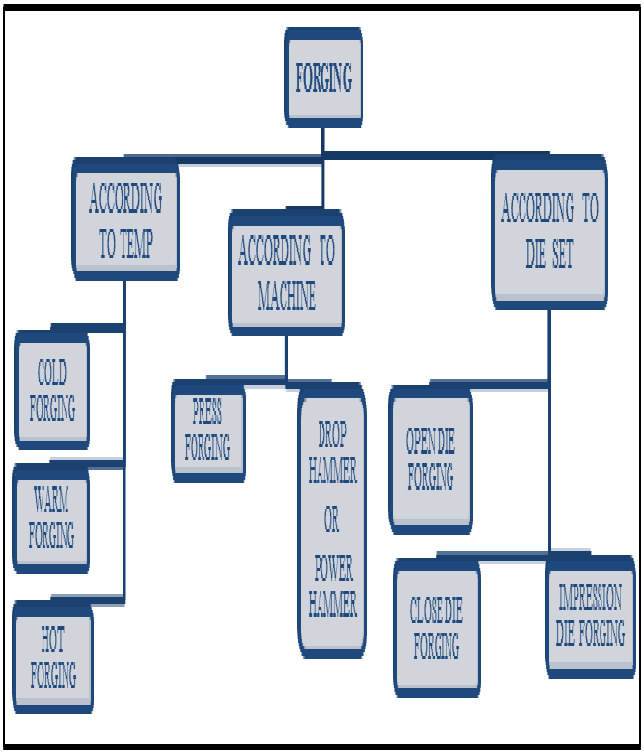

Fig. 1: Classification of Forging Process

In hot forging, the billet is heated above its recrystallization temperature thus avoiding strain hardening. A greater degree of deformation can be achieved in a single operation than in cold or warm forging method. During this process, the raw material and dies are subjected to severe thermal and mechanical fatigue because of high pressure and heat transfer between the dies and the work piece [3]. In comparison to hot forging, warm forging offers advantages due to reduced energy costs of heating the work piece between 600°C and 950°C. In cold forging, the temperature of the metal may range from room temperature to few hundred degrees. Its application is limited to very small components such as screws, other fastening devices and small decorative items.

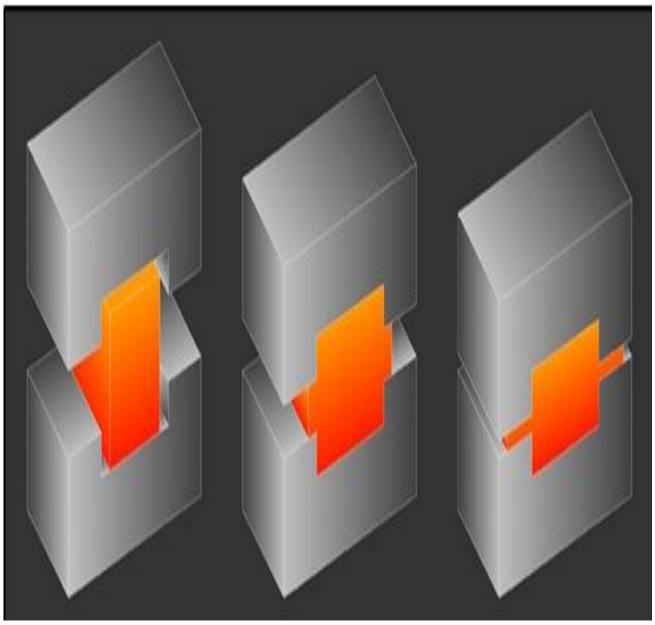

Fig. 2: Illustration of (a) Open Die forging, (b) Closed Die forging and (c) Impression Die forging.

Open die forging generally compression of solid work piece takes place between two plat dies (platens) and finally reducing its height. In closed die forging, work piece is completely surrounded by the die and no flash is formed during the process. In impression die forging, the work piece acquires the shape of the die cavities (impressions) while it is being up settled between the closing dies. Some of the material flows radially outward and forms a flash [8]. Figure 2 shows illustration of open die forging, impression die forging and closed die forging processes.

D. Defects in Forging

During forging operation defects may occur at any stage i.e. raw material (composition) or those formed during forging or post forging operations. These imperfections can be categorized differently as per their origin [27]. :

1. **Material defects:** Occurs due to material composition.
2. **Rolling defects:** Caused during rolling process before actual forging.
3. **Imperfections due to die design:** Caused due to undesirable die geometry.
4. **Defects due to fabrication:** Occurs during forging operations.
5. **Defects due to trimming:** Occurs during trimming and deburring operations.
6. **Defects due to operator error:** Inappropriate handling of part /inappropriate setting/ unskilled worker.
7. **Heat treatment defects:** Defects occurred during heat treatment.

II. LITERATURE BACKGROUND

Various researchers had done remarkable work in implementing six sigma techniques in industry. Some of the contribution of the researchers is explained in this section. Wang and He (2004) presented a review regarding developments made in the field of forging of connecting rods to meet the demand of geometrical accuracy and internal quality. Authors discussed the new precision forging technologies and equipments that had been introduced to improve the production capabilities of manufacturers of connecting rods in China [30]. Kaushik et. al, (2008) made an attempt to justify the highly useful role of quality management techniques like Six Sigma for SMEs which are normally presumed to be in the domain of large industries. Six Sigma methodologies has been applied to a small unit manufacturing bicycles chains and brought up the process sigma level to 5.46 from 1.40. This increase in sigma level is equivalent to monetary saving of Rs 0.288 Million per annum [14].

Chandna and Chandra (2009), discussed the forging analysis of six cylinder crankshaft manufactured by TAT motors, Jamshedpur INDIA , produced by hot forging having engine bore of ninety-seven mm popularly known as 697 crankshaft. Forging analysis has been being made to explain that how the defects appear and how to prevent them. Analysis has been done with the help of various quality tools generally used for quality improvement process such as Pareto analysis, Brainstorming session of workers and Cause and Effect diagrams. Based on the analysis Corrective measures were suggested to overcome the forging defects in existing crankshaft production line in the forging shop and controlling forging defects will reduce the present rejection rate from 2.43% to 0.21% and rework from 6.63% to 2.15% [2]. Kumar et al. (2011) carried out a case study in foundry unit. Through the research, they presented some facts and benefits of using Six-Sigma (DMAIC Approach) in improving the efficiency and performance level of the casting process at the lowest possible cost. They found optimum process parameters of the green sand castings process, which contributes to minimum casting defects[17].

Gebremeskel and Uppala (2012), observed the rejection of mill grinding steel ball for cement industry. They studied the surface cracks, oxide scales, internal cracks, surface folds, etc. During the course of research they observed that the chemical composition of these balls lie within acceptable levels. However, serious deviations were observed during the heat treatment process due to absence of temperature controls and atmosphere controls in the furnace. They found that chemical composition particularly carbon content and chromium were the main reasons behind rejection of the product. They finally suggested the following suggestions: (1) The industry has to fix temperature as well as atmosphere controls for the furnaces while following the standard rules for the furnace temperature, soaking time, and selection of the right quenching media corresponding to the forging material, (2) If some modifications are possible in the industry, after forging of the balls and removing flashes, immediate quenching of forged balls in oil and tempering should be done in forging section [16]. Kumar and Sambhe (2012) discussed a case of motivated mid-sized auto ancillary unit consisting of 350-400 employees which had recently employed Six Sigma (SS) methodologies to elevate towards the dream of SS quality level. They executed the methodology on one of product assembly for trimming down defects level which are critical to customers. The authors in the end concluded with the results that the Six Sigma quality management practice exhibits to improve stratum as well elevate internal and external customers through its amendments and redesigns made or eliminating defects and also creates culture of perpetual improvement, but it needs right focus and commitments [8]. Mathew et al. (2013) implemented Statistical Quality Control (SQC) technique for analyzing the internal defects in an integral axle arm produced by hot forging. The various defects identified in the integral axle arm were un-filling, crack, lap, scale pit, mismatch and oversize. Pareto analysis was used to analyze the intensity of defects and it shows that 83.33% of the total rejection were due to un-filling and lap. The cause and effect diagram was drawn to identify the major causes of these two defects. Authors also suggested some remedial measures to eliminate the defects [20]. Thottungal and Sijo (2013), used Fish bone diagram and Pareto analysis for identification and intensity of defects in a forging unit. Results indicated that the rejection rate is more than 5% and major defects include lapping, mismatch, scales, quench cracks, under filling. Authors accordingly proposed remedial actions to reduce the rejection rate. These 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 (Espon-lss) instead of furnace oil etc [28].

Joshi and Kadam (2014) used Pareto principle and cause & effect diagrams to identify and evaluate different defects and their causes for these defects at different stages of manual metal casting operation in automotive industry. Authors used Pareto principle for identifying major defects like Fins/Flash, Mould shifting, Crushing, Lower Surface finish, Shrinkage, Porosity, Cold shut and Extra material. Cause and Effect diagrams describes that the defects occur due to negligence of human workers during the manual casting operation and suggested that defects like shrinkage, porosity and cold shunt are due to inappropriate pouring system and temperature of pouring metal. Authors concluded their research by proposing Automation of pouring system will be very effective in reducing these defects. Secondly the use of Air blasting rammers can minimize the defects like Fins/Flash and mould shifting up to 50%. In last defects like buckling, surface finish and porosity also are minimized by changing the sand properties [13].

III. CASE STUDY

Present study was conducted at XYZ Forging unit situated in Ludhiana. Name was not disclosed due to some concerns of management of the organization. Company was started in early 90's with production of pipe joints and flanges. Now days it has wide range of product it its catalogue and ship them around the globe. With turnover of around 20 Million INR annually it has 70 to 80 workers including fore mans, machine operators and other laborers. The forging capacity of unit is up to 7000 kg daily if it runs on its full efficiency. Total work distribution is divided into three departments (Tool room, production department and quality assurance department). The management activities are undertaken by the managing director of the organization.

Production department is equipped with all necessary machinery required for forging e.g. induction furnace, oil heating furnace, shearing machines (1ton and 2ton), power hammers (1ton and 2ton), grinders, shot blasting machine and hardening setup. For maintaining the quality and keeping the quality record quality control department is actively working in the company. Quality control department is equipped with latest machines required for quality check. These include Rockwell hardness testing machine and Magna flux testing machine.

A. Product Range

Various products of the organization include couplings, knuckle joint and heavy hand tools. 75 % of the production includes heavy hand tools. List of various hand tools produced are shown in Table 1.

Table 1: List of products and Sub products

S.No.	PRODUCT NAME	SUB PRODUCT
1.	HAMMER	DRILLING HAMMER
		CROSS PEEN HAMMER
		SLEDGE HAMMER
		CLUB HAMMER
2.	WEDGE	SPLITTING WEDGE
		DIAMOND WEDGE
3.	AXE	MICHIGAN AXE
4.	MAUL	SPLITTING MAUL

B. Common Flow Process Chart for Products

In this section, the various processes involved in manufacturing of various types of hammers, maul, axe and wedge through a common process flow chart are explained. Manufacturing processes for Maul, Axe and Wedge are same but differ from hammer at one stage, so this can be described through a common process flow chart shown in figure 3.

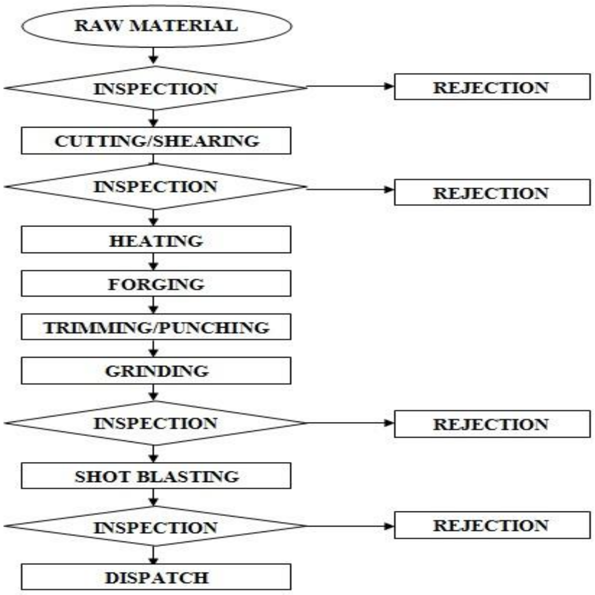

Fig. 3: Common Process Flow Diagram

C. Defect Analysis

To understand and assess the current situation of the organization, final dispatch inspection reports are collected from Quality control department. Collected reports are sorted according to product wise production for January and February 2014. Table 2 shows the detail reports with product wise production, quantity inspected and number of defects detected.

Table 3 represents that, defect rate in January and February is 9.8% and 6.3% respectively. These defects include scaling, crack, cut mark and Unfilled. This data is prepared from final inspection reports; during Final inspection forging defects are considered.

Pareto analysis shows that the major defects which contribute to 75% of defect rate are cracks and scaling. In January 2014, 82 % defects detected are scaling and cracks, where as in month of February 75% of the defects occurred are due to cracks and scaling. Scaling and cracks are already prioritized at 1st and 2nd position in priority list. Other defects i.e unfilled and cut mark stand at 6th and 8th position respectively. Pareto charts for month of Jan. and Feb. are shown in Fig. 4 and Fig. 5.

Table 2: Final Inspection report for January and February 2014.

S.No	Product Name	Weight (Kg/Pc)	Jan-14		Feb-14	
			Quantity	Defects	Quantity	Defects
1	4LB Cross Peen	1.81	N/A	N/A	330	30
2	4LB Drilling	1.81	N/A	N/A	315	19
3	4LB Sledge	1.81	200	21	325	18
4	6LB Sledge	2.72	200	24	N/A	N/A
5	8LB Sledge	3.62	775	132	200	12
6	10 Lb Sledge	4.53	330	38	250	15
7	16LB Sledge	7.25	250	12	N/A	N/A
8	3.5 LB Cross Peen	1.58	50	4	N/A	N/A
9	5 LB Cross Peen	2.26	125	12	N/A	N/A
10	5 LB Splitting	2.26	375	14	N/A	N/A
11	3.5LB Diamond	1.58	205	9	N/A	N/A
12	8LB Splitting Maul	3.62	125	6	N/A	N/A
13	Michigan Axe 3.5	1.58	250	12	200	9
TOTAL				284		103

Table 3: Various defects as identified in month of January and February.

S.No.	Month	Quantity inspected	Defect Type				Total defects	Defect %
			Scaling	Crack	Cut	Unfilled		
1	JAN.	2885	72	141	24	47	284	9.8%
2	FEB.	1620	42	42	8	11	103	6.3%

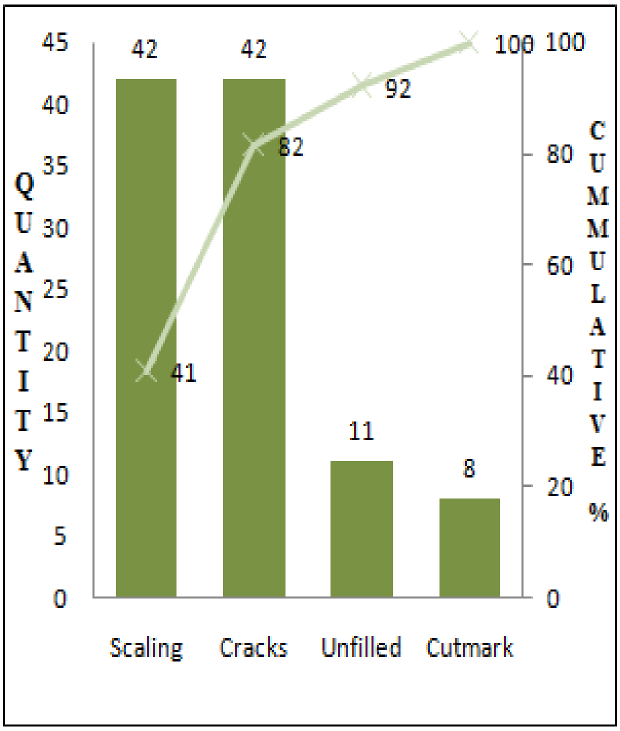

Fig.4: Pareto for Month of Jan.

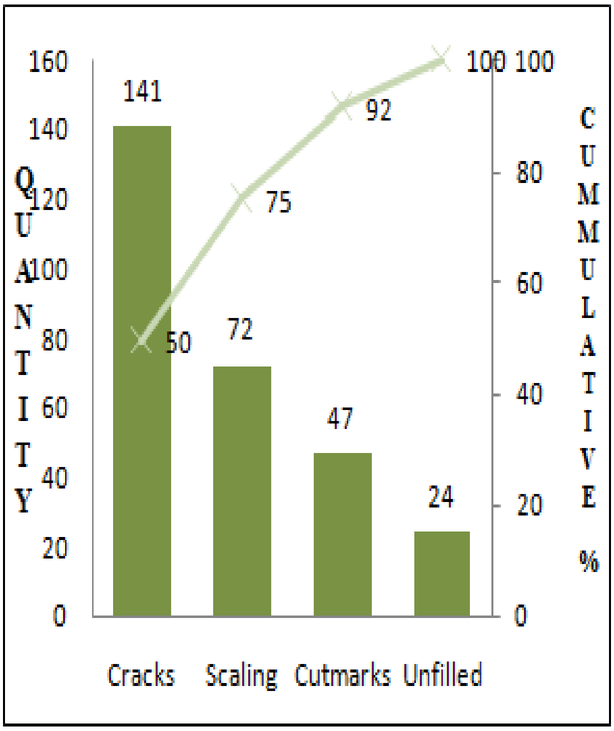

Fig.5: Pareto for Month of Feb.

D.Defect Validation

The previously discussed data is collected from daily inspection reports prepared by the QC department with the organization. In order to present a clear picture of problems faced by the organization, defect validation phase was conducted within the organization. Under this phase; data was collected from the organization during production hours by performing in house inspection of parts being produced. For this purpose, sampling plan is undertaken.

Sampling is all about making measurement simpler, especially when it is required to take a large number of measurements. It is impossible to look at whole population because of time and resources to carry out the measurements or survey. In any large volume manufacturing process, such challenges cannot be ignored. In present research sampling is important in order to find out the root causes behind rejection and defects.

Any successful sampling requires striking a balance between the required "accuracy & precision" and the "available resources". The key steps are outlined below.

1. Defining the population
2. Determining the sample size
3. Selecting the sampling technique

A products having high defect rate which can represent the picture of whole product range are selected. The selected product is:

- 8LB Sledge Hammer (8LB C-413)

The selected products for sampling is called sampling frame. A brief introduction about the sampling frame is given below:

- In a single day about 4000 kg to 5000 kg of raw material can be forged to 8LB Sledge hammer, if sufficient order for the product is in demand.
- Raw material weight is 3.850 kg and Net weight of product is 3.62 kg.
  Flash weight is 100 gms and Punch weight is 50 gms.
- It means about 1100 to 1200 numbers of 8LB sledge hammers can be forged in a single day. Taking population size equal to 1200 (Daily production of sledge hammers) a true sample size will be calculated as discussed below:

True Sample Size for finite population of 1200 can be determined by

(http://www.surveysystem.com/sample-size-formula.htm):

$$\mathbf{TSS} = \frac{\mathbf{SS}}{1+\frac{\mathbf{SS-1}}{\mathbf{Population}}} \qquad (1)$$

Where; TSS is True sample size for finite population and

$$\mathbf{SS} = \frac{\mathbf{Z^2 * p * (1-p)}}{\mathbf{c^2}} \qquad (2)$$

Where;

Z = Z value (e.g. 1.96 for 95% confidence level)
p = Percentage picking a choice, expressed as decimal (.5 used for sample size needed)
c = Confidence interval, expressed as decimal (e.g., .04 = ±4)

Using equations 1 and 2, TSS for population of 1200 is calculated as 400.3. 400 samples are collected at four different stages to identify major defects and reasons behind those defects. These samples are inspected using inspection tools available in the organization and used by the quality control personals. Finding from these samples are discussed in the observation phase.

IV. OBSERVATIONS

Under this phase, parameters recorded during the sampling phase are discussed. 400 samples are collected at each of the four different stages. The results obtained are shown in Table 4.

A total of 54 defects are detected during sampling. Major defects include cracks, scaling, burring and overlapping. Defect of burring is included in sampling because it affects the cracks during forging of product. Burring occurs during shearing of raw material.

At the second stage of inspection under which temperature of quenching medium is to be recorded. The observations were made at 30 minutes of interval during whole day of production and a Temperature Time graph is plotted which is shown in Fig. 6. It is observed during the inspection that the temperature lies in range of 36 ^{0}C to 45 ^{0}C (Refer Fig.6) But it is to be kept in between 40^{0}C to 50^{0}C. Quenching medium used is water. Lower temperature of quenching medium can result in cracks and does not produce required hardness. This temperature range is maintained manually by mixing cold water and hot water through flow control valves.

Table 4: Observations of Sampling Inspection

SAMPLING INSPECTION REPORT			
PRODUCT NAME: 8LB SLEDGE HAMMER			
SAMPLE SIZE: 400			
S.No	**PARAMETERS INSPECTED**	**OBSERVATIONS**	
		QTY.	**RANGE**
1	Gross Weight	**0**	
2	Burring	4	
3	Net Weight	0	3450 - 3620
4	HARDNESS	7	36 - 64
5	CRACK	29	
6	Scaling	9	
7	Overlapping	2	
8	Underfilling	1	
9	Cutmark	1	
10	Mismatch	0	
11	Stamping	1	
12	Rust	0	
Total		54	

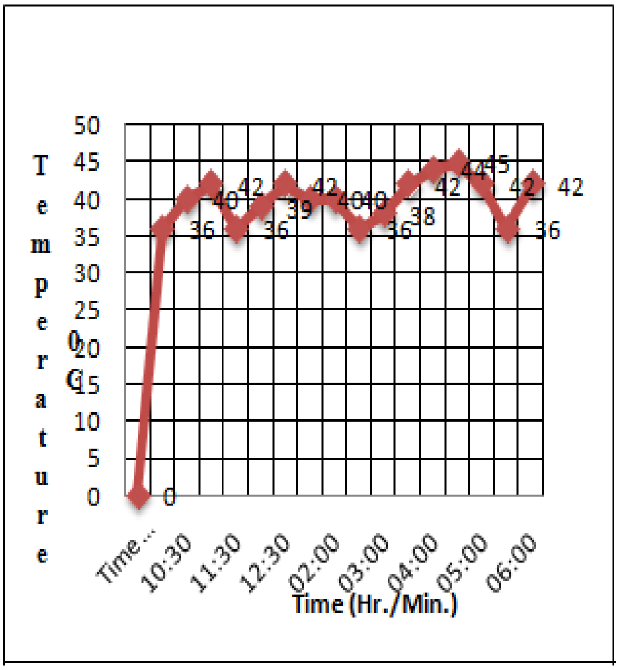

Fig. 6: Temperature Time graph

Pareto Analysis

Pareto chart for the collected samples is prepared, which shows that from the total 54 defects, major defects which contribute to 83% of the defects caused/observed are 29 cracks defects, 9 scaling defects and 7 low hardness defects. Majority of defects are due to cracks (53.7% defect rate) as shown in figure 7.

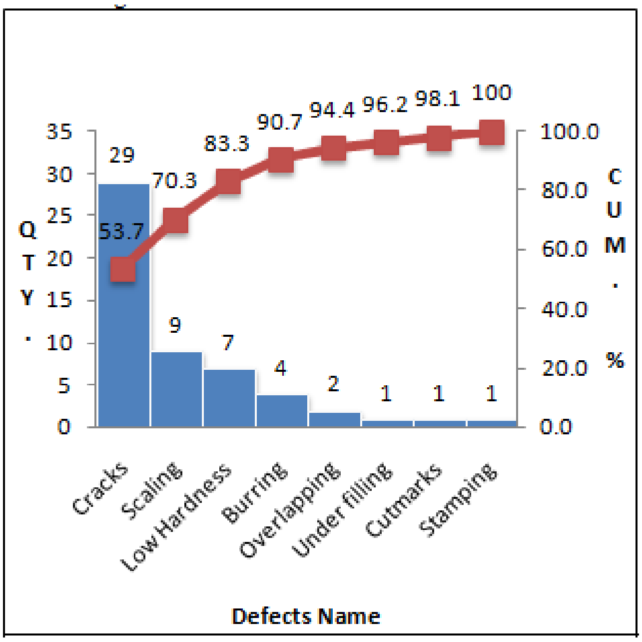

Fig.7: Pareto chart prepared from sampling data.

A. Cause and Effect Diagrams

Bagchi suggested that statistical tools like cause and effect diagram can be used for problem solving and quality improvement [1]. Analysis of data through these tools focuses over identifying most promising factors causing defects and its strength lies in analyzing relationship in a structured way.

Various causes for major defects are identified using cause and effect diagram prepared using brainstorming and literature surveys. The reasons identified are then put into a cause and effect matrix so, as to identify common reasons for major defects. Cause and effect matrix is shown in Table 5

Table 5: Cause and Effect matrix

S.No.	CATEGORY	CAUSE	CRACK	SCALING	LOW
1.	MATERIAL	Mass and size of product	✓		
		Composition of material	✓		✓
		Highly Rust Material		✓	
2.	ENVIRONMENT	Soaking	✓		✓
		Presence of Air and		✓	
3.	PROCESS	Temperature of work	✓		✓
		Temperature of	✓		✓
		Excess	✓	✓	
4.	METHOD	Type of Lubrication oil		✓	
		Type of Quenching	✓		✓
		Burring/Oblique cutting	✓		
		Heating medium used.		✓	
		Type of Furnace oil used.		✓	
		Setting of work piece in			✓
5.	OPERATOR	Insufficient Quench	✓		✓
		Bottle necks during peak	✓		✓
		Excess Lubrication		✓	
		Forging Die not cleaned		✓	

V RESULTS AND DISCUSSION

The study for detecting major defects occurred during the production of hand tools is done and the major defects contributing towards the defect rate are identified as cracks, scaling and low hardness. After collecting and analyzing the data, cause and effect diagram was drawn to identify causes of cracks, scaling and low hardness.

The major causes of cracks are identified as improper quenching medium in use, insufficient quench delay, Temperature of quenching medium and temperature of forged product during quenching. After controlling the temperature range of forged product during quenching in a range of 900 ^{0}C to 950 ^{0}C and also the temperature range of quenching medium between 45 ^{0}C to 60 ^{0}C help in reducing the crack defects. It is also recommended to use mixture of polymers and water with 4% to 8% polymer in water as quenching medium instead of plain water to control this defect.

Second major defect is identified as scaling and the major reasons behind this defect was identified as improper scale removal technique, insufficient lubrication, improper furnace oil or high temperature of heating furnace and chips or bubbles formed in forging die. Use of suitable lubricants of specified quality for the lubrication of dies and billet contact surface during forging operation or use of spray lubrication methods over the billet and forging die contact surface will allows the metal to flow more easily. Also, if the air blowers installed with the forging hammers are operated at proper speed and pressure will help in removing chips and bubbles formed in the forging die during forging operation.

Third major defect was identified as low hardness, Hardness range below 40HRC is not recommended. While controlling the defect of cracks and scaling when the temperature of product and quenching medium is maintained it affects the hardness of the product. More soaking time helps in eliminates the defect of cracks on the other hand contributed towards low hardness if this time is very high. If the temperature range of quenching medium is high it will give low hardness ranges but eliminates the chances of crack formation and vice versa. So, there is a serious need to achieve a optimum temperature range which could balance between all the parameters. This could be possible only with the help of Design of Experiments (DOE) or trough Finite Element Analysis (FEA).

VI CONCLUSION

During the course of study forging defects like cracks, scaling, low hardness, burring, overlapping, mismatch, cut mark and under filling are found to be contributing towards rejection/rework of forged parts. Using Pareto analysis it is found that the major defects contributing towards 83% of the defect rate are cracks, scaling (scale pits) and low hardness. For these major defects cause and effect diagram was drawn to identify the major cause's defects. The major causes of these defects are identified as improper lubrication methods and use of improper lubricants. Temperature of forged product and quenching medium is among serious issue which needs serious attention.

By changing the type of lubricant in the forging unit it gives positive results. Spray cooling method is also being installed in unit which is to be replaced with conventional brush type lubrication method. Further it is recommended to conduct DOE and FEA study in order to obtain optimum range of temperature required during hardening operation.

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