

# Sequential Optimization of Rod Hot Rolling Processes with Help of Rolling Temperature

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**ABSTRACT:** Wire rod rolling is a complex process which has influenced by different process parameters like, speed, drought, load, temperature, final size and tension etc. Generally a wire rod plant uses high speed block mill in order to obtained high production and consistent performance as in mass production system. Plant system should be capable to roll high grade steels of every type. Now rolling processes improvement object are performed in a manner that, further processing may be avoided for different finished rolled product. A case study is presented to illustrate the rolling processes sequential optimization to demonstrate its applicability for quality improvement of the plant processes and finally energy losses by low temperature rolling.

**KEYWORDS:** Wire Rod, Hot rolling, Sequential Optimization, CUSUM chart and rolling temperature.

## I. INTRODUCTION

India is the world 2nd largest steel producer. India being a developing country has high future demand of steel and positive atmosphere for growth and has a great potential for energy conservation to support to increase the manufacturing share in GDP. The rolling processes are performed in sequences to obtain different sizes and different defects are also developed due to process variability in different sequences. The influence of work hardening is also used to obtain the desired strength at different temperature ranges for different material grades by cold working. The defects generation process to developed desired strength and material structure by cold working is also sequential as rolling deformation sequence proceeds.

Indian conditions are favouring to develop competitiveness for both internal and external steel production. Per capita steel consumption in India is one of the lowest. The Indian integrated steel plants percentage of quality and certified steel are varies from 80-90%, needed a policy to improve it. It is estimated that the rolling process is used for 80-90% of the steel production worldwide. In private secondary steel sector the percentage of standard quality is very low except some giants like Tata etc. The many of the units in the private secondary sector particularly the induction furnace unit produces and sell steel products which do not conform to the prescribed quality standards.

The steel rolling technology whether conventional or modern, suffering from high energy cost, due to energy wastages as unused process energy and less plant utilization, which actually resulted into pollution to the environment. Steel wire rod rolling plants are developed and modernized with a view to satisfy different customers' demands for precise size, consistent quality of different grades and to reduce post-processing cost. The wire rod products include diameters ranges from 5.5mm diameters to 12 mm diameters. The respective steel grades include S.S, bearing steels; tool steel grade etc. The role of wire rod mill is important to justify the necessary expansion and increased output for any steel rolling plant. The wire rod steel plant continuous operation is a step towards mass production manufacturing system to get continuous and consistent quality. The high speeds of the wire rod rolling processes and due to equipment, speed variation and tension different types of defects may be also developed. The final size and shape, along with defect free operation are essential to obtain the required quality. For wire rod rolling grooved rolls are used depend on final size. The steel rolling plants of India divided as public and private sector. Energy saving potential in Indian steel rolling plant is high due to high energy losses and low efficiency. Rate of improvement in last few years indicates saturation in the energy consumption reduction in both modern and conventional plants and needed more research and efforts. The rolling processes are divided into roughing, intermediate and finishing operations. The roughing rolling operation is predominant for quality steel production. The roughing rolling operation is performed to reduce size for sound and defect free wire rod grades. The process has influenced by different process parameters like, speed, drought, load, angle of bite, temperature, roll material and final size etc. The role of set variable and control factors for minimum

temperature and energy losses is very vital. To get the desired quality of finished products the different pass sequences are used. With help of this work the routine rolling complexity of manufacturing are tried to be minimized.

## II. RELATED WORK

The average specific energy consumption in India is 6.4 GCal/tcs in comparison to 4.1 GCal/tcs for rest of world (Singhal K.K., 2009). Das et al. (2014) analysis that the rolled bars exhibit a variation in microstructure in their cross section, having strong, tough, tempered martensite in the surface layer of the bar, an intermediate layer of martensite and bainite, and a refined, tough and ductile ferrite and pearlite core. Manufacturing of steel products are needed in consistent quality, at economic prize. Shunichi et al., (2015), raised the need of rolling process optimization to reduce the energy all forms losses and wastage. According to Ministry of steel (2015), SAIL plants achieved the best ever specific energy consumption of 6.59 Gcal/tics', an improvement of 1% over last year by improving efficiencies, reducing costs and upgrading technologies etc.

In order to improve different work are performed and models developed. Chumachenko et al. (2010) developed a compact mill with minimum temperature loss during rolling. Ali and Maghsoudi (2010) developed an optimum process control model for specialty steel to improve the dimensional accuracy, shorten the roll-changing time by implementing size-free rolling, and reduce surface defects. Bagheripoor and Bisadi (2013) consider, speed, %age thickness reduction, temperature and friction coefficient as variables for rolling force prediction by ANN. Cadoni et al. (2013) discussed hot rolling of ZK61 Mg alloy sheets with homogeneous structure which was performed at the temperature range of 553–433 K to examine the influence of rolling temperature on the microstructure refinement and uniformity and pollution. Altinkaya et al. (2014) prefer ANN as it provides a way for accurate and fast decision making and modelling. Bambach and Seuren (2014) emphasized that the performance of rolling processes is difficult to control due to the dynamic processes and new customer requirements. Ohara et al. (2014) discussed that the mechanical properties of sheet products are determined not only by chemical composition, but also by rolling process conditions such as temperature and transfer bar thickness.

## III. SEQUENTIAL ROLLING PROCESSES

The steel rolling is a complex process and performed in various sequence in various passes. Rolling is done progressively in different pass to obtain required shape and size. Roll pass design of roll is also important for final quality. Different types of pass design are developed to get perfect reduction at high speed. Optimal rolling surface and closest tolerances can be obtained only by tension-free and twist-free rolling. To obtain good surface finish tungsten carbide{T-C} rolls are used for finishing operation. The T-C rolls retain the shape, size for long service life. The reduction provided in each pass depends on different variables and parameters, but also decided by roll designer. For examples minimum 10-12 passes are required to obtain 12 mm round from 100 mm square billet. The optimum size development required that process performed in minimum or single setting of mill. The recent trends in steel rolling plants are for sequential manufacturing system for small batch, so energy wastage may minimize due to non-continuous operations. Quality controls of rolling processes are essential as the rolling operation is very costly.

The finishing pass dimension should be considered in taking account the linear expansion of material. The importance of rolling knowledge to obtain desired results as designed in different pass sequences is useful for optimization. The contribution of most influential parameters on finished product is important. In absence of clear knowledge of rolling the rollers can-not obtained the desired quality results. This is a major issue and problem.

The need of rolling process optimization is developed to reduce the energy all forms losses and wastage. The improvements in energy efficiency result in reduced production costs and thereby improved competitiveness. Any improvement in energy front by optimizing the waste rolling heat for example by in-line heat treatment, thin slag casting-rolling, etc. results in substantial saving due to reduction in post processing cost. Energy saving potential in Indian steel rolling plant is high due to high energy losses and low efficiency. Continuous R & D can reduce rolled product energy consumption similar to Japanese manufacturer. Additional methodology and techniques are needed to take benefit of low labour cost in India in steel rolling manufacturing system.

The aim of sequential manufacturing is to get the desired rolling results in independent sequences with a common goal or objective. To obtain consistent performance along with quality the continuous production system is preferred with no change in parameters after obtaining the desired dimensional and metallurgical results. The increasing competition in rolling sector and financial health of rolling plants and their market position insists to reduce the energy

content of products by optimizing energy use and to reduce the contribution of energy in overall production cost. Optimization of process for minimum or zero defects obtain by rolling process sequential optimization.

#### IV. METHODOLOGY

In modern steel rolling plants the different parameters are easily monitored and controlled due to different sensing devices and new technology in comparison to old conventional rolling plants, which generally work with manual judgment system. Conventional rolling plants have to run the plant in difficult condition for in-line-control of the various rolling parameters like temperature, speed and tension etc. finished rolling at lower temperature influence the grain size, transformation speed and structure. The recent trends in steel rolling plants are for sequential manufacturing system in small batches for different sizes and shape in different pass.

Conventional rolling plants have to face the challenges of producing more consisting output with more efforts than modern steel plants. Chances of variation in final output and low mechanical properties are more in conventional rolling plants due to old technology. Conventional and modern plants both have to work for dimensional and metallurgical consistent output in more precise manner.

Detail comparative energy analysis of different manufacturing system of different case studies performed in different steel rolling plants of India indicates that, energy consumption and production processes energy losses, for steel manufacturing is very high. It very difficult to achieve the set targets as in National steel policy of India. Rate of improvement in last few years indicates saturation in the energy consumption reduction in different modern and conventional plants and needed more research like energy optimization of manufacturing system.

The energy consumption saving target in National steel policy of India is, 5% reduction for three years are difficult to achieve in current situation by help of currently using techniques. Rolling plants different new requirements can be achieved by robust or consistent performance with minimum energy losses in different sequences. In steel rolling processes there are many possibilities to reduce energy losses in different rolling sequences.

#### V. NEED OF PROCESS OPTIMIZATION

For steel rolling manufacturing system many improved model are developed to improve the product performance and final quality. Rolling process different models for high growth rate and process optimization are only approximate models and new models are required for current requirements. The new model will help the roller for consistent quality.

The rolling manufacturing system most important elements of process optimization are the consistency of processes all sequences. The output of all sequences should indicates, minimum shape and size variation and low process energy losses. The rolling people should concentrate only on most important process influencing variable to reduce process complexity. The customer expectations and requirements also demands for reduced quality variations and all this with reduced cost with process atomization and high tonnage.

Different work also suggest for optimization. Ali and Maghsoudi (2010) indicate that the temperature control rolling made revolutionary improvements in rolling mill design. Chumachenko et al. (2010) show the important of finite-element modelling to determine rolling forces due to thermo-mechanical behaviours and location of rolling defects. According to Jin-ling and Zhen-shan (2011), the actual energy savings by hot charging system will be highly plant dependent. . Balogun et al. (2011) prefer rolling temperature control at different stage; speed, inter-stand time, true strain and strain rate ranges at each stage are also as parameters for grain refinement. Bagheripoor and Bisadi (2013) consider, rolling scheduling and on-line-control is required for consistent performance. Agrawal et al. (2014) discussed the importance of mathematical models which have been widely used for prediction of microstructure and mechanical properties in hot rolling of strip. Modi et al., [2017] refer rolling as generation of optimum defects such as dislocations, vacancies and imperfections density in crystal structure through thermo-mechanical-in-line-treatment.

#### VI. CASE STUDY

Rolling is the most extensively used mechanical metal working process. About 70% steel is processes through rolling mills. It is widely used to convert steel ingots into blooms, billets, slabs and into plates, sheets, rods and strips etc. This is followed by further hot or cold rolling into rod and bar. Roll pass design is used to distribute the deformation shape and size in different pass sequences.. A good designer developed it in minimum number of pass in roll of roughing mill for wire rod product. It finally processed into wire rods with acceptable dimensional tolerance depend on different rolling parameters. A case study of wire rod plant is considered here to demonstrate the complete methodology. Figure-1 shows the finished rolled wire rods and plant view showing hot rolled coils in the conveyors.



Figure-1 Plant view showing hot rolled coils in the conveyors and finished rolled wire rods

Figure-2 indicates the wire rod plant’s finished products total production and rejection percentage for three months for 7mm wire rod. The rejection percentage is high as high grade steel like S.S., Bearing steel, free cutting steel is rolled.

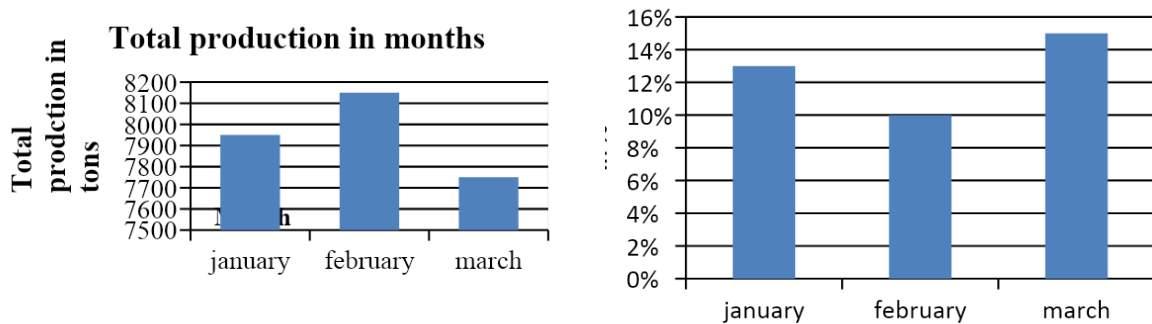


Figure-2 Plant 3 month’s production and rejection

In order to determine the causes of rejection high percentage CUSUM charts for different months and sizes are plotted as below. The collected data are used to determine the main cause of variation. The different causes or process variables has individual importance for rolling wire rod quality. The Indian steel rolling plants are now to work with global competition to prove them and to reduce technology and performance gaps.

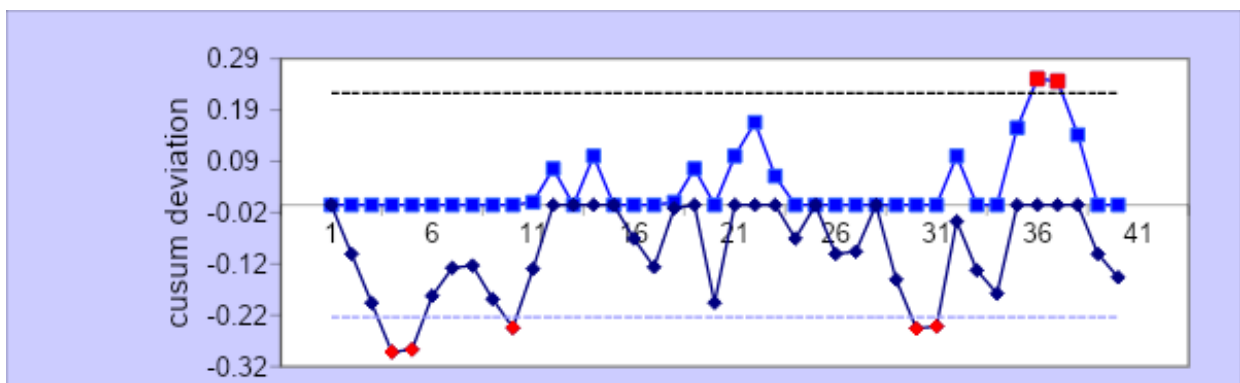


Figure-3 CUSUM Chart for 7mm wire rod in January month of Plant

Rolled wire rod products different data are used to plot CUSUM chart and used to determine variations for one sigma shift in rod size. In March rejection percentage is more than other two months. The reasons are that in this month S.S.grades is rolled. The rejected samples rolling temperature are also recorded to determine root causes.

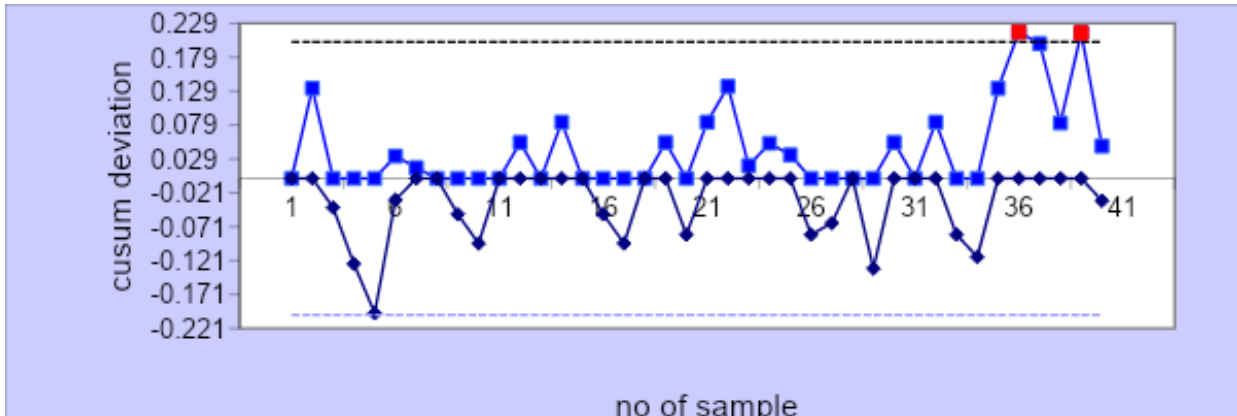


Figure-4 CUSUM Chart for 7mm wire rod in February month of Plant

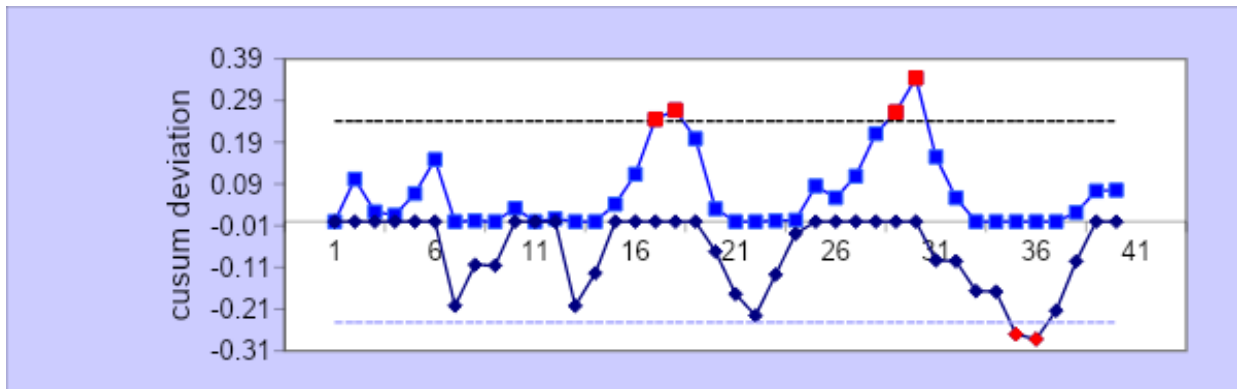


Figure-5 CUSUM Chart for 7mm wire rod in March month of Plant

### VII. RESULTS

Following Figures-6 and Figures-7, shows the relationship between temperature and size variations for different rejected samples. The role of CUSUM chart is very important as one sigma shift from mean is indicated by it. The rolling process is easily controlled by them. Whenever rolling temperature varies the chart indicate the same and in this way complete rolling process is optimized. The rejection percentage of rolling process is also minimized due to less temperature variations. The rolling miss-rolls and cobbles are also reduced. The wire rod rolling process size variations, rejection percentage, miss-rolls are minimized and quality is maximized by proper use of CUSUM chart. The case study indicates that wire rod rolling process is optimized by rolling temperature optimum control.

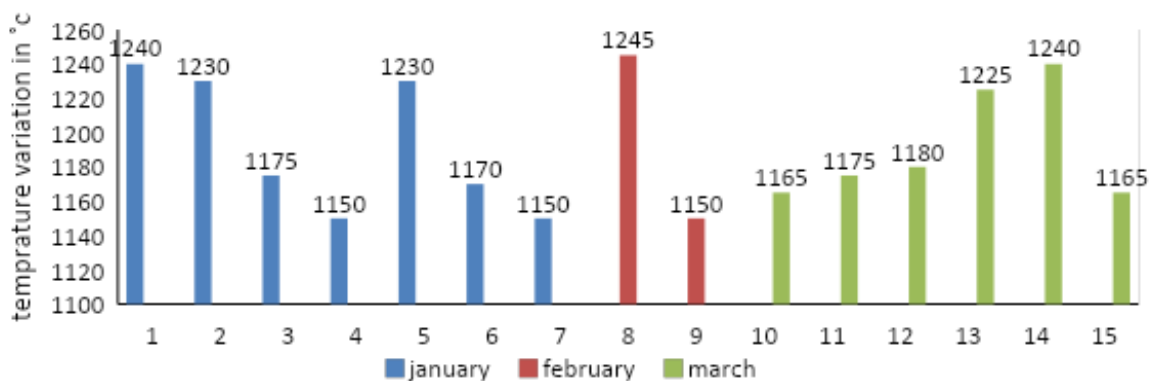


Figure-6 Bar Chart for Temperature variations of rejected samples of 7mm wire rod



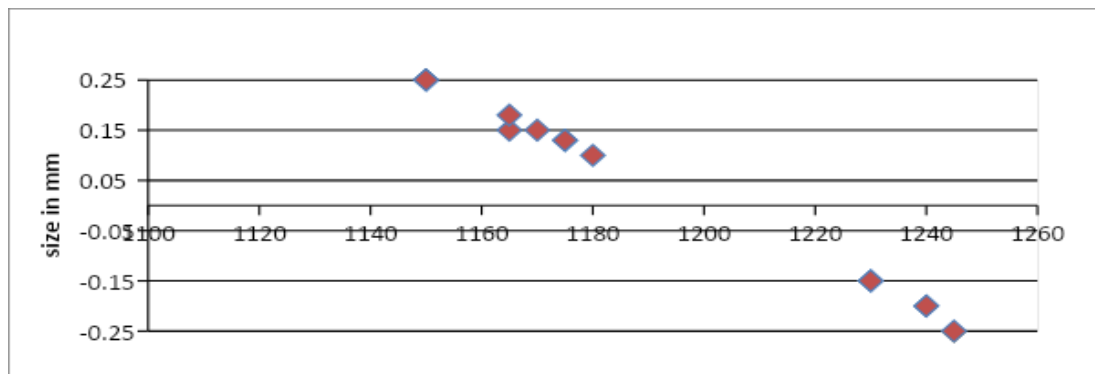


Figure-7 Chart for Size variations of rejected samples of 7mm wire rod

In all rolling sequences the temperature role is an essential element for process energy optimization. Rolling system obtained a saving of subsequent heat treatment in some case and facilitates for its latter processing. Parameter optimization is also useful to optimize the complete rolling sequences by minimum energy losses and wastages. Goal oriented consistent output performance is developed for different grades and sizes in minimum setup time. Role of temperature in complete rolling cycle is also useful to reduce breakdowns and delays as well as for rejection control. With help of proper monitoring of most influential parameters the complete process is optimized and different losses are minimized. The CUSUM chart indicates rolling process failure before the actual size varies beyond the set control limits. If CUSUM chart apply in rolling process than expected reduction in rejection is about 30%. The temperature variable affects the complete rolling process.

#### REFERENCES

1. Agrawal, K., Shivpuri, R., and Bonthapally, V., "Process-structure-microstructure Relationship in Hot Strip Rolling of Steels Using Statistical Data Mining" *Japan Procedia Engineering*. 81, pp. 90-95, 2014.
2. A. Ali, A.A. and Maghsoudi, A., "Optimization of Production Systems through Integration of Computer Simulation. Design of Experiment and Tabu search The Case of a Large Steelmaking Workshop" *International Journal of Advance Manufacturing Technology*, 48, pp.785-800, 2010.
3. Altinkaya, H., Orak, I.M. and Esen, I. "Artificial neural network application for modeling the rail rolling process" *Expert Systems With Applications*, 41, pp.7135-7146, 2014
4. Bagheripoor, M., Bisadi, H., "Development of a geometric modelling strategy for roll pass optimal design" *Robotics and Computer Intergated Manufacturing*. Vol-30, (6), pp. 622-628, 2014.
5. Balogun, S.A., Lawal, G.I., Sekunowo, O.I. and Adeosun, S.O., "Influence of Finishing Temperature on the Mechanical Properties of Convectional Hot Rolled Steel Bar", *Journal of Engineering and Technology Research*.39110, pp.307-313, 2011.
6. Bambach, M., Seuren, S. "On instabilities of force and grain size predictions in the simulation of multi-pass hot rolling processes" *Journal of Materials Processing Technology* 216, pp.95-113, 2014.
7. Cadoni, E., Dotta, M., Forni D., Tesio, N., Albertini, C., "Mechanical Behavior of Quenched & Self-Tempered Reinforcing Steel in Tension under High Strain Rate. *Material science & Design*.49, pp.657-666, 2013.
8. Chumachenko, E.N., Aksenov, S.A. and Logashina I.V., "Mathematical Modelling and Energy Conservation for Rolling in Passes" *Metallurgist*. 54, pp.498-504, 2010.
9. Das, S., Mathur, J., Bhattacharyya, T., Bhattacharyya, S., "Failure Analysis of Re-Bars during Bending Operations", *Case Studies in Engineering Failure Analysis*. 2, pp. 51-53, 2014.
10. Jin-ling, Z. and Zhen-shan, C., "Continuous FEM Simulation of Multi-Pass Plate Hot Rolling Suitable for Plate Shape Analysis", *Journal of Central South University Technology*, 18, pp.16-22, 2011.
11. Ministry of Steel, Government of India, 2014-15.
12. Modi A., Hindolia D.A. and Sharma R., "Sequential Improvement of Quenching-Self-Tempering-Thermal-Treatment Rolling Process for a Modern Manufacturing System -A Case study" *International Journal of Scientific & Technology Research*.4, 04, ISSN: 2319 - 1058, 2017.
13. Ohara, K., Tsugeno, M.,Imnan, H., Sakiyama, Y., Kitgoh, K., Yanagimoto, J.," Process optimization for the manufacturing of sheets with estimated balance between product quality and energy consumption" *CIRP Annals: Manufacturing Technology*63. (3), pp. 257-260, 2014.
14. Singhal, K.K., "Energy efficiency in Steel Industry and Clean Development Mechanism (CDM)" *International Convention on Clean. Green and Sustainable Technologies in Iron And Steel Making At Bhubaneswar*. Pp.15-17, 2009.
15. Shunichi T., Yota K., Tomoyuki Y., Katsumi Y., Yutaka M., Chikara K., "Effect of hot rolling and cooling conditions on intergranular corrosion behavior in Alloy625 clad steel", *Corrosion Science*, Volume 99, pp. 125-133, 2015.