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A Case Study of the Effectiveness of Rolling Process to Manufacture the Strip of Leaf Spring

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Abstract—**Hot rolling is the key process that convert cast or semi finished steel into finished products. Since the rolling operation is very costly, hence quality control of rolling process is essential. The raw material of leaf spring i.e. strip of SUP 11 is manufactured with hot rolling process. Any defect in the material may result rejection of final product that leads to major loss in terms of money and sometimes major accidents also. In this paper, the concept or voice of customer of India has been developed and shown the internal customer relationship among the various flow processes to achieve the full satisfaction of internal customer that leads to the satisfaction of external customer. Internal customer's job is to look after proper functioning of the process and minimization of the defects in the final process which leads to minimization of defects in the final product. Different defects have been taken into consideration by using Juran seven quality tools & New Seven quality tools, like Brain Storming, Cause and Effect diagram, Pareto analysis, problem solving session etc. to diagnose the root cause of the defect and accordingly corrective measures have been suggested.**

Index Terms—**Hot rolling, internal and external customer, juran quality tools, leaf spring, SUP 11.**

I. Introduction

Due to economic globalization, industry is facing severe competition from foreign competitors. To get success in this environment, the industry must significantly improve productivity and quality and reduce scrap and waste during production. In addition to economic consideration, the environmental concern and energy consumption requirement also strongly derive steel industry toward that direction therefore; there is an urgent need from steel industry for effective process quality control. Since the rolling operation is often the last process step of raw materials of several products, hence the scrap at rolling stage is very costly and the quality control of rolling process has a vital role. In present work we establish voice of customer, which really state much about the customer satisfaction, type of customer also. The work has been carried out at M/s Magnum Steels Ltd, Banmore, Morena.

In the present work internal customer ship is divided among the whole process flow. Foundry is the customer of reheating furnace, Reheated ingot is the customer of the rolling mill, and rolled product is the customer of the inspection department. If these customers are satisfied, external customers will automatically be satisfied. Kano model (Fig. 2) is best studied for customer satisfaction.

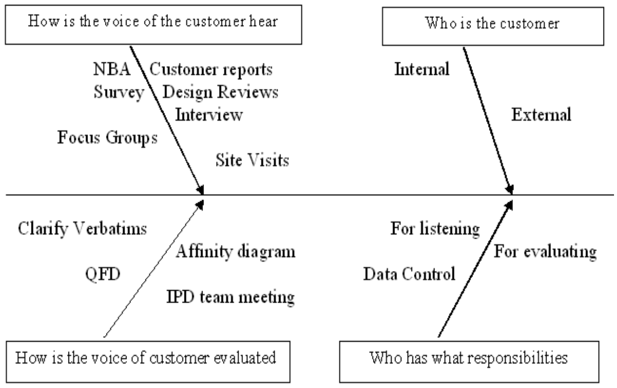

Fig. 1. Voice of customer.

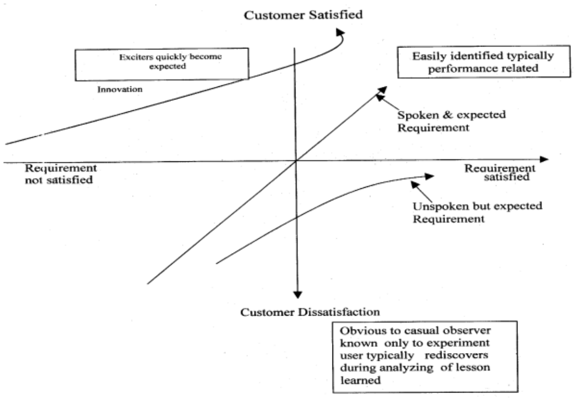

Fig. 2. Kano model.

Springs are crucial suspension elements on cars, trucks, buses etc necessary to minimize the vertical vibrations, impacts and bumps due to road irregularities and create a comfortable ride. A leaf spring, especially the longitudinal type, is a reliable and persistent element in automotive suspension systems. These springs are usually formed by stacking leafs of steel, in progressively longer lengths on top of each other, so that the spring is thick in the middle to resist bending and thin at the ends where it attaches to the body. The leaves are manufactured by hot rolling process.

Rolling is a process where the metal is compressed between two rotating rolls for reducing its cross sectional area. This is one of the most widely used process among all the metal working process, because of its higher productivity and low cost [1]. Rolling would be able to produce component having constant cross section throughout its length many shapes such as plate, I, T, L and channel section are possible [2].

Rolling which accounts for about 90% of all materials produced by metal working process, was first developed in

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the late 1500's [1]. The basic operation is flat rolling or simple rolling, where the rolled products are flat, plate or sheet (Fig. 3).

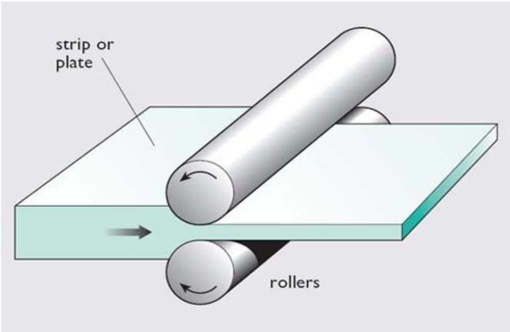

Fig. 3. Principle of rolling.

Hot Rolling is first carried out at elevated temperature above the re-crystallization. During this phase, the coarse-grained, brittle, and porous structure of the ingot or the continuously cast metal is broken down into a wrought structure having finer grain size and enhanced properties [1].

There are three zones in rolling process. These are Backward or lagging zone, Neutral Zone, Forward or leading zone [3].

Plastic deformation of metal is the basic concept used for rolling process commonly used for manufacturing of materials where smallest part are called crystal grain that has uniform properties, the diameter is only 0.1 to 0.01 mm and distance between the atomic particles lattice is of the order of 10^8 cm[3]. A metal with very fine grains has in general a greater strength than the same metal with a coarse granular structure. In engineering construction, fine metallic elements are seldom used and very little amount of additional constituents considerably change the strength properties of metals. The magnitude of the forces under which a metal will yield plastically or fracture, depends on its composition and crystal structure.

The absolute size of the grains can be changed by re-crystallization. The amount of previous cold deformation, temperature during reheating and its duration affect the absolute size of the grains after re-crystallization. The grains of metal may be, Lamellar i.e. needle type, Spheroid zed i.e. globules type, Dendrites i.e. branches of a tree type.

The metal structure of the crystal may be of the Simple cube, Body centered cubic (B.C.C.), Face centered cubic (F.C.C.). Alloying elements may affect the properties of the metal to a greater extent.

Deformation is the change in dimensions or form under the action of applied forces. Deformation is caused either by mechanical action of external forces or by various physical and physiochemical process. The process of deformation comprises the Elastic deformation, Plastic deformation, and Fracture. The plastic deformation of metal may occur by slip, by formation of Twins, Deviations from regular positions of atoms, Break down of structure [3].

In the Re-crystallization process, new equiaxed and strains free grains are developed that replaced the older grains at re-crystallization Temperature [4]. It results in a decrease in the density of dislocations, lower strength and higher ductility of the material. Metal such as lead, tin, cadmium and zinc re-crystallize at about room temperature (Fig. 4).

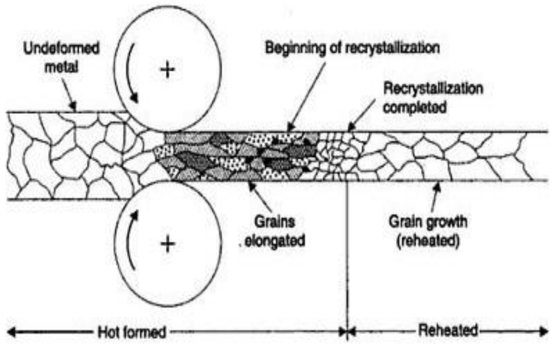

Fig. 4. Re-crystallization.

II. Literature Survey

Nong Jin and Shiyu Zhou [5] presented the "Identification of impacting factors of surface defects in hot rolling processes using multi level regression". Surface defects have been a long standing troubling issue in hot rolling processes due to the ineffectiveness of existing detection methods. This paper presents an advanced statistical analysis method to identify the impacting factors in surface defects of hot rolling processes. The surface defects of hot steel are measured by a new reusing system the "Hot eye" imaging system. The process variable considered in this paper includes the heat number, strand number and billet location. Due to the structural characteristic of the data multi level analysis is presented to help identify the relationship between the process variables and the number of surface defects.

N. Chakraborti, B. Siva Kumar, V. Satish Babu, S. Moitra and A. Mukhopadhyay [6] presented the "Optimizing surface profiles during hot rolling". Several variants of genetic Algorithms have been used to study surface profile of hot rolled slabs quantified in terms of crown a major parameter related to their geometric tolerance. Two different models are presented and simulations in a multi objective mode are carried out to generate the relevant pareto fronts; which in turn are tested against the operational data of an integrated steel plant.

Hiromi Hirono, Toshio Sakai, Shigeru Hishikawa [7] presented the "Upgrading of Hot Finishing Mill to 4-Stands and Replacement of Computer Control System".

T: TarnoPolskaya, D.J. Gates F.R. de Hoog [8] presented "A model and numerical algorithm for the analysis of lateral movement of a metal strip during cold rolling". The model includes a simplified description of the physical process responsible for strip lateral movement, such as plastic deformation of the strip elastic deformation of rolls, deformation and dynamics of the strip outside the plastic reduction region.

Saroj K. Biswas, Shih J. Chen and A. Satyanarayana [9] presented the "Optimal Temperature Tracking for Accelerated Cooling Processes in Hot Rolling of Steel". Control of temperature during cooling is essential for achieving desired mechanical metallurgical and metal logical properties of steel.

III. Methodology

ISO 9001-2008 Certification shows a frame work to standardize the manufacturing process of product, test the product, employees training, keep records of defects etc. Internal and external customers are finalized. Internal customers are decided by flow chart. Customer satisfaction is the ultimate goal of this certificate. If all the internal customers are satisfied, final product will be of as per specification, and of good quality, which is the requirement of the external customer. Every customer of the flow process has to put their best effort to minimize defect and improve the quality of the final product. This is possible only when each of the internal customers of the flow chart remains satisfied with the unfinished product which they receive from their previous step. At last if all the internal customers are satisfied throughout the process means final product will be of good quality and external customer will automatically satisfied.

Basic problem solving techniques equipped with quality tools are used for data analysis to solve problems. Every technique has its own merit and demerit. The members of quality control team will need to be trained in the application of these techniques. The commonly used techniques are Brain storming, Pareto diagram, Cause and effect analysis, Data collection and Data analysis [10].

Tools used for data analysis are Tables, Bar charts, Histogram, Circle graphs, Line graph, Scatter graphs, and Control charts.

IV. Data Collection

The raw material of strip is ingot and billets. The annual requirement of the unit at the full capacity of utilization is approximately 36000 MT per annum. Raw material is received from the local market (scrap) and from the SAIL and TISCO etc. The specifications of strip manufactured are shown in Table I.

TABLE I: Specification and Chemical Composition of Spring Steel Raw Material

Grade	C %	Mn %	P %	Si %	Cr %	V %
SUP 9A	0.56-0.60	0.8-1.0	0.03	0.15-0.35	0.8-1.0	-
SUP 11A	0.56-0.64	0.7-1.0	0.03	0.15-0.35	0.7-1.0	-
EN 45A	0.55-0.65	0.7-1.0	0.05	1.7-2	-	-
EN 47	0.45-0.55	0.5-0.8	0.04	0.5	0.8-1.2	-
EN 48A	0.5-0.6	0.6 -0.9	0.06	1.35 -1.65	0.55-0.85	-
65Si 7	0.6-0.7	-do-	-do-	-do-	-	-
60Si 7	0.55-0.65	-do-	-do-	1.5-1.8	-	-
50CrV 4	0.45-0.55	-do-	-do-	-do-	0.9-1.2	0.15-0.3
SAE 52100	0.95-1.1	0.25 -0.4	0.025	0.15-0.35	1.3-1.6	-

The plant and machinery available in plant is shown in Table II.

TABLE II: Description of Rolling Mill

1.	Size of Rolling Mill	400 mm (16') Roughing mill
		250 m (10') Finishing mill
2	No. of stand	01 Roughing & 06 finishing stand
3.	Speed of Rolling	180 RPM finishing
4.	Reheating furnace	(Double zone) Pusher type
		Dimension 17000 x 1600 x 700 MW
		Capacity – 5 MT/hrs
		Furnace temp control digital display pyrometer flame gas analyzer, temperature and pressure gauge
		Temperature of furnace soaking zone 1150 ℃ Heating zone 900 ℃
		Length of soaking zone 5000 mm
		Number of burner/blowers 4 No/125 KW
		15 KW Motor
5	Cooling bed	Size 22000 mm x 300 mm
6	Nos. of crane	01 No. E.O.T. crane capacity 2 MT

TABLE III: Melting Report for Month June (Rolling Mill Section 20"/16"

Prodn	Quantity	Ingot size	Defect %
Sup 11A	707x140 kg 98,980 MT	4½"x5½"	Melting scrap 7.9 MT – 7.35% Defect short length 6.0 MT – 6.1% OK short length 5.5 MT – 5.6%
65Si7	2553x140 kg 357,420 MT 1428x100 kg 142,800 MT 500,220 MT	4½"x5½" 3½"x4½"	Melting scrap 38.8 MT – 6.18% Defected short length 25 MT – 5% OK short length 25 MT – 5%

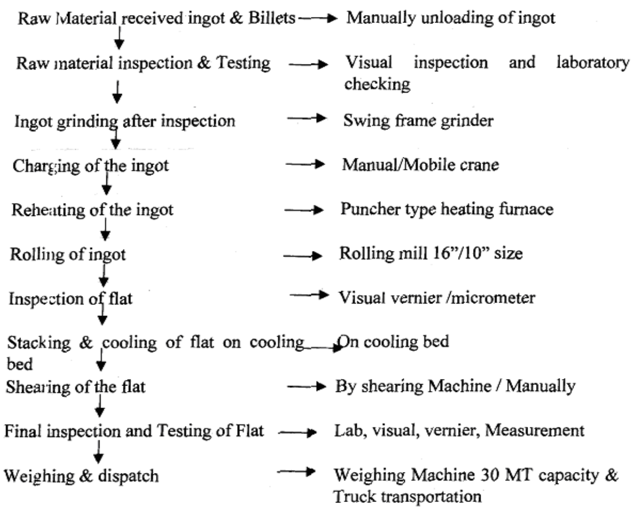

Fig. 5. Process flow chart of spring steel flat.

In the above flow process chart, internal customer ship has been shown.

Step 2 is the customer for material supplied by foundry, see defects such as surface defect, finding macro structure of the sample cut from the ingot and take the action – surface grinding, welding etc. otherwise reject the material.

Step 6 is the customer for the material received from reheating furnace; See that proper heating should be done.

Step 7 is the customer of the rolling mill produced product. At the inspection stage, cut down the sample and check it thoroughly for visual defect, macro structure under non destructive testing machine; size variation of the product etc. If any short coming is found direct it to the rolling mill section so accordingly action may be taken and hence quality can be improved.

Step 9 is the customer of the inspected stacked product. At this stage ends of the every flat are cut. Short length may occur which is to be informed to the reheating furnace zone where ingot length is to be ensured for correctness.

Step 10 is the customer for overall production, inspection, stacking etc. Here at this stage complete checking is needed, where all possible all defect are to be seen, under strict inspection then pass the product for weighing/ loading etc.

If all above process with internal customer ship is followed under ISO 9001-2008 system; consequently external customer will get full satisfaction because internal customer is already satisfied.

At every stage of the internal customer ship short coming found are to be taken for analysis hence effectiveness of the rolling process can be improved.

V. Data Analysis

Pareto analysis reveals that seam, piping, refractory and cutting defect are major defects (Table IV). These defects should have been taken care for improvement in quality to establish the process effectiveness.

TABLE IV: Defects in the Section 80×15 (Sup 11A)

Type of Defects	Defect (%)
Seam	20
Piping	14
Refractory	6
Lapping	-
Rolling dent	2
Roll Mark	5
End cutting	8

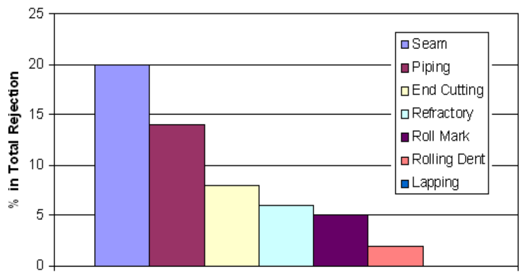

Fig. 6. Pareto analysis.

The Cause and Effect Diagrams (Fig. 7, 8, 9) have been drawn to find out the root cause of the defects.

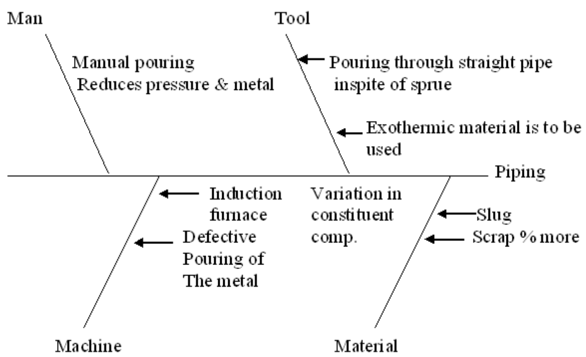

Fig. 7. Cause and effect diagram for piping defect.

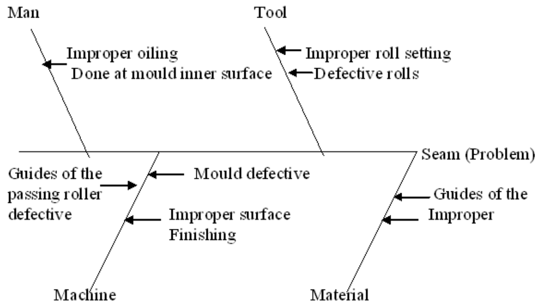

Fig. 8. Cause and effect diagram for seam defect.

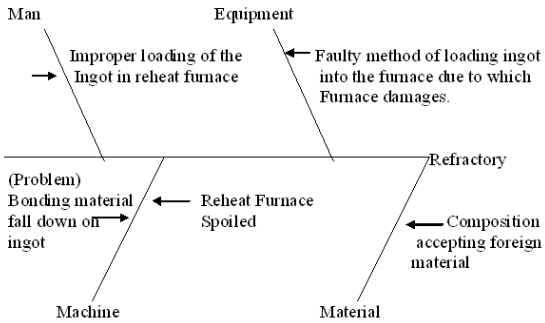

Fig. 9. Cause and effect diagram for refractory defect.

VI. Discussion and Recommendations

The following points have been proposed to reduce the defects and ultimately rejections during the manufacturing of strip for leaf spring.

- Internal, external customer ship type scenario is to be developed.
- Applying recommended statistical quality control tools like, brain storming, pareto diagram & cause & effect diagram to correct the problem and minimize defect level.
- Roll surface can be maintained by polishing the roll with oil stone in the running condition of the mill.
- Roll reconditioning is to be done once or twice afterwards rolls may be replaced.
- Roll to be checked after fix interval of production.
- Training is to be imparted to the supervisor and main worker for efficient working and also for improving the skills.
- Furnace capacity is low that should be increased.
- Molten metal poured through plain pipes are to be replaced by sprue so that momentum of the molten metal can be maintained and entrapped gas can be minimized.
- Manual pouring is to be replaced by automatic arrangement so that pouring pressure uniformity can be maintained.
- Some exothermic material is to be used at the mould face so that end defects on ingot can be minimized.
- Some stainless steel grate may be used to avoid slug inclusion in the metal. Slug can be trapped on the grate and can be thrown away.

During the idle time, loss of fuel oil is also there that can be reduced by automation of the plant.

VII. Conclusion

In the present work, customer satisfaction among the various flow processes as well as internal and external customer ship phenomenon has been established for enhancing the effectiveness of rolling process. During the process, different defects occur either due to method, material, Man, equipment/Machine. Cause & effect diagram revealed analysis of the defect with their root cause. Serious efforts on the problem by using root causes analysis will eliminate the defects and the quality can be improved. Defect may be occurred in foundry during the ingot casting, to follow reheat furnace. It is hereby also suggested that ingot must be carefully checked for surface defect; length and their proper stock size. If any hidden defect lies within the ingot, specimen should be cut down and should be investigated by non destructive test.

Other defect which comes on product must also be taken care at rolling mill area, handling of the material and proper stacking of the product etc.

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