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Controlling Measures to Reduce Rejection Rate due to Forging Defects

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***Abstract*-** The objective of this paper was to investigate the various forging defects that occur in a forging industry that causes high rejection rates in the components and this paper describes the 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 various defects that occur in the components during forging are identified. 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. In this paper, it describes the remedial actions that to be done inorder to reduce the rejection rates. 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 (espon lss) instead of furnace oil etc.

Index Terms- forging defects, forging defects remedies, forging errors, closed die forging, controlling measures for forging errors

I. INTRODUCTION

Forging is the process by which metal is heated and is shaped by plastic deformation by suitably applying compressive force. Usually the compressive force is in the form of hammer blows using a power hammer or a press.

Forging refines the grain structure and improves the physical properties of the metal. With proper design, the grain flow can be oriented in the direction of principal stresses encountered in actual use. Grain flow is the direction of the pattern that the crystals take during plastic deformation. Physical properties (such as strength, ductility and toughness) are much better in a forging than in the base metal, which has, crystals randomly oriented.

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. Defects can be defined as imperfections that exceed certain limits. In other words, there may be imperfections that are not classified as true “defects” because they are smaller than allowances in the applicable specifications.

There are differences in allowable imperfections on the surfaces of forgings and these vary depending on the material being forged. This is the area that requires attention especially that going to focus in this paper and the remedial or controlling measures to be taken to reduce the rejection rate in the forging industry due to these imperfections.

This article describes the investigation that carried out in a forging industry in kerala, south india. By investigating the plant it’s noted the defects that are occurring in the forged parts that causes rejection rate, and the remedial actions or controlling measures that should be taken to avoid these rejections.

II. IDENTIFICATION

During the investigation that done within a forging industry, its manufacturing more than 24 types of components by the hot forging technique. With the help of the QA department within the plant its clear that in July 2012 company manufactured 24 types of components for different clients using ten ton hammer. In the total number of 2798 products about 150 products were rejected, which means the plant has a rejection rate of more than five percent per month. These much rejection rate cannot be tolerated by the company, this lead me to undergo an detailed study in the company about the defects that caused these much rejection rate and the remedial actions suitable for that to reduce the rejection rate.

From the table:1 it’s clear that the quantity received for each components both in numbers and in metric tons, quantity accepted and the quantity rejected during the specific month. From the inspection report given from the quality assurance department within the plant out of 2798 manufactured components a total of 143 components were rejected.

This led me to undergo an investigation in the company about the defects that caused these much rejection rates and the remedial actions suitable for that to reduce the rejection rates.

III. STUDIES AND FINDINGS

The quality assurance department made remarks after conducting various tests to analyze the defects caused to the components that forged within the company.

The various tests conducted by the quality assurance department include dye penetrant testing, magnetic particle testing, and ultrasonic inspection to check whether there are internal cracks or external surface defects after the forging process. After these testing processes they are making a detailed report on these as shown in table 1.

INSPECTION REPORT FOR MONTH JULY 2012						
Sl no.	**item**	**Quantity received**		**Quantity accepted**		**Qty rejected**
		No.s	M tons	No.s	M tons	No.s
1	680 bevel pinion	119	16.07	118	15.93	1
2	786 crank shaft gear	155	17.83	155	17.83	0
3	254 saddle	101	11.11	62	6.82	39
4	833 coupling	42	3.23	39	3	3
5	819 pylon	20	0.59	18	.53	2
6	621 saddle	10	1.55	10	1.55	0
7	807 integral axle arm	58	10.21	58	10.21	0
8	794 cam shaft gear	55	3.96	55	3.96	0
9	256 crank shaft gear	39	2.34	39	2.34	0
10	496 rod wheel arm	180	7.38	180	7.38	0
11	175 con rod	635	25.84	549	22.34	86
12	855 gear	25	11.25	20	9	5
13	55 valve body	200	21.4	200	21.4	0
14	263 cam shaft gear	81	11.34	81	11.34	0
15	837 gear	55	18.15	54	17.82	1
16	814 companion flange	63	4.28	63	4.28	0
17	779 gear	250	14.88	250	14.88	0
18	958 mf center	37	4.51	37	4.51	0
19	959 mf inter	15	1.38	15	1.38	0
20	960 mf end	15	1.58	15	1.58	0
21	527 d cage	113	2.6	111	2.55	2
22	127 valve body	200	36.6	200	36.6	0
23	219 mb cap	285	19.38	281	19.38	4
24	272 gear	45	8.28	45	8.28	0
total		**2798**	**255.74**	**2655**	**244.89**	**143**

Table 1: inspection report by the QA department for month July

By plotting the defects that caused on the components graphically the figure 1 shows it. From the graph we can get a clear idea that out of 24 components a total of 14 components are affected by the unfilling and scale pits which are the major defects. The other major defects are mismatch, lapping, oversize in the forged components.

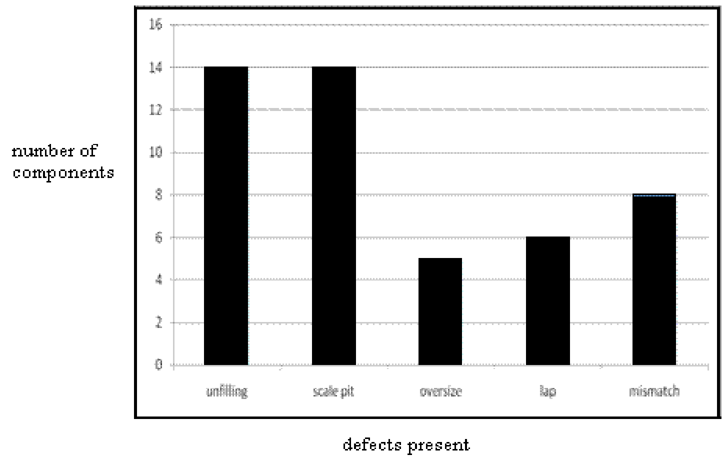

Figure 1: graphical representation defects presented in the components

IV. TECHNIQUES USED BY QUALITY ASSURANCE DEPARTMENT TO ANALYZE THE DEFECTS DURING FORGING

A: GREEN STAGE

There are several techniques that used for check the defects that caused in that forged components. It may be in hot stage or it may be in green stage. The green stage checking is done after the forged components are cooled.

1. Dye penetrant inspection
2. Magnetic particle inspection
3. Ultrasonic inspection

1. DYE PENETRANT INSPECTION

Dye penetrant inspection (DPI), also called liquid penetrant inspection (LPI) or penetrant testing (PT), is a widely applied and low-cost inspection method used to locate surface-breaking defects in all non-porous materials (metals, plastics, or ceramics). The penetrant may be applied to all non-ferrous materials and ferrous materials; although for ferrous components magnetic-particle inspection is often used instead for its subsurface detection capability. LPI is used to detect casting, forging and welding surface defects such as hairline cracks, surface porosity, leaks in new products, and fatigue cracks on in-service components.

2. MAGNETIC PARTICLE INSPECTION

Magnetic particle inspection (MPI) is a non-destructive testing (NDT) process for detecting surface and slightly subsurface discontinuities in ferroelectric materials such as iron, nickel, cobalt, and some of their alloys. The process puts a magnetic field into the part. The piece can be magnetized by direct or indirect magnetization. Direct magnetization occurs when the electric current is passed through the test object and a magnetic field is formed in the material. Indirect magnetization occurs when no electric current is passed through the test object, but a magnetic field is applied from an outside source. The magnetic lines of force are perpendicular to the direction of the electric current which may be either alternating current (AC) or some form of direct current (DC) (rectified AC). The presence of a surface or subsurface discontinuity in the material allows the magnetic flux to leak, since air cannot support as much magnetic field per unit volume as metals. Ferrous iron particles are then applied to the part. The particles may be dry or in a wet suspension. If an area of flux leakage is present the particles will be attracted to this area. The particles will build up at the area of leakage and form what is known as an indication. The indication can then be evaluated to determine what it is, what may have caused it, and what action should be taken, if any.

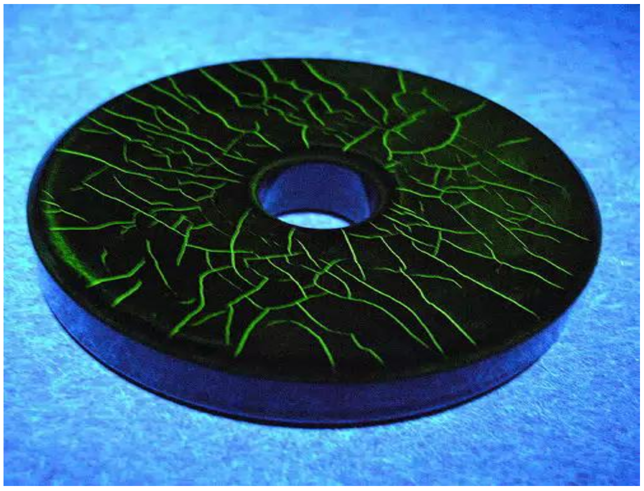

Figure 2: magnetic particle inspection

3. ULTRASONIC TESTING

In ultrasonic testing, an ultrasound transducer connected to a diagnostic machine is passed over the object being inspected. The transducer is typically separated from the test object by a couplant (such as oil) or by water, as in immersion testing.There are two methods of receiving the ultrasound waveform, reflection and attenuation. In reflection (or pulse-echo) mode, the transducer performs both the sending and the receiving of the pulsed waves as the "sound" is reflected back to the device. Reflected ultrasound comes from an interface, such as the back wall of the object or from an imperfection within the object. The diagnostic machine displays these results in the form of a signal with an amplitude representing the intensity of the reflection and the distance, representing the arrival time of the reflection. In attenuation (or through-transmission) mode, a transmitter sends ultrasound through one surface, and a separate receiver detects the amount that has reached it on another surface after traveling through the medium. Imperfections or other conditions in the space between the transmitter and receiver reduce the amount of sound transmitted, thus revealing their presence. Using the couplant increases the efficiency of the process by reducing the losses in the ultrasonic wave energy due to separation between the surfaces.

B: HOT STAGE

There are several techniques that used for check the defects that caused in that forged components .Hot stage checking consists of the analysis of forged part at the stage of forging itself. In this it will thoroughly inspect the laps, scale pits, unfilling, cracks, and mismatch by directly. And for control the dimensions we will use the GO and NO-GO gauges.

DEFECTS DURING FORGING ANALYZED BY THE QUALITY ASSURANCE DEPARTMENT

1. UNFILLED SECTION

Some section of the die cavity is not completely filled by the flowing metal or Metal does not fill the recesses of the die completely. Its mainly due to the improper design of the die. This unfilling process is occurring due to following.

- improper design of the forging die .
- improper material flow in the die.
- air, gas or lubricant being trapped in a corner feature of a forging dies.

2. LAPS AND FOLD

A lap is defined as surface to surface contact in the workpiece when the surface of the workpiece folds or collapses on itself. A section of the workpiece flowing into itself.A “flow-by” in which the workpiece surface is in contact with a die and is subsequently pulled away by a tensile stress component and closes on itself.“Peeling” that can form when the surface of a billet or preform is sheared by a die, resulting in an area of localized folding. A die corner is frequently involved, as it forces material ahead of a moving contact region, without significant subsurface deformation. This defect can be the result of a poor design or inadequate process control.

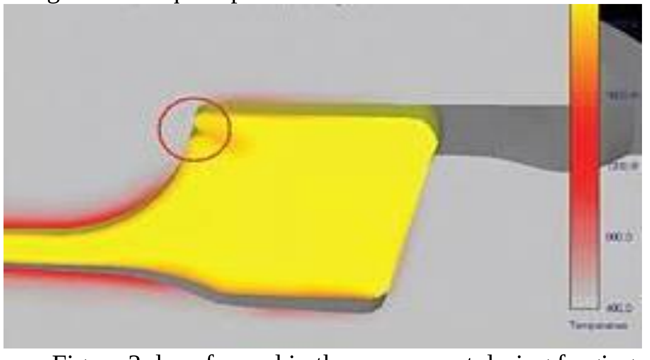

Figure 3: laps formed in the component during forging

3. SCALE PITS

The oxidation and decarburization of steel take place when steel components are heated in the presence of air or products of combustion. Undesired and excessive oxidation can lead to problems such as scale pit marks, dimensional changes, poor surface finish, rejections and quench cracking. Additionally, these problems may lead to the need for expensive operations like shot blasting, machining and acid pickling. Protection against scaling and decarburization is achieved by heating in molten salts, fluidized-bed furnaces, protective gaseous media or vacuum. These measures demand heavy capital investment, highly skilled personnel and special safety precautions. Many companies cannot afford them, yet they are under mounting pressure to prevent oxidation and decarburization.

4. QUENCH CRACKS

Forgings such as knuckle joints and crankshafts, when heat treated in furnaces of oxidizing atmosphere, are susceptible to quench cracking. Quench cracks appear when stresses generated during quenching are greater than the tensile strength of thin sections of the forging. Chrome-moly grades of steel are most susceptible to quench cracks, which usually occur in the gear-end portion of the crankshaft. By coating the gear-end with an anti-scale coating, the cracking is prevented.

Figure2: Quench cracks

- Overheating during the austenitizing portion of the heat treatment cycle can coarsen normally fine grained steels. coarse grained steels increase hardening depth and are more prone to quench cracking than fine grain steels. Avoid overheating and overly long dwell times while austenitizing.
- Improper quenchant. Yes, water, brine, or caustic will get the steel “harder.” If the steel is an oil hardening steel, the use of these overly aggressive quenchants will lead to cracking.
- Too much time between the quenching and the tempering of the heat treated parts. A common misconception is that quench cracks can occur only while the piece is being quenched. This is not true. If the work is not tempered right away, quench cracks can (and will) occur.

5. MISMATCH

Mismatch is occurring due to the deflection or the movements caused in the upper die and lower die from its centre due to the repeated blows. The die here is examined after a large batch of components being forged. We have to examine the die, its position periodically to identify the deflection caused in the dies.

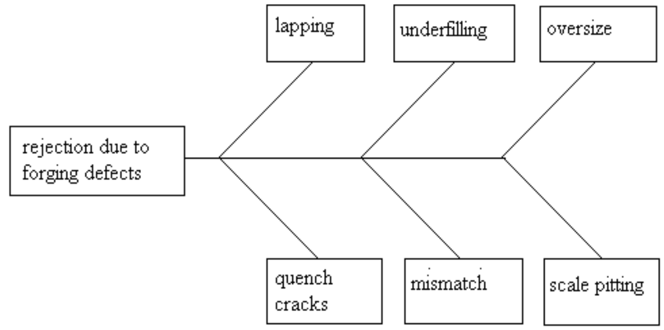

Figure 3: cause and effect diagram for the rejection rate

The figure shows the cause and effect diagram of the forging defects and its causes as shown in the figure 3.

V. RESULTS AND DISCUSSIONS

REMEDIAL ACTIONS TO BE TAKEN

1. USE ANTI-SCALE COATING

An anti-scale coating, which we call ESPON, is applied on components or billets to be heated before charging them into the furnace. Care is taken to apply a uniform coating by brushing, dipping or spraying. The coating is then allowed to dry for 30 minutes at ambient temperature of 35°C. This anti-scale coating acts as a barrier to the basic reactions of oxidation and decarburization. To prevent scaling and decarburization, care is taken to apply a uniform coating layer on the component. The coating also reduces decarburization on billets and ingots during hot-forging and hot-rolling operations. Heat transfer from the heating medium to the metal is unaffected by the coating. Additionally, the coating has no reaction with the steel surface and no release of toxic fumes during use, heat treatment or storage. The coating is nonhazardous and economical to use.

Benefits:

- Prevention of Quench Cracks – Forgings such as knuckle joints and crankshafts, when heat treated in furnaces of oxidizing atmosphere, are susceptible to quench cracking. Quench cracks appear when stresses generated during quenching are greater than the tensile strength of thin sections of the forging. Chrome-moly grades of steel are most susceptible to quench cracks, which usually occur in the gear-end portion of the crankshaft.By coating the gear-end with an anti-scale coating, the cracking is prevented.
- Reduction in Shot-Blasting Time - After Heat Treatment Operations like shot blasting, grinding and pickling are expensive and time-consuming procedures. They are necessary to remove scaling from components and to enhance the product’s aesthetic appeal, but they do not add value to the product. These operations can be substantially reduced if a coating is applied to components before heat treatment.

- Reducing Decarburization During Hot Forging and Hot Rolling – During the hot rolling of special grades of steel in which decarburization needs to be kept in check, unforeseen conditions like mill breakdown and unplanned downtime may arise. Even when the plant is closed for a weekly holiday, the furnace may be shut off abruptly, leaving billets inside. Billets left in the furnace are subjected to prolonged heating, leading to decarburization. Applying an anti-scale coating ensures that billets are protected from decarburization.

2. VENTING TO PREVENT UNDERFILLING

Underfilling is typically a problem when a large part is manufactured on a small press with a less-than-optimum preform geometry. Smaller equipment does not provide the option of overpowering a less-than-optimum design or leave much margin for process variation. Depending on the equipment, force, power, speed or energy can be the culprit for an underfill. a steel forging being produced on an undersized hydraulic press. Because the press is slow, there is significant chilling of the work piece, as indicated by the temperature profiles in the figure. This causes the flow strength of the steel to increase and require more force to deform it. Because of its small size, the press will stall before the component is completely forged, leaving an underfilled region. To avoid this, equipment of the right capacity must be used.

Venting: Underfills can also result from air, gas or lubricant being trapped in a corner feature of a forging. These can be eliminated by a redesigned preform, which provides a vent for gas, or by adding corner closure to the final forging. The ideal gas law can be used to describe the behavior of gas being compressed in a die corner

3.USE SIMULATION SOFTWARE FOR THE MATERIAL FLOW

During open-die forging or forging without any die contact, the work piece may flow in a manner that is different from the design plan. Even though we would like the material to flow in a prescribed manner, if it is unconstrained it may move in an undesirable fashion, leaving a part that does not meet the customer's specifications. This type of material movement is not random or arbitrary and will take the path of least resistance in determining its flow. Simulation programs can aid the forger in understanding actual material flow. These packages incorporate the flow along the path of least resistance within their calculations and provide a detailed view of the actual geometry that a part would take when the dies do not provide constraint.

Simulation programs: It can be effectively used to see the formation of defects. These tools allow the forger to "see" inside the die and the work piece during deformation. The simulation tool can also provide a serial view of the process dynamics in both forward and backward directions. These can provide the forger with significant insights into the origin and evolution of the geometrical defects that are described in this paper.

Simulation has allowed us to clearly illustrate die designs that contribute to geometrical defects of laps and underfills. The programs also allow the forging engineer to test a number of "what if" scenarios without having to actually sink a die and run tests in the forge shop.

Today there are some simulation software to analyse this forging operation. For example: quantor form, forge 3D etc

4. PROPER LUBRICANT (ESPON LSS)

Many forge shops in India use furnace oil as ‘lubricant’. They are realizing day by day that it is a wrong practice. First of all, furnace oil is not a lubricant. When it comes in contact with the die surface which is at temperatures up to 500^{0} C, the hydrocarbons present in it burn out partially. The gas pressure generated between the forged component and the die wall give rise to hairline cracks. These cracks grow fast during subsequent operations of the forging hammer or press. The serrations so generated in the die cavity impair the surface finish of the forgings. Due to incomplete combustion of the hydrocarbons, a lot of smoke is generated. Sulphur present in the furnace oil enhances pungent smell of the smoke. This smoke is carcinogenic. Workmen feel tired soon and their efficiency is affected. Pollution Control Board would raise serious objections to the use of furnace oil for swabbing the dies.

5. CORRECT DIE DESIGN

A "flow-by" in which the work piece surface is in contact with a die and is subsequently pulled away by a tensile stress component and closes on itself.
"Peeling" that can form when the surface of a billet or preform is sheared by a die, resulting in an area of localized folding. A die corner is frequently involved, as it forces material ahead of a moving contact region, without significant subsurface deformation. This defect can be the result of a poor design or inadequate process control.
Flow localization that can also show up as a forging lap in alloys where flow softening exists. Most laps are resolved by changing the forging preform, forged shape or process. The prevention of laps is primarily a process-design issue due to improper preform geometry or improper impression geometry.

- Proper draft, corner radius and fillet.
- Reduction of friction by the use of polished dies and suitable lubrication.
- By grinding the die in the curved edges before us

VI. CONCLUSION

In this paper it’s described the different factors for effective forging is studied and the remedial actions that required for controlling the rejection rates due to forging defects.By the proper usage of anti scale coating, proper lubricant, proper design of dies by polishing and grinding, and use the simulation programs for monitoring the material flow inside the dies. Thus it will be very useful in control the forging defects effectively.

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