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Reduction of unforged bar bulb in engine valve manufacturing

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***Abstract*—Valves play an important role while converting chemical energy into mechanical energy during the cycle in IC engine. The valves made of several processes like preparing cut bar, upsetting and forging in the premachining. At the premachining stage of valve manufacturing, there are manual and robot-assisted forging shop used to produce the head of the valve from preformed bar or bulb produced bar. In this project, the ways to reduce the unforged bar bulb at the robot-assisted forge shop are found. The root cause analysis (RCA) method is used to find the problems which cause unforged bar bulb. From the analysis, It has been found that the major cause of the occurrence of the unforged bar bulb is the stem bend. Because of there is no guidance for the bar, the stem bends while upsetting and it leads other causes like loss of copper jaws life, Robot collision, die damage, etc., In order to overcome this main and other causes, the design of the upsetter stopper bush is redesigned. By doing this, the quality and quantity of valves in production are increased, the occurrence of the unforged bar bulb is reduced and stem run achieved and maintained within the limit at the premachining stage.**

***Index Terms*—Unforged bar bulb, Electric upsetting, Forging, Engine valve, Root cause analysis.**

I. INTRODUCTION

The engine valve is one of the main parts which are used in all internal combustion(IC) engines.

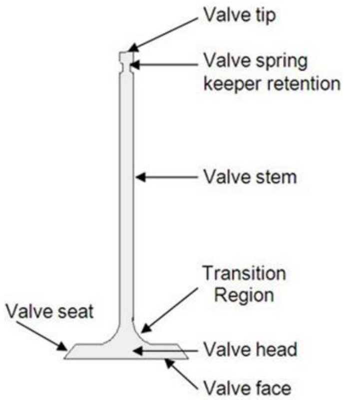


Figure 1. Parts of engine valve

Valves are used in piston engines to open and close the intake and exhaust ports in the cylinder head. So there are two types of engine valve, inlet and exhaust valve. Inlet valves permits the required amount of air-fuel mixture in the engine. Then, exhaust valve passes the exhaust gases to the atmosphere. This is why valves play a critical role in IC engine. The engine valve is also used to seal compression or prevent the combustion products from escaping during the cycle. The valve is usually a flat disk of metal with a long rod known as the 'valve stem' attached to one side.

Materials that are commonly used for manufacturing engine valves include carbon steel alloys, stainless steels, high-strength nickel-chromium-iron alloys and titanium. The alloys are commonly used to produce valves include various high chromium stainless alloys for intake valves, and 21-4N for exhaust valves.

Abhishek Jayswala*et al.*[1] studied and investigated on A sustainability root cause analysis methodology. In this the major problem in it is to identify the bottleneck issue and to improve sustainability.RCA method is able to focus attention on the designer and provide critical guidance to design. It helps the designer to advance their practice for sustainability development more systematically. Dalgobind Mahto, Anjani Kumar[2] The authour investigated and disscussed about the root cause identification for quality and productivity related problems. In the root cause identification method has been adopted to elimate the dimension defect in cutting operation cnc oxy flame cutting machine. It is identified using structural approach with techniques to resolving problems. Guo-zheng Quan *et al*.[3] studied the formation process of upsetting defect in electric upsetting and optimizing the process parameters based on multi-field coupling FEM. The main factor causing the secondary upsetting defect is the large temperature decrease of the deformed portion after the formation of deformed shape in the preliminary stage of electric upsetting. The effective elimination of secondary upsetting defect was developed by a current sub routine in MSC. Marc.K.Elayaraja, P.Periyasamy[4] investigated and developed a process quality control through proportionate valve in electrical upsetting. They conducted a number of trials like varying the power intensity, different anvil position and velocity to obtain the bulb without crack or fold. From the result of the trials, they conclude that shape of bulb can be changed by anvil position. Karan soni*et al*.[5] carried out an investigation based on optimizing the internal combustion engine exhaust valve design using finite element analysis. By using finite element method, it significantly shortens the design cycle by reducing the number of tests required. By utilizing the computational capability to identify the possible design optimization of exhaust valves for material and weight reduction, without affecting thermal and structural strength.Naresh Kr. Raghuwanshi &*et al*.[6] kept focussing on different failure modes of internal combustion engine inlet & exhaust valves. The failure occurs mainly due to fatigue at high temperature, high operating temperature effects on mechanical properties. Wear failure which is because of impact loading, and wear rate that depends on load and time. This is helpful for researchers to develop the valve materials to achieve a prolonged life. Quan guozhong *et al*.[7] analyzed and discussed about the influence of electric upsetting process variables on temperature field by multi field coupling finite element analyses. As the current increase , the secondary upsetting defect are in less distinct and in order to eliminate the secondary upsetting defect on the work pieces. . Thus optimizing the upsetting pressure and a three stage current load mode the secondary upsetting defect is eliminated completely.Xi yang*et al*.[8] investigated about cracking and fracture issues in precision forging of engine valve using finite Element Method. . For the forging process, finite element simulation was conducted with commercial Finite element code DEFORMfracture occurs. In micro based damage mechanics model (MDM) derives an analysis on isolated unit cells involving idealized defects such as cracks. By the utilization of finite element analysis it gives a great potential of such application in the mass production.Yuvraj K Lavhale, Prof.Jeevan salunke[9] investigated on the failure trend of intake and exhaust valves. Valve failure occurs due to thermal fatigue, Inlet valve failures occurs due to wear, impurities in air. In the exhaust valve flue gases forms the scale formation which are mainly due to the erosion and corrosion. So, the important attention should be given while designing of intake and exhaust valve. Zhang-xing men *et al*.[10] developed and investigated on continued electric heating in upsetting process by the influence of coupled electr-thermo-mechanical simulation. An axi-symmetric model has been developed to analyze a deformation process by continuous resistance heating. By increasing the current intensity, it leads to decrease in cooling rate and the optimized forming force can be obtained.

A. COMMON PROBLEMS FACED IN ENGINE VALVE MANUFACTURING

In valve manufacturing, there are many problems faced as following mentioned**.**The problems which are commonly facedbar bulb crack, seat uneven, face pittings, stem bend, face crack, overall length low.

B. FORGE SHOP

Forge shop is one of the stages in the premachining process. It consists of

- Forging Press
- Upsetting Machine
- Robot
- Loading and Unloading unit
- Pyrometer sensor

Figure 2.Forge shop

In the forge shop where the head of the valve is produced. First, the raw material is prepared as a cut bar for the premachining. Then it brings to the forge shop of premachining. The cut bar is loaded by the operator. Then loading unit loads the cut bar to an upsetting machine. By upsetting the cut bar, the onion-shaped bulb is produced. The copper jaws and Mallory anvil act as electrodes and by placing the cut bar, the circuit gets closed. The robot picks preformed bar from upsetter and places it in the die. At the die, the temperature of the bulb is monitored to ensure that it is within range of 850°C to 1100°C. If it is not, it cannot be forged. The pyrometer pointed towards the direction of the bulb. If bulb temperature is within the range, the press produces head by applying force. Then the unloading unit is used to unload valve to bin.

C. UPSETTING PROCESS

To perform forging, the job has to be drawn to required temperature and plastic deformation stage. The bulb temperature should be in the range of 850°C to 1100°C for SUH 11 and 21-4N steel. For preforming purpose, the upsetting process is carried out.

When a high-density electric current at a very low voltage is made to pass through a portion of bar stock, which is held against an anvil and clamped between two jaws and supported by the hydraulic stopper bush, to generate sufficient heat to make the portion red hot and plastic. An upsetting force is applied in the axial direction on the rod against the anvil, making the portion which is in the plastic stage, to deform into a bulb shape and to gather the required volume.The overall length of valve is varied by adjusting the travel distance of a hydraulic piston movement.

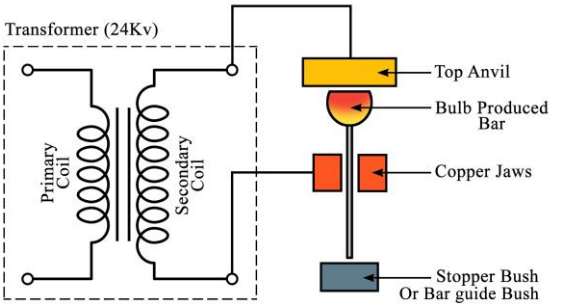


Figure 3. Upsetting machine

A diagram of the upsetting process is as shown in Figure. 3and the operating parameters of upsetter is shown in Table 1.

Table 1. Upsetting machine operating parameter

Parameters	Values
Upsetting pressure	20-45 Kg/cm^2
Clamping pressure	15-40 Kg/cm^2
Anvil gap	2-5 times of bar dia
Anvil changing frequency	1000 Nos
Jaws changing frequency	350 Nos

D. UNFORGED BAR BULB

Unforged bar bulb is one of the rejections in valve production. Unforged bar bulb means not head produced valve after and while bulb produced in the upsetter. Forging of a valve is carried out with the help of automation. It happens due to a lot of causes. For example, when robot collides with the press, it stopped to moving and the bars which are processed in upsetter come to stop upsetting. Thus the unforged bar bulb occurs while upsetting.

It leads to production loss, consumes a lot of time and money to convert the unforged bar bulb into a valve. Due to this, a lot of industries avoid to rework it. The unforged bar bulb is as shown in Figure 4.

Figure 4. Unforged bar bulb

E. CAUSES TO PROBLEM OCCURING

1) Stem Bend

There is no guidance for the bar. So stem slides over the surface of the stopper bush during the process. Owing to this, Stem bends while upsetting process. It causes high stem run out (Stem run out should be up to 0.3mm). So the bars that have high stem run out will be a burden in straightening process. When these bars placed in the die, it cannot be placed properly and it cannot get into die. So, the unloader unloads this bar which is not forged.

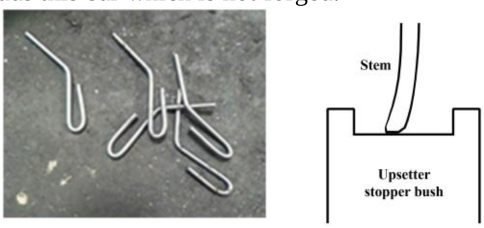


Figure 5. Stem bend

2) Loss of jaws life

When jaws life (350 NOS) get over, stem starts to bend. Sliding of a stem during the upsetting process, the groove of the copper jaws tends to change as shown in the Figure 6. Once the groove gets bend, it also causes a bend in the preformed bar.

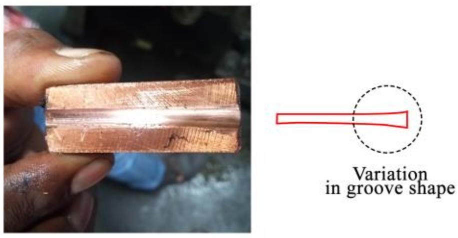


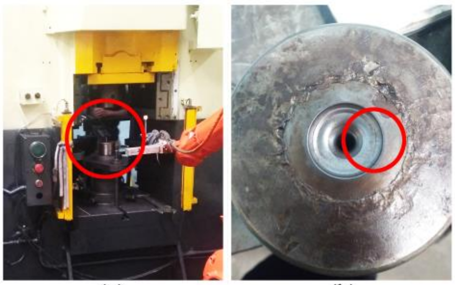
Figure 6. Variation in jaws groove

Copper jaws that have a bend in the groove cannot be used any longer. By following this deflected groove, upcoming bars also upsetted and results stem to bend. Thisalso leads to unforged bar bulb.

Variation in the groove shape is shown in the Figure 6.

3) Die damage

When the bent job is placed in the die, it additionally gets bend during forging because of the heavy load. Due to the excessive deflection, it got stuck in the die as shown in Figure 7. During this, another upsetter stopped to upset the bar. So, it remained as unforged bar bulb.



(a) (b)

Figure 7. (a). Job stuck at die (b). Die damage

4) Gripper misalignment

When the robot gripper picks the bent job from upsetter machine, alignment of the gripper gets changed. If it happened, the gripper cannot pick and place the job properly. It also causes unforged bar bulb.

Figure 8. Gripper misalignment

5) Robot collision and position change

Either job get stuck at die or bar bends while upsetting causes the robot collision. The collision of the robot is as shown in Figure 9. This also causes robot position change. If the position of robot changes, it cannot perform the task properly. So engineer needs to teach the robot and it also consumes more time.

Figure 9. Robot collision

II. METHODOLODY & MATERIALS

A. Materials

Inlet valves are made up of mono materials and it is rare to use bi-metals if more strength needed. Where SUH-11 or 21-4N is used to produce the inlet valves. The dimensions of a cut bar are given below in the Table 2.

Table 2. Cut bar parameters

Parameters	**Values**
Length	182±0.5 mm
Diameter	5.675±0.025 mm

Super alloys or high performance alloys have an ability to operate at temperatures above 540ºC (1000ºF) with deformation resistance and high surface stability. As they have good oxidation and creep resistance, super alloys can be commonly forged, rolled to sheet or produced in various shapes. Iron-base, nickel-base and cobalt-base alloys are the major types of super alloys.

Table 3. Compositions of SUH 11 steel

Elements	**Min.** (≥)	**Max.** (≤)
C	0.45	0.55
Si	1.00	2.00
Mn	-	0.60
P	-	0.03
S	-	0.03
Cr	7.50	9.50
Ni	-	-
Mo	-	-

Nickel-base and cobalt-base super alloys may be cast or wrought based on its composition or application. The iron-base super alloys are generally wrought alloys that can be strengthened by precipitation hardening, work hardening and solid-solution hardening.

Table 4. Compositions of 21-4N steel

Elements	**Min.** (≥)	**Max.** (≤)
C	-	0.05
Si	-	0.20
Mn	-	0.50
P	-	-
S	-	-
Ni	-	remaining
Cr	15.00	17.00
Al	4.00	5.00
Cu	-	-
Ti	-	0.50
Fe	2.00	4.00
N	-	-
Mo	-	0.50
B	-	0.006
Zr	-	0.05

B. Methodology

This project carried out by the root cause analysis method in order to eliminate the problems by finding and eliminating the root problem. Root cause analysis is a systematic approach to get to the bottom of the problem and it aims at improving products or processes.

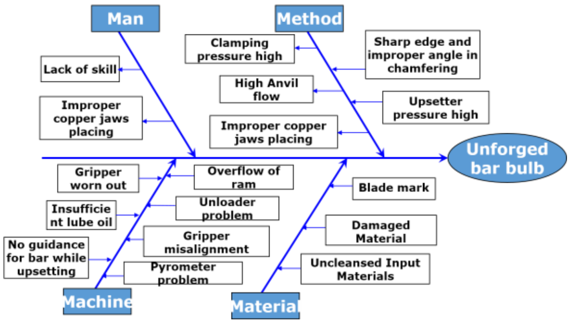


Figure 10. Cause and effect diagram

Cause and effect diagram is drawn as shown in Figure 10for every possible cause to unforged bar bulb during brainstorming. Possible causes are observed and evaluated.

C. Geometrical parameter

In order to eliminate all the causes, the design of upsetter stopper bush (which is the root cause) is changed. The upsetter stopper bush is modified as shown in the Figure 11 and named as bar support bush. The dimension of the groove is 7mm to guide the bar during the process.

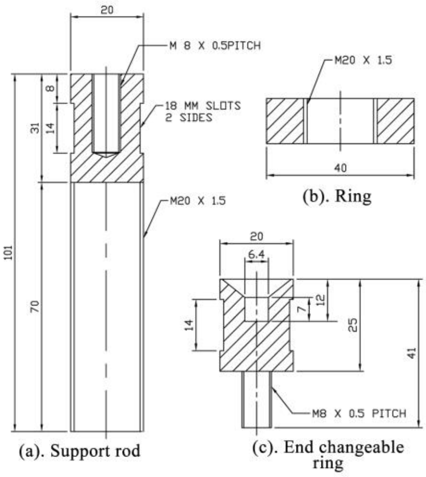


Figure 11. Upsetter bar guide bush – Modified design

In this design, an end changeable bush is provided as shown in Figure 11. (c). Simply changing the end changeable bush with different groove diameter can produce valves with various diameter bars easily.

III. RESULT & DISCUSSION

Through the root cause analysis method, it has found that stem bend is the main problem for unforged bar bulb and other causes which are responsible for unforged bar bulb. During observation and analyzing, several trials conducted and RCA tools like fishbone diagram, cause and effect diagram used to analyse respectively. In order to eliminate the root cause, the design of the upsetter stopper bush is modified(modified design - upsetter bar guide bush).

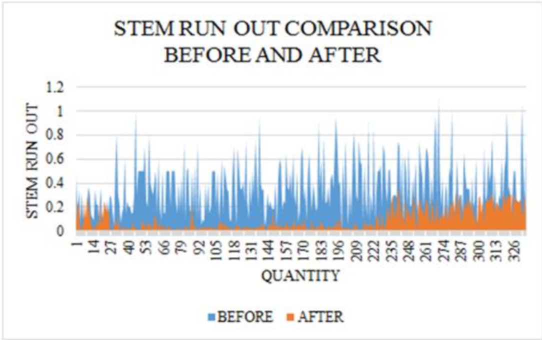


Figure 12. Stem run out comparison before and after changing the design

Before and after employing a new design, a trial was conducted to measure stem run out after changing a new pair of copper jaws. Each upsetter machine requires a pair of copper jaws. A new pair is efficient up to 350 jobs. In this trial, there were two upsetters.Before and after, 335 jobs were taken in the trial out of 700.The result of this trial is shown in Figure 12.

The highest and the smallest stem run out were 1.1mm and 0.01mm before changing the design of upsetter stopper bush. The valves which are out of specification(0.3mm) were 171 and 51% of 335. After the design implentation, the highest and the smallest stem run out were 0.35mm and 0.01mm respectively. Out of specification valves were 13 and 3.88% of 335.

As a consequence of not having any guidance, stem bends while upsetting. By providing groove and tapper surface it guides the bar while upsetting and also prevents the bar from slipping from groove respectively. So the stem bend controlled within the limit(0.3 mm).

From Figure 12, we can see the difference between before and after changing the design of upsetter stopper bush and the improvement in the copper jaws life. The stem run out was random wise changing when there is no guidance. After providing guidance, it seems the stem run out uniformly changing.

If stem bends while upsetting, it will get stuck at die after forging and it leads to die damage. By controlling the stem bend while upsetting, the problem is eliminated from occurring. Robot collision, gripper misalignment which are occurred because of stem bend has been eliminated.

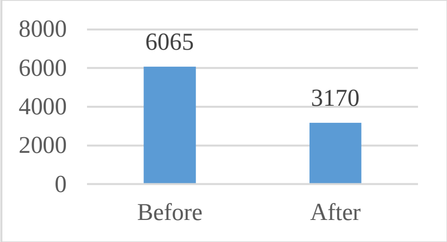


Figure 13. Unforged bar bulb – Rejection

In Figure. 13, a chart shows rejection between before changing the design and after changing the design of upsetter stopper bush. The unforged bar bulb rejection has been reduced to 52.26%.

IV. CONCLUSION

In the present study, a problem called 'unforged bar bulb' has encountered in the forge shop of valve production area. Unforged bar bulb is actually a rework. But heating unforged bar bulb again causes bulb crack and other problems. Rework process has to be done manually. Unforged bar bulb leads to production loss, consumes a lot of time and money to convert it into a valve. Due to this, a lot of industries avoid to rework it. This problem has various causes which are responsible for occurring. For this situation, Root cause analysis (RCA) method has chosen to carry out this project. By doing continuous observation and analyzing, a problem which is responsible for main and all other problems has been found.

Stem bend was the root cause of the problems and the process line where it occurs have also been found that it was during upsetting. Because there was no guidance to the stem during the upsetting process. The upsetter stopper bush which holds stem has flat surface Due to this, it slides over the surface. So, the design of upsetter bush is modified as upsetter bar guide bush. In this design, a groove which is 7mm height is provided to guide the stem and tapper surface is provided to prevent the escaping of stem from the bush. If other than 5.675±0.025 mm diameter bars to upset, the total bush has to be changed and it consumes time. Now simply changing the end changeable bush that has different diameter groove, can upset valves with various diameter bars easily. Thus, the design was modified to minimize the stem bend. Unforged bar bulb leads to production loss, consumes a lot of time and money to convert it into a valve. Due to this, a lot of industries avoid to rework it when having no time. Therefore, the rejection rate is reduced at forge shop and the flexibility of upsetter stopper bush is increased as upsetter bar guide bush.

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