Adoption of Quality Tools to Abate Rejection Rate in Pipe Manufacturing Process: A Case Study

Zakir S Ansari¹, Imran Khan², Rehan Shaikh³, Shafiuuddin Syed⁴, Asif Khan⁵
¹Assistant Professor, Department of Mechanical Engineering, Anjuman-I-Islam’s Kalsekar Technical Campus, New Panvel 410206, Navi Mumbai
²,³,⁴,⁵UG student, Department of Mechanical Engineering, Anjuman-I-Islam’s Kalsekar Technical Campus

Abstract—Tube milling industries are actively involved to reduce the scrap rejection during the manufacturing process of the components. To achieve this, the production concerns must follow the quality control procedures correctly and perfectly without any negligence. Timely implementation of the modified techniques based in the quality control research is a must to avoid defects in the products. This paper is a case study of the work carried out in a pipe manufacturing setup in Navi Mumbai for reducing the occurrence of defects during pipe manufacturing. The work is focussed at reducing the occurrence of defects by following scintifically the Quality Control Tools. In the initial stages the data relating to the defects was collected followed by data segregation to determine the most severe and most frequently occurring defect. The root causes of the defect were then found using Why-Why analysis, Fish Bone diagram. Finally the remedies to avoid the causes of the defect were suggested to the company.

Index Terms—Quality control tools; Why-Why Analysis, Pareto Chart, Fish Bone Diagram, Defects in pipe manufacturing, Reducing rejections

I. INTRODUCTION

Quality is defined as the fitness for use or purpose at the most economical level. It is an integral part of the process of design, manufacture and assembly. It can be assured by having effective procedures and controls at various stages. Manufacturing industries like tube mills do not enjoy monopoly but they have to face competition. To overcome this problem and to retain the share of the market, it is necessary to constantly improve the quality of the milled product without the increase in the price of the products [1,2]. The price is influenced by the cost of production, which in turn is influenced by rework or rejection. Attention to quality assurance can reduce the wasteful rework. Aiming for quality in the first instance can reduce the cost of tube mill production. This quality production results in the company’s growth and profitability.

Quality in a product is difficult to define and invariably involves a consideration of the service environment. The most meaningful definition involves the concept of fitness for a given purpose or application at a prescribed life of number of hours, months or years in service. For a given set of service conditions, quality and reliability are interrelated to a certain extent. The minimum quality acceptable in any application is that level of quality necessary to ensure that the prescribed portion of the components will pass through the predicted service life without failure. If all the cast components survive the designed period of service under the given environmental conditions, then this constitutes 100% reliability [2]. The basic concepts of quality are that the finished cast products must meet established
specifications and standards and hence customer’s satisfaction will be derived from the quality products and services. Both of these can be attained by integrating quality development, quality maintenance and quality improvement of the product. These three aspects of a product can be achieved through a sound milling quality control system [3,4]. The various meanings of quality are the fitness for purpose, conformance to requirements, grade, degree of preference, degree of excellence and measure of fulfillment of promises. The milled products should have certain abilities to perform satisfactorily. The factors governing are suitability, reliability, safe and foolproof workability, durability, affordability, maintainability, aesthetic look, satisfaction to customers, economical and versatility. The factors controlling the quality of milling design depends on the type of the customer in the market, profit consideration, environmental conditions and special requirements of the milled products. There exists a close relationship between quality and reliability. It is given as the sum of the quality now and quality later, which equals to reliability. The quality circles help in the improvement of product quality and productivity [5,6]. It implies the development of skills, capabilities, confidence and creativity of the people through cumulative process of tube milling engineering education, pertinent training, work experience and participation [3]. A quality circle is defined as a way of capturing the creative and innovative power that lies within the work force and it is a group of employees, 3–12 doing similar work.

II. METHODOLOGY
The company was not maintaining the data of the number of rejections occurring due to different defects so the data for different defects occurring in the pipe manufacturing process was collected for 20 days at a stretch. After collecting the data the most frequently occurring defect was identified and also its severity on the final product was estimated. After the most frequently occurring defect was identified, the causes for that defects were worked out by using quality control tools like Why-Why Analysis, Fish Bone Diagram, Pareto chart etc. Using these quality tools the root cause of the defect was determined and accordingly remedies were suggested to the company.

III. DATA COLLECTION
The data was collected during the manufacturing process of the pipe. It was found that a particular defect is more frequently occurring so it needs immediate attention hence that defect was selected for further analysis. The table below gives the details of the collected data.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Defect Code</th>
<th>Component</th>
<th>Description</th>
<th>Rejected Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>D01</td>
<td>Circular &amp; Square pipe</td>
<td>Cracking</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>D02</td>
<td>Circular pipe</td>
<td>Corrosion</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>D03</td>
<td>Circular &amp; Square pipe</td>
<td>Porosity</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>D04</td>
<td>Circular &amp; Square pipe</td>
<td>Lack of Fusion</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>D05</td>
<td>Circular pipe</td>
<td>Pitting</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>D06</td>
<td>Circular pipe</td>
<td>Dents</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>D07</td>
<td>Circular &amp; Square pipe</td>
<td>Operator error</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>D08</td>
<td>Circular pipe</td>
<td>Overlap</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>D09</td>
<td>Square pipe</td>
<td>Bend</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>D10</td>
<td>Square pipe</td>
<td>Twisting</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>D11</td>
<td>Square pipe</td>
<td>Seamline error</td>
<td>1</td>
</tr>
</tbody>
</table>
From the table it is quite clear that D04 lack of fusion is more significant with a frequency of 6 so this defect was considered for further analysis.

**IV. DEFECT ANALYSIS**

The following QC techniques were used in the current work for determining the causes of identifies defect
a. Fish Bone Diagram  
b. Why-Why Analysis  
c. Pareto diagram

*a. Fish Bone Diagram:*
Man, Machine, Method, Measurement, Material and Management were identified as the main causes were while using these main causes the sub causes were evaluated as shown in the diagram.  
The following were a few identified root causes  
1. Sometimes when the requirements of client are not very stringent and specific, quality of raw material coming from outside is not accounted seriously.  
2. The mechanical properties of incoming raw material is checked on an equipment which is not calibrated and can’t be relied on.  
3. Lack of skilled labour at the shop floor.  
4. Irregular and sudden breakdown of machines due to poor maintenance  
6. Lack of technical knowledge for manufacturing operations like ERW welding of pipe by the welder

*b. Pareto Chart:*
A Pareto chart, named after Vilfredo Pareto, is a type of chart that contains both bars and a line graph, where individual values are represented in descending order by bars, and the cumulative total is represented by the line.

The left vertical axis is the frequency of occurrence, but it can alternatively represent cost or another important unit of measure. The right vertical axis is the cumulative percentage of the total number of occurrences, total cost, or total of the particular unit of measure. Because the reasons are in decreasing order, the cumulative function is a concave function. To take the example below, in order to lower the amount of late arrivals by 78%, it is sufficient to solve the first three issues.

The purpose of the Pareto chart is to highlight the most important among a (typically large) set of factors. In quality control, it often represents the most common sources of defects, the highest occurring type of defect, or the most frequent reasons for customer complaints, and so on.
c. **Why-Why Analysis:**
   
   Rejection at plant & consumer end
   
   Why#1 Why pipe is rejected?
   Ans. Because it contains defects.
   
   Why#2 Why there was a defect in pipe?
   Ans. Improper welding due to lack of fusion
   
   Why#3 Why there is lack of fusion?
   Ans. Incorrect welding parameter settings, insufficient cleaning.
   
   Why#4 Why there is insufficient cleaning?
   Ans. Due to improper maintenance.
   
   Why#5 Why there is improper maintenance?
   Ans. Due to lack of attention by MANAGEMENT.
   
   After this detailed investigation by observations and also brain storming with the people involved at the shop floor it was found that there are a few reasons for incomplete fusion which are discussed in the parts.

V. **INCOMPLETE FUSION IN ELECTRIC RESISTANCE WELDING (ERW)**

Weld defects of ERW are perpendicular to the plate surface and have planar shapes caused by upsetting in a process of welding. It is reported that these defects have occasionally caused a burst accident in field tests of ERW pipelines. Because of their shape and orientation, it is very hard to find them with NDT, and many efforts have been made to develop an effective NDT method for locating such defects.

Very few investigations, however, have been reported in regard to the cause of the weld defects in ERW; the defects have been simply conceived as certain oxides that form on the surface of strip edges and of the weld defects showed that there are two kinds of the defects: a cold weld and a penetrator. In most cases the former is found over a wide range along the weld line and the latter only intermittently. It is difficult to understand by the past simple explanation why two different kinds of remain without being squeezed out between them. Macro- and microscopic observations defect are generated. The welding phenomena encountered in ERW, as mentioned in a previous report, can be classified into three types according to the periodicity of the welding process and the edge profile between the V-convergency.
point and the weld point. It is inferred that the type of welding phenomena might determine which kind of the defects will be generated.

Table 1—Chemical Composition of the Materials Used, Wt-%

<table>
<thead>
<tr>
<th>Element</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.11</td>
</tr>
<tr>
<td>Si</td>
<td>0.25</td>
</tr>
<tr>
<td>Mn</td>
<td>0.70</td>
</tr>
<tr>
<td>P</td>
<td>0.01</td>
</tr>
<tr>
<td>S</td>
<td>0.01</td>
</tr>
<tr>
<td>Al</td>
<td>0.015</td>
</tr>
<tr>
<td>Nb</td>
<td>0.013</td>
</tr>
</tbody>
</table>

A. ERW Pipe Manufacturing Process

For diameters above 36 inches, double seam welded pipe is specified as an alternative in API 5L. This has two longitudinal seams. Solid phase butt weld, was produced using resistance heating & high pressure to make the longitudinal weld (ERW), Nowadays, most pipe mills now use high frequency induction heating for better control and consistency. However, the product is still often referred to as ERW pipe, even though the weld may have been produced by the ERW process. The defects that can occur in ERW pipe are those associated with strip production, such as laminations and defects at the narrow weld line.

d. Occurrence of Most frequently occurring Defect

Lack of fusion due to insufficient heat and pressure is the principal defect, although hook cracks can also form due to realignment of non-metallic inclusions at the weld interface. Because the weld line is not visible after trimming, and the nature of the solid phase welding process, considerable lengths of weld with poor fusion can be produced if the welding parameters fall outside the set limits.

In addition, early ERW pipe was subject to pressure reversals, a problem that results in failure in service at a lower stress than that seen in the pre-service pressure test. This problem is caused by crack growth during the pressure test hold period, which in the case of early ERW pipe was due to a combination of low weld line toughness and lack of fusion defects.
e. Lack of Fusion & its Occurrence
During the pipe manufacturing, in the vicinity of the plate edge to be joined by welding (seam) the shape of the pipe deviates from cylindrical forming a sharpened edge.

Incomplete root fusion is when the weld fails one side of the joint in the root. Lack of Fusion occurs when both sides root region of the joint are not fused. Lack of fusion can arise in following situations.

- Too small the weld gap
- Misplaced Welds
- Using too low energy or heat input
- Too small the electrode angle
- Too large electrode thickness

VI. CAUSE OF LACK OF FUSION
These types of imperfection are more likely in consumable electrode processes (MIG, MAG, FCAW, MMA and ERW) where the weld metal is 'automatically' deposited as the arc consumes the electrode wire or rod. The welder has limited control of weld pool penetration independent of depositing weld metal. Thus, the non consumable electrode TIG process in which the welder controls the amount of filler material deposited independent of penetration is less prone to this type of defect.

In ERW welding, the risk of incomplete root fusion and root penetration can be reduced by using the correct welding parameters and electrode diameter to give adequate arc energy input and satisfactory penetration. Electrode diameter is also important in that it should be small enough to give adequate access to the root, especially when using a small included angle (Fig 2). It is common practice to use either a 2.5mm or 3.25mm diameter electrode for the root run so the welder can manipulate the weld pool and control the degree of penetration. However, for the fill passes where penetration requirements are less critical, a 4mm or 5mm diameter electrode may be used to achieve higher deposition rates.

Too low a current level for the size of root face will give inadequate weld penetration. Too high a level, causing the welder to move too quickly, will result in the weld pool bridging the root without achieving adequate penetration. It is also essential that the correct root face size and bevel angles are
used and that the joint root gap is set accurately. To prevent the root gap from closing, adequate tacking will be required.

VII. DEFECT ANALYSIS

Defect analysis is part of the continuous quality improvement planning in which defects are classified into different categories and are also used to identify the possible causes in order to prevent the problems from occurring. It helps projects to identify how issues can be prevented and in reducing or eliminating significant numbers of defects from being injected into the system.

All the above used Quality tools clearly indicate that Lack of Fusion is most occurring & most severe defect causing a huge loss of finished products.

VIII. FACTORS INFLUENCING FREQUENTLY OCCURRING DEFECT

a. Too Narrow Joint Preparation

Too narrow a joint preparation often causes the arc to be attracted to one of the side walls causing lack of side wall fusion on the other side of the joint or inadequate penetration into the previously deposited weld bead. Too great an arc length may also increase the risk of preferential melting along one side of the joint and cause shallow penetration. In addition, a narrow joint preparation may prevent adequate access into the joint or encourage flooding the joint with melting weld metal. For example, this happens in ERW welding when using a large diameter electrode, or in MIG, MAG and FCAW welding where an allowance has not been made for the diameter of the shielding gas nozzle. Consideration should also be given to fabrication features that may obstruct the welding torch.

b. Incorrect Welding Parameters

It is important to use a sufficiently high current for the arc to penetrate into the joint sidewall and previously deposited weld runs. Consequently, too high a welding speed for the welding current will increase the risk of these imperfections. However, too high a current or too low a welding speed will cause weld pool flooding ahead of the arc resulting in poor or non-uniform penetration.

Poor welder technique such as incorrect angle or manipulation of the electrode/welding gun, will prevent adequate fusion of the joint sidewall. Weaving, especially dwelling at the joint sidewall, will enable the weld pool to wash into the parent metal, greatly improving sidewall fusion. It should be noted that the amount of weaving may be restricted by the welding procedure specification limiting the arc energy input, particularly when welding alloy or high notch toughness steels.
c. **Insufficient Cleaning:**
The extent to which a surface is made clean before the coating is applied, is a balance between the expected performance of the coating, the paint manufacturers recommendations, the time available for the job, the relative cost of the various surface preparation methods available, access to the area to be prepared and the condition of the steel prior to surface preparation. In many instances, coatings cannot be applied under ideal conditions, especially under repair and maintenance conditions. The quality of surface cleanliness which is achieved (or which it is possible to achieve) will be very different for an un-corroded high quality steel plate with tightly adherent mill scale. Any substance which prevents a coating from adhering directly to the steel can be considered a contaminant. Major contaminants include are as follows

- Moisture or water.
- Oil and grease.
- Weld spatter.
- Weld fume.
- Cutting fume.

d. **Contamination of Cutting Fluid**
Cutting fluid is a type of coolant and lubricant designed specifically for metal working processes, such as machining and stamping. There are various kinds of cutting fluids, which include oils, oil-water emulsions, pastes, gels, aerosols (mists), and air or other gases. They may be made from petroleum distillates, animal fats, plant oils, water and air, or other raw ingredients. Depending on context and on which type of cutting fluid is being considered, it may be referred to as cutting fluid, cutting oil, cutting compound, coolant, or lubricant.

IX. **REMEDIES FOR CONTROLLING LACK OF FUSION**
The following techniques can be used to prevent lack of fusion.

- Do not prepare too large weld gap
- Do not use too large diameter weld electrode
- Use a sufficiently high welding current level which is supported by appropriate arc voltage.
- Make sure that weld gap is of adequate width and does not close up during welding
- Ensure proper welding environment
- Make sure that the welder has completely cleaned slag and joint already, and there has been no oil, rust, slag, water, paint at the groove.

X. **RESPONSIBILITIES OF MILLING INDUSTRIAL PERSONNEL IN QUALITY CONTROL**
Quality control responsibilities in milling process control include evaluation of the incoming raw and production materials, performance of selected process control in all the sub-processes involved and process control checks performed by the production personnel and information regarding the feed back should be communicated to the production department [2]. The final inspection is on the defects observation, properties testing, highest frequency, statistical sampling and thorough evaluation for the suspect condition prior to being released to the finishing area or to being rejected [27]. The milling quality control system comprises a set of procedures that should be followed to fulfill the quality policy. It has to be built in such a way that the best coordination of all the activities will be achieved without compromising any elements affecting the quality of the cast products in the metal casting industries [28,29].
XI. CONCLUSION

It is concluded that careful supervision with effective motivation of individual employees in achieving the quality is a must in reducing the rejection and scrap in metal casting manufacturing industries. It is to be emphasized that quality is contributed to by all the members of an organization from the chief executive to the worker and is not the job of only milling quality control staffs. In foundries addition to the quality control department, a scrap prevention team is needed to improve the quality and this should be felt by each employee. A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

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