# Mini-Steel-Rolling Sequence Critical Analysis For Reinforcement Bar Production For Sustainable Manufacturing-A Case Study

Atul Modi, Ravikant Sharma, Yogesh Jaiswal, Sukhlal Mujalda, Sujeet Pratap Singh Baghel

**Abstract:** The modern mini-steel plant is a step toward quality, flexibility productivity, efficient energy use and good working conditions for consistent performance. The increased energy costs due to strict environment norms have created the demand for a system in the steel plant, that recover the process thermal heat or improve rolling process so next further processing may be avoided [14]. The Hot-charging system is a new development and its critical analysis for process energy optimization and energy cost also improve the rolling plant energy efficiency, improve the working atmosphere of the plant and environment both. The optimization strategy is also useful for pollution minimization by energy minimum use, which is now essential due to strict norms and regulation. By this paper a methodology will be develop for batch manufacturing organization to work as robust enterprises with energy considerations.

**KEYWORDS:** Sustainable manufacturing, Hot-charging system, Mini-Steel-Rolling processes Energy wastage.

## Introduction:

The mini-steel-rolling plant is a resource based energy intensive industry, as huge energy is consumed and they are the major emitters of greenhouse gases also. Historically, industrial energy-efficiency improvement rates have typically been around 1% per year [12]. Total energy-related industrial emissions have grown by65% since 1971[18]. China and India have high primary energy intensity compared to the other countries [7]. The hot rolled material are manufactured into machine parts after undergoing one or more stages of so-called post-processing such as heat treatment, forging and wire drawing. The metal flow behavior in a hot rolling process is a complex phenomenon, which is complicated due to tonsorial stress distribution that is influenced by the material properties and deformation parameters such as temperature, strain and strain rate [4]. The different types of rolling mill such as rolling-forging mill, plate mill and wire rod plant are developed to produce different finished products easily and to capture the market.


- *Atul Modi, Prof. Department of I. P. Engineering S.G.S.I.T.S. Indore M.P. India e-mail: atul_123modi@yahoo.com.*
- *Ravikant Sharma, Department of I. P. Engineering S.G.S.I.T.S. Indore M.P. India, email: Ravikantsharma.sharma3@gmail.com*
- *Yogesh Jaiswal, Department of I. P. Engineering S.G.S.I.T.S. Indore M.P. India. e-mail: yougeshjaiswal25@gmail.com.*
- *Sukhlal Mujalda, Assistant workshop superintended, S.G.S.I.T.S. Indore M.P. India, e-mail: sukhmjaan@yahoo.com.*
- *Sujeet pratap singh Baghel, Department of I. P. Engineering S.G.S.I.T.S. Indore M.P. India, e-mail: Sujeet.mach@gmail.com.*


In a wire rod and bar rolling plant processes, the aim of energy conservation and saving can be achieved by reduced resource consumption of process energy and by efficient use of plant installation and utility [20]. The manufacturing must be flexible, easy to operate and mistake-proof, this is a robust organization. Work-force and resources multiple-utilization and total quality is the final objective [11]. The modern steel rolling plants uses different energy saving approaches; among them hot charging of billets from arc furnace is the most successful approach which saves the heat left in the billets after exists from con-cast machine and increase plant productivity, quality and yields simultaneously [21]. The energy cost constitutes a major portion of manufacturing cost [17]. The costs of the post-processing is sometimes several times the price of the hot-rolled steel material, so it is increasingly important to reduce the total energy cost from the steel material to final product [20]. The hot charging is a best way to reduce the energy cost and improve the product quality at the same time. The hot charging system has different layouts depend on the final products and its complexity . The hot charging system is considered as best steel techniques available. The steelmaker also takes care during manufacturing, regarding the final products for optimum processes and fulfillment of required properties after the processing [5]. Temperature is the main process variable needed for every operation in hot rolling process for any value addition activity and to minimize the energy use [11]. It is a tool to improve environment and productivity of the steel hot rolling plant by controlling the rolling process heat and its wastages.

### Literature review

Sustainable development implies to integrate product, manufacturing process, and supply chain models to optimize product design variants in terms of costs and environmental impacts [8]. Sustainable design should consider life cycle costs and environmental impacts, including those related to materials and energy requirements during the manufacturing, use, and end-of-life phases of a product's life. Sustainable manufacturing and development are committed to adopting regenerated or environment-friendly materials of energy conservation, to constructing on the basis of green buildings and ecological environment, to rationally using water resources and energy, and to conducting scientific operations and management [17]. For a modern steel bar mill with hot charging system sustainability implies minimum energy use and or wastage from hot charging system to rolling sequences like roughing, intermediate, finishing rolling to thermax sequence of in-line treatment to finally at cooling at cooling bed. It needs minimum variations of rolling parameter with the help of reductions of variations by anticipating which uncontrollable factors or noise factors which will influence the sequence of rolling process. In the hot charge technique for round rolling, the billets are delivered for hot rolling in the wire rod or bar mill after they exit the casting unit but before they lose all their heat [15]. In practical life it is very difficult to achieve rigid input and other boundary conditions [2]. The final output has multi-objective target [2]. Energy is fundamental requirement for growth of any plant and India is in serious shortage of it [10]. The India reputation as low cost manufacturing base is in danger and high energy cost similar to raw material dent it [15]. Time demands to reduce rely on more energy production but work more for energy saving [1]. To obtain an optimum condition, the mini steel plant scheduled is a way to get maximum hot charge and alloy steel production is planned in a manner that it cast during time when mill is not working and in case of rolling mill failure the reheating furnace is also provided as buffer. [8] The reinforcement bar production system is also rapidly changing in order to minimize the effect of different uncontrollable process and design factors. The hot charging system is a way to obtain optimum quality by optimum rolling temperature, optimum speed and tension and finally by optimum reduction [12]. To improve the process and optimization a sequence of design of experiments in the progressive sequence of rolling is also needed [11]. Designing high quality products and processes at low cost is an economic and technological challenge to the engineer.

## Reinforcement bar production

The mini-steel-rolling plant consist of arc furnace, continuous casting and the hot rolling mill to save billet and process heat by direct hot charging. The mini-steel plant is now considered as backbone in the industrial growth of any nation. Hot continuously cast steel billets can be directly hot rolled through a hot charging in mini-steel-rolling plant to form reinforcement bar products. The high rolling temperature deformation due to hot charge decreases the deformation energy required for lowering the flow strength and enhancing ductility. The metal flow behavior in a hot rolling process is a complex phenomena, which is complicated due to tonsorial stress distribution that is in influenced by the material properties and deformation parameters such as temperature, strain and strain rate. Hot deformation of a cast billets results in the elimination of inter-dendrite micro-shrinkage, gas voids and center line porosities apart from breakage of as-cast dendrite micro structure. The figure-1 represents the different conventional and modern methods of reinforcement bars production as under-

(1) Rolled bars with alloy addition
(2) Reinforcement bars with cold working / twisting
(3) Reinforcement bars with quenching-self- tempering treatment process.

Out of all three methods the third method is most useful and now preferred [6].

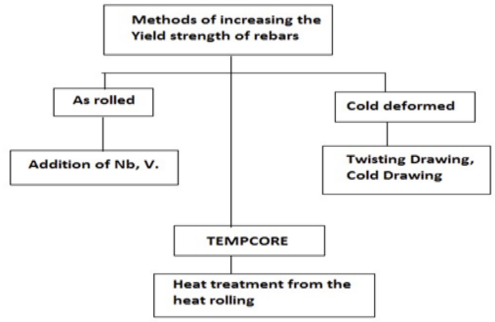


***Figure-1*** *Reinforcement bars production*

The hot charging system should plan in a manner to reduce life cycle costing of manufacturing processes and so the manufacturing costs [12]. In manufacturing processes design a major portion of cost are developed due to losses, these losses are due to variations in various functions of organization like manufacturing, personnel, finance, purchasing, etc. The plant operation with minimum break-down delays and miss-roll helps to obtained maximum hot charging and at a maximum billet temperature, so optimum product quality may developed at minimum energy costs [11]. The amount of energy needed for the hot-rolling can be reduced by lowering the working temperature and optimizing the rolling speed and pass design, which might involve a reduction in the total number of passes used in the rolling operation [20]. Such changes would require optimization of the characteristics of the production process during the design of the technology, and that in turn would entail a large volume of preliminary evaluation and calculation [9].

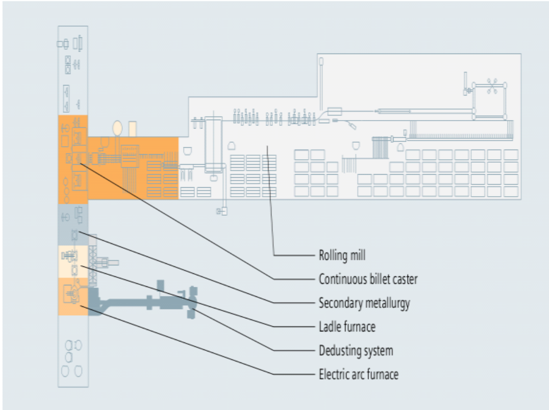


***Figure-2*** *Hot charging system for steel plant*

## Energy Efficiency and Energy Balance in Mini steel rolling plants

Energy can exist in numerous forms such as thermal, chemical, mechanical, magnetic and nuclear. For applying the energy in a controlled way machinery and tooling are used as means. The human energy is used for controlling the machine, to check the work piece or to load and unload parts [20]. The conversion efficiency of less than 100% indicates that conversion of energy is not perfect and some losses may be occurred during conversion process. More than half of the total energy is used in industries to operate various machineries. The energy optimization is a means to determine and control wastefulness or losses of the manufacturing system. In a process industry like modern steel rolling plants energy optimization applies for wise use of energy to get more output for money spends. The energy optimization is an economic way of plant operating and continuous improvement cycle and by reducing energy losses of processes. The hot charging process also need proper scheduling, delay and break-down control and optimum output results of performance, quality, defects and set-up-time. The efficiency of any plant may be differing from plant to plant, as in every plant different machinery and technology may be used. An engineer knows that all kinds of functions are energy transformations. Some process industries consumes huge amount of energy like in chemical and steel industries [2]. The 100% efficiency indicates a perfect conversion with no friction or other irreversibility [14]. The law of energy conservation state that the net energy transfers during a process is equal to the change in the energy content of the system. The way to obtain ideal efficiency is to obtain energy balance of all main equipment of processes [10]. The energy balance principle is based on losses recovering equipment, employed during process operations like heat exchanger or cooler or recuperator etc. [2]. These losses are mainly reduced due to maintaining of ideal parts size during operations, by maintaining the temperature during process or energy recover from flue gases of furnaces. The hot charging system can be used to maintain energy balance of a steel rolling plant, if follows the best energy techniques for standard energy consumption In some organization like steel plant, a huge energy loss is developed due to large energy imbalance. The energy balance is carried out in the operation and the process design stage. It is carried out from design stage to operation stage in complete process. It helps to understand the patterns of energy consumption and suggest means for the conservation of energy [3]. An energy balance is required in steel plant to obtained optimum conditions. The total manufacturing cost may be divided into unit manufacturing cost plus operating costs. The operating costs consist of energy needed to operate the product, environmental control and maintenance etc.

## Methodology

The Fig. 3 showed the complete methodology for sustainable development of mini-steel-rolling-plant and to optimize the hot charging system also by robust design from melting-furnace to finish material dispatch. The methodology is considered the importance of hot charging system success also.

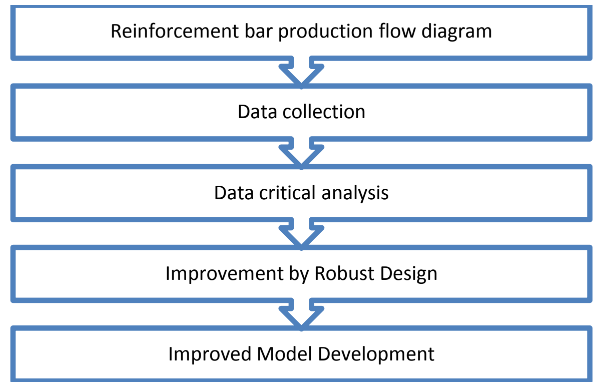


***Figure-3*** *Methodology*

### Requirements for Sustainable development in mini-steel-rolling-plant

The mini-steel rolling plant is now essential for industrial growth and sustainable development of any developing Nation like India. Reinforcement bars customer demands more product range and variety. The mini-steel rolling have to change for customer demand and for strict pollution norms and to go for sustainable manufacturing system. The rolling plant now needed to work as flexible and robust manufacturing system also. Main requirements for sustainable development and manufacturing in a modern mini-steel rolling plant with hot charge-

- To obtain maximum hot charge with maximum temperature of billets without any delays and casting defects like blow holes, piping, refractory and non-metallic inclusions etc.
- To obtain optimum quality of reinforcement bars and desired mechanical properties of bend-ness, weld ability, corrosion resistance etc.
- To obtain maximum use of con-cast billets without off grade and alloy additions possibilities, so minimum wastage of billets.
- To obtain temperature control during rolling sequence for optimum output of performance, quality, set-up time and defects.
- To minimize the wastage of energy by controlling rolling process heat loss and process delays and miss-roll. The minimum conversion time and minimum numbers of rolling stands are used.
- The Thermax process quenching time is set so desired yield strength in safer side obtained.
- To reduce the chance of recycle, repair, rerolling, scrap miss-roll and delays during rolling all sequences steps.
- To obtain maximum yields of the billets by minimizing end cutting, bar cutting, scale loss and miss roll during rolling.

### Case study of hot charged wire rod/bar plant

A case study of a steel mini steel rolling plant with hot charge is considered. The concept of mini steel plant is to melt the iron scrap, continuous cast the billets and these billets after cutting into required length directly rolled in the rolling mill, thus save the reheating process as employed in the conventional steel rolling plants. The energy required to extract the iron ore is thus saved and energy required for rolling reheating process is also saved. In this way a considerable energy is saved. The continuous cast machine cast the billet, slab or net shape casting depend on shape of rolling product as round, square, plate or other section like beam, channel etc. The rolling mill produced thermo-mechanical (TM) treated bars in different size and grades. The plant layout is optimum with respect to layout but the plant quality, economic and environment results are not satisfactory due to temperature and performance variation. The Fig. 2 represents the Thermax process of reinforcement bars.

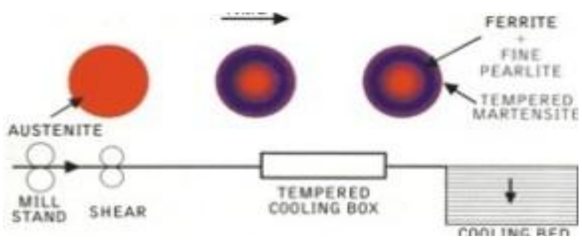


***Figure-4*** *Rolled finished products*

### Problem formulation

The main problem in mini-steel-rolling plant with hot charging system is to reduce life cycle costing of manufacturing by robust design. In order to obtain maximum hot charge the current mini-steel-rolling-plant runs round the clock e.g. 24 hours working. In manufacturing processes a major portion of cost is developed due to losses and these losses are due to variations in various functions of organization. The plant operation with minimum break-down, delays and miss-roll helps to obtained maximum hot charging and at a maximum billet temperature, so optimum product quality may obtained at minimum energy costs. The main criteria and object of the hot-charging system can be obtained by following objectives-

- Improve efficiency and reduce the total cost of producing and using maximum hot charge through the use of technologies and equipment by robust design
- Minimize the technogenic effects of the energy sector on the environment
- Develop a system for government regulation of energy-conservation efforts based on evaluation of the energy efficiency of energy users.

The figure-5 indicates the improved model by robust design as-

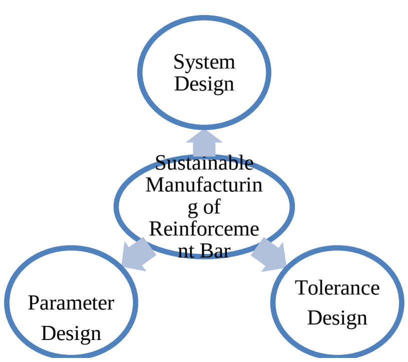


***Figure-5*** *sustainable Manufacturing by Robust Design*

### Flow process diagram

Figure-6 indicates the flow process diagram of modern reinforcement bar production

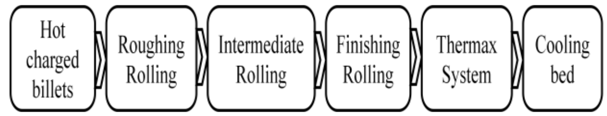


***Figure-6*** *Flow process diagram*

### Data collection:

Data collection is made and arranged for problems and failure area on basis of system problems for hot charging, the problems and delays areas of reinforcement bars production and tolerance problems of billets, pass of rolls, the diameter of rolls and setting etc.

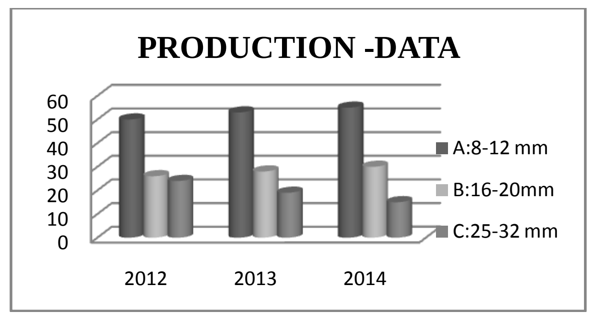


***Figure-7*** *Production data*

To determine the most influential parameter to delay and miss-roll of last three year are analyzed for failure reasons.

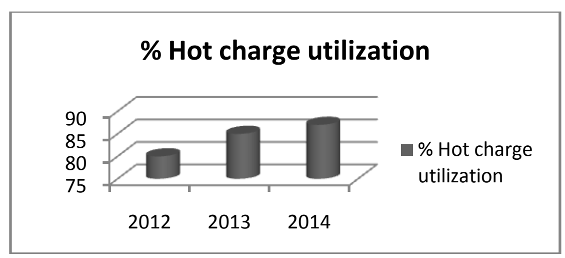


***Figure-8 %*** *Hot charge utilization*

### Critical analysis of mini-steel-rolling areas:

The hot charging system data are collected for analyzing the hot charging % in the rolling mill. The increasing trend of hot charging % in 3 year data represents a hope to maximize it and save the valuable energy input and so the environment. The environmental factors such as lighting, noise control and air conditioning support for consistent performance in rolling environment which is affected by high temperature, dust and noise. The Pareto diagram is used to analysis the main contributing area of failure.

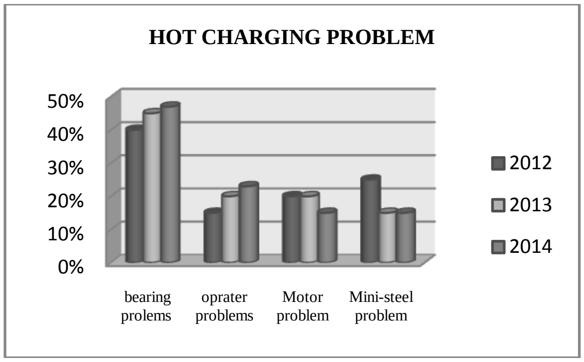


***Figure-9*** *Hot Charging Problem*

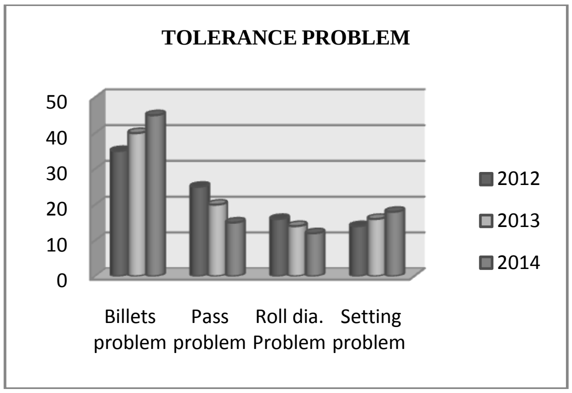


***Figure-10*** *Tolerance Problem*

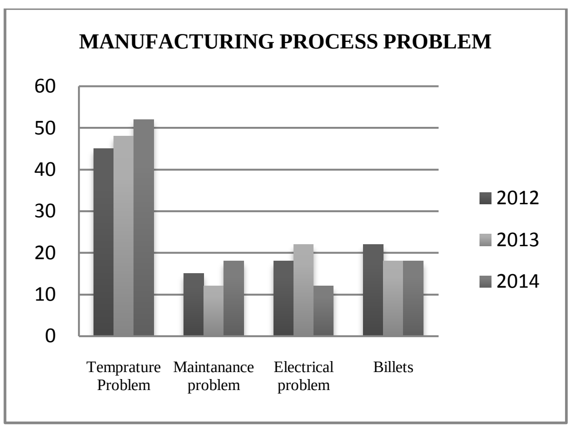


***Figure-11*** *Manufacturing Process Problem*

Critical analysis is done by fish bone diagram as in figure-12 for hot charging system bearing failure.

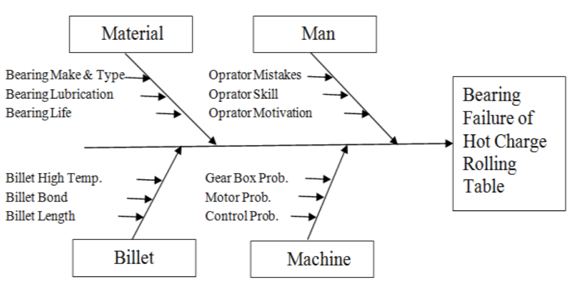


***Figure-12*** *Failure of Bearing*

## Improvement by Robust Design

The critical analysis indicates temperature as main factor or variable which causes the delay, miss-roll and emission**.** The rolling bar temperature variations, then desired results into delay, miss-roll and losses. The improvement is done in three steps as-

- System Design
- Parameter Design
- Tolerance Design

The modern mini-steel rolling plant are design to run 24 hour, so maximum hot charge may be obtained.

## System design

The mini-steel-melting furnace produced heats of 25 tons in a interval of ¾ hour. The interval of time gap is used by the rolling people to maintain the rolling plant and hot charging conveyor system maintenance for trouble free operation. The week area is the guide box maintenance and hot charging conveyor rollers bearing. The critical analysis of guide failure indicator that reasons are bed design of guide rollers and inserts, similar the critical analysis of rolling table bearing failure indicate that for high temperature working bushing better than ball/roller bearing. The aim is to improve system from design stage for trouble free and perfect operation and delays due to man, machine and material are analysed as in figure-13.

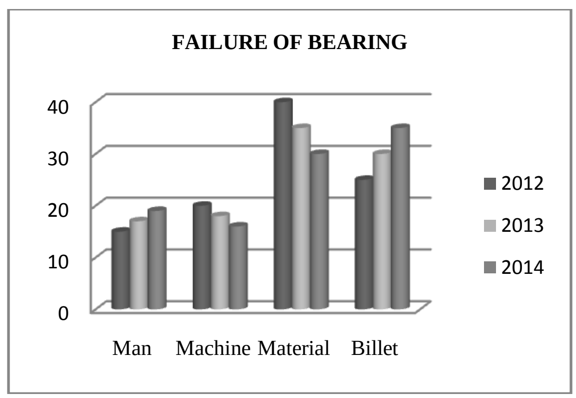


***Figure-13*** *Failure of Bearing*

## Parameter design

The mini-steel rolling plant rolling process is influenced by different parameter. Many parameters are interrelated so their relationship and influence effect is also determined and some parameter effect is more than other parameter. The robust parameter design determines the set value of parameters for final product with minimum variations under all conditions. The Taguchi method aims to determine and understand the influence that parameter had or variation not just on the mean in reality. To minimize the product results or performance and process variation is the aim of robustness. The mini-steel rolling plant is capable process to create robust workplace by improvement of output, process and performance by optimum setting of control variable. The rolling process is influenced by different variables as show in table-1**.**

**Table-1 Rolling process Noise-factors**

| S.N. | Factors |
|---|---|
| 1. | Temperature drop during hot |
| 2. | charging. |
| 3. | Cold ends of hot charge billets. |
| 4. | Defects in billets. |
| 5. | Guide setting not o.k. |
| 6. | Roll groove not o.k. |
| 7. | Roll setting not o.k. |
| 8. | Split front ends. |
| 9. | Dividing Shear cutting is not o.k. |
| 10. | Finish roll groove and lugs are not o.k. |
| 11. | In-line treatment cooling water |
| 12. | temperature is not o.k. |
| 13. | Thermax system control panel |
| 14 | problem. |
| 15 | Bending at cooling bed. |
| | Bending during shifting. |
| | EOT crane problem. |

Some other variables are also affecting the rolling deformation process. But there influence is not significant to the process. The sequential design of experiment is the technique used for parameter optimization. The Pareto diagram is used to analysis the delays and miss-roll due to parameters like Temperature, Roll diameter setting, speed for 3years as in figure-14

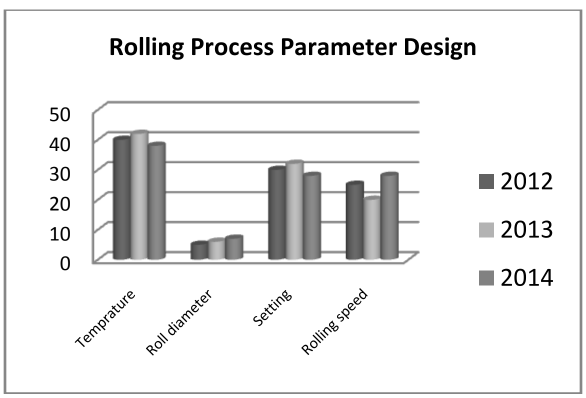


***Figure14*** *Rolling Process Parameter Design*

The cause and effect diagram are used to determine the effect of temperature due to man, machine, process and material as in figure-15.

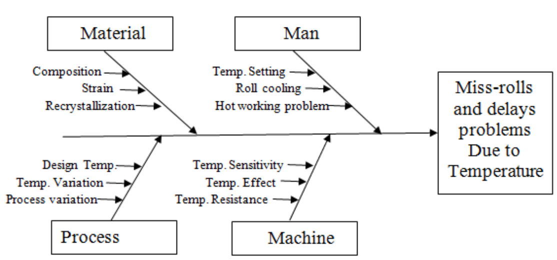


***Figure-15*** *cause and effect diagram of temperature*

## Tolerance Design

The hot charged reheated billet has advantage of uniform and optimum heating at all places so suitable for uniform and trouble free rolling in all sequence of roughing intermediate and finishing operation. To obtain the billets of required temperature from hot charging all delays points of transfer table are to be minimized. The billet quality variations are minimized so that they can easily rolled in present rolling layout with minimum defects and setup optimum quality performance etc. The various delays and miss roll are first categorized on basis of heads and responsible causes. The total delays and miss roll Pareto diagram indicates that operational delays and miss roll causes maximum contribution in all three year continuously. The mini-steel rolling plant performance is mainly depend on billets quality and reinforcement bar percentage of O.K quality. It needs minimum energy consumption, miss-roll and delays and maximum quality result and yields. The table2-indicates that the tolerance of billets, rolling parameters and finished product is set so minimum rolling losses and delay and improvement in tolerance design for optimum rolling output with minimum performance variation.

**Table2-The tolerance Design improvements**

| S.N. | Area | Improvement in tolerance |
|---|---|---|
| 1 | Billets | Proper length, taper end cutting, minimum rombodity. |
| 2 | Roll Pass | Proper groove cutting and pass design, corner radius. |
| 3 | Roll Diameter | Same roll diameter, Speed setting, Roll grove. |
| 4 | Setting Problem | Pass line, Guide line, Roll line, Roll gap, Schedule. |

## Improved model Performance

The improved model is representation of robust design of system for hot changing the most influential parameter design and tolerance design for minimum rolling difficulties The improvement in the system design helps to reduce about 35% Delays of hot charging system as well as to roll the red hot billet at 1200 $^{o}$c in the rolling mill and save the electrical consumption per ton by 5% Or 7 unit per ton. In this way sustainable manufacturing system design is also improved by robust design and costly process heat and power energy is saved. The reinforcement bar production process is affected by number of factors and variables. Which causes some time energy extra use and wastage also.The reinforcement bar mechanical properties is control by different treatment process, in-line or off-line. Designing of low energy manufacturing process is key of sustainable development in a high energy intensive plant like steel rolling process The hot charging plant is also low energy process for sustainable development which reduce product energy consumption by wastage control to obtain optimal performance. With help of improved model by robust concept a improvement in hot charge percentage from 70 to 90 % and quality result of O.K bars increased from 94 to 98% and delays miss-roll and power consumption is also reduce as shown figure-16. It indicates that reheating/rolling temperature is the main process parameter to be required to be in-line control during all rolling sequence.

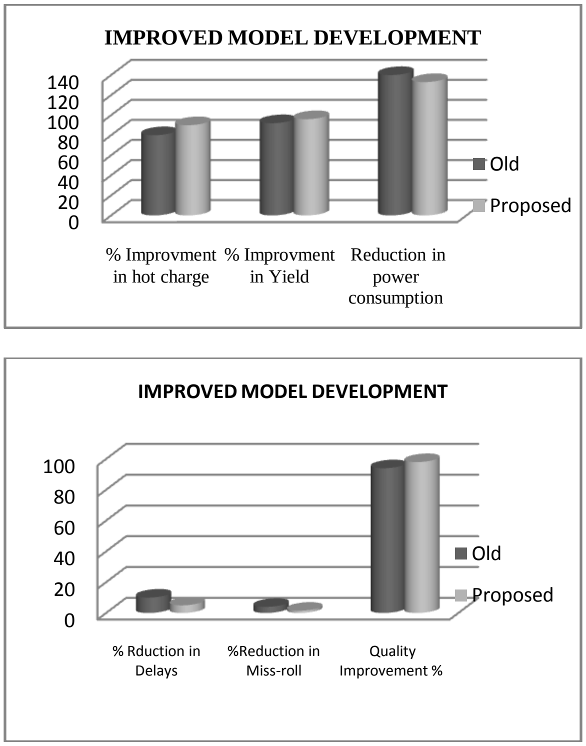


***Figure16-*** *Proposed improvement in rolling result*

In order to improve the mini-steel rolling plant, robustness in all manufacturing element is required. The improvement cycle starts from proper billet quality to maximum hot charging utilization and finally the best performance of reinforcement bars.

### Results and conclusion

In this work robust design concept is used to improve the reinforcement bar production for sustainable development, in a modern steel rolling plant. The mini-steel-rolling-plant is properly layout but the rolling process analysis indicated that large improvement cycle is still pending. The Robust design concept output for sustainable development are summarized under as in Table-3

**Table-3 Improvement for sustainability**

| S.N | Robust design step | Output result |
|---|---|---|
| 1 | System design | To improve the rolling performance by 90-100% hot charge by new design of bearing bushing. |
| 2 | Parameter design | To perform rolling deformation process at optimum rolling temperature so optimum output obtained. |
| 3 | Tolerance design | To improve the tolerance design by tighter billet quality, So minimum Rolling problems and miss-roll developed. |

Creating a robust process is like putting shock absorber is a vehicle for uncontrollable road conditions for smooth performance without any variations. The Taguchi robust design concept is best to start the improvement cycle and to reduce the process losses for sustainable manufacturing.

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