Review on cold rolling mill roll deformation

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Abstract—*There are various reasons by which the damage in the cold rolling mill rolls occurs. The main objective is to highlight those reasons which are responsible for the breakage. The parameters considered during the manufacturing and during the regular use of rolls in cold rolling in the past researches and the effect of these parameters to increase the life of a roll. These are based upon the various factors and summarize the effect of parameters responsible for the deformation concluded by the various researchers in the past history of cold rolling mill.*

Keywords- Cold Rolling Mill Rolls; Thermal Breakages; Spalling.

I. INTRODUCTION

Rolling is one of the oldest process for reducing the cross section of metal sheet, the other metal forming processes like forging, casting, extrusion and others. All these metal forming processes are parameters dependent and tool dependent. For example the forging will be punch and die based, the casting is based upon the mold and the rolling is based upon the rolls. Secondly the hot working and cold working of the metals are effecting the process of forming. In this research the various parameters which effects the rolling process are being included and analyzed. The research shows the findings of the past researchers in the field of cold rolling process and the future work about the rolling field. The rolling mill consist of rolls as the main tool, there are various rolling mills depends upon the number of rolls used in the machine. According to the number of rolls the rolling mill can be designed as 20 Hi, 12Hi, 8 Hi, 6 Hi, 4 Hi and 2 Hi rolling mills. In India now a days mostly 20 Hi and 4 Hi rolling mills are installed in big steel production units. Bhushan Steel Gaziabad is having 6 Hi Rolling mill, Jindal Steel Hisar is having 20 Hi and 4 Hi rolling mills, whereas Ruchi Strips and alloys ltd and National steel is having 20 Hi and 4 Hi rolling mills, chiefly the mill is being decided along with the thickness of the strip, the thinner (2 to 3 microns) sheets can be produced by 20 Hi rolling mill whereas the more thick sheets can be produced by 4 Hi or 6 Hi rolling mill (4 to 10 microns).

The arrangement of the rolls in the rolling mill decides the speed and the maximum reduction in the rolling mill. The rolling mills which are having more number of rolls will give more reduction in the sheet. The complex arrangement in the rolling mill gives thinner sheets whereas the speed which is another important performance issue in the rolling mills is dependent upon the diameter and motor speed of the rolling mill. A brief comparison according to the number of rolls is given in Table No 1

Table No. 1 – Rolling Mill Arrangements

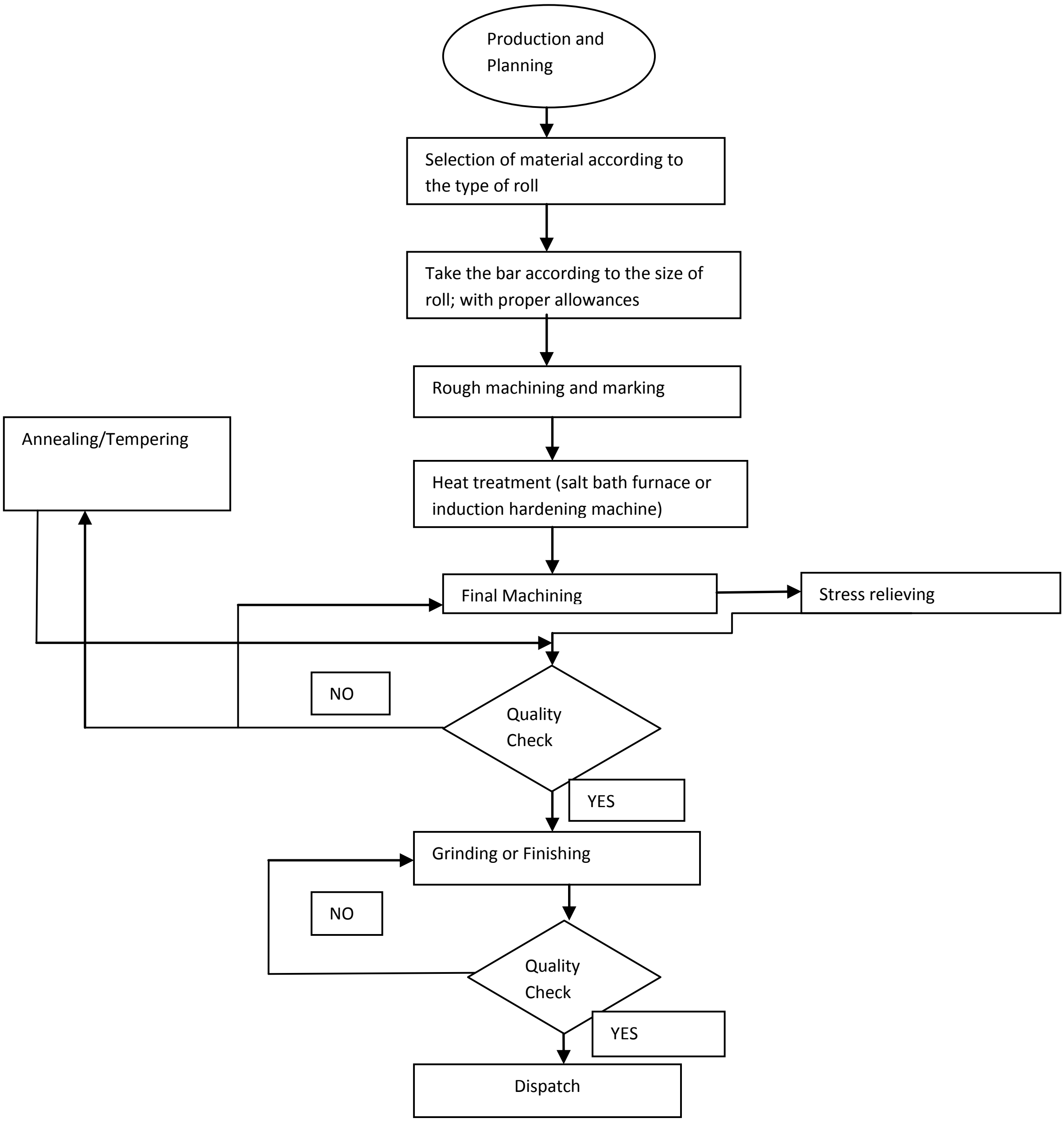
Sr. No.	Type of mill	No. of rolls	Type of rolls	Performance
1.	20 Hi	20	Work Rolls –2 ; First Intermediate Rolls – 4 ; Idler Rolls –2 ; Drive Rolls –4 ; Back Up Rolls –8	Able to produce thinner sheets with less speed.

2	12 Hi	12	Work rolls – 2; First Intermediate Rolls – 4; Back Up Rolls - 6;	Speed is higher than 20 Hi.
3	6 Hi	6	Work rolls – 2; Back up rolls – 4	High speed
4	4 Hi	4	Work rolls – 2, Backup rolls -2	Very high speed
5	3 Hi	3	Work rolls – 3	Moderate speed
6	2 Hi	2	Work rolls – 2	Less speed

The manufacturing of the Cold Rolling consist of various processes. The process parameters based upon Machining, Heat Treatment and Finishing. The correct machining process and parameters of heat treatment process results in a good quality roll. The Production sequence of roll manufacturing starts with the selection of the material. Usually ally steel are used for manufacturing of the rolls. The forged steel circular cross section bars are used. For work roll generally EN 31 Tool Steel is used for rolling of Mild Steel Sheet metal. The selection of material is based upon the rolling material. For rolling of aluminum sheet, copper sheet, stainless sheet or plain MS sheet the material of the roll will be different for different material. The EN 31 Bar is to cut on the machine according to the length then the rough machining is to be done where the excess material of the bar is removed and only 1 or .5 mm material is to be kept on the circular shaft compared with the final dimensions.

After Roughing operation the roll material is to be kept for hardening operation where the hardness of the tool is increased according to the required parameters. The work roll of 20 Hi rolling mill generally maintains 50 – 55 HRc up to 4-5 mm depth. This hardness is to be achieved by hardening operations. The furnace used for this purpose either is salt bath furnace or induction based furnace. The hardness is also based upon the quenching method. In cold rolling mill rolls the quenching method usually is cold water. The hardened roll after quenching passes through martensitic embrittlement. This causes the internal stresses and may be the hardness achieved could be higher than the required hardness, so the tempering is become essential for the hardened rolls. In tempering process the quenching media generally used is oil. A refined grain structure is obtained after tempering where excellent mechanical and physical properties achieved. Due to oxidation the outer surface of the roll appears bluish in color but when its machining on turning or milling center it appears shiny. After Heat treatment the next step is to for machining and this machining is called fine machining. This machining is prior to the final finishing. In this fine machining the profile or bearing seats are derived.

At final machining stage the roll must be tested by some non-destructive method to identify the cracks occurred due to machining. For surface die penetrant test or magnetic particle testing can be conducted and for internal the ultrasonic or x ray testing can be conducted. This tests helps us to decide whether the roll is having any internal residuals or not. If there is any internal cracks or surface cracks then only heat treatment like annealing or stress reliving can remove these cracks. Once these things completed the final finishing is to be done. The Cylindrical Grinding and Surface Grinding Machine are to be used. On Cylindrical surface which is called as main body of the roll is ground and required tolerances and roughness are met with the required specifications. A very less depth of cut gives better surface finish on the product. The profile called as camber which is in microns only can be given on the grinding machine. Here the machining done in the presence of coolant. The surface finish and the geometrical dimensions are to be measured by very accurate and precise measuring instruments. In final finishing the human sense is required to judge the quality of machining. The quality check at every stage is required to produce a roll which can be used in rolling mill.



Flow Chart 1- Production Sequence for Cold Rolling Mill Roll

II. REVIEW OF LITERATURE

In cold rolling process the main tool is roll and for rolling the desired properties of the roll are playing important role. Hardness, stiffness, load, machinability, rigidity should be in such a way that the tool (roll) should work safely and without unexpected breakage and deformations. It is necessary to know the load applied to the component and to understand the material properties. When a component fails it is a result of fatigue after crack initiation and crack propagation under alternating loads. The review of various journals and publications published in various journals are being considered and their findings are as follows:

Singh,Mondal [1] have published the importance of Non Destructive testing and they stated that it is almost impossible to detect and remove the cracks that are generated on the surface and sub- surface regions of the rolls. These cracks when present on the rolls, may lead to in – service or catastrophic failure. By the use of eddy current testing our ultrasonic testing the cracks can be detected and removed by machining if they are small in size and shape. In ultrasonic testing machine a pulsar/receiver type electronic device which produces high voltage pulses, the high energy ultrasonic energy produces by transducer, this energy takes the form of wave by means of sound energy. When there is any discontinuity in the path of the wave it reflected back, this signal transformed into the electric signal and displayed on the screen.

W. Soszyński, A. Studnicka [2] have published in their research paper about the behavior and mechanism of defect formation, Defects that are due to cold plastic deformation can be estimated by the deviation from their original geometric shape of the flat sheet. These deviations are dependent of the several factors, these factors are affecting the final shape and tolerances of the sheet metal the factors are: 1. available rolling equipment solutions, 2. the way of technological process realization, 3. applied tool (roll) solutions. The most important element involved in the manufacturing process and having an influence on the obtained dimensional tolerances is the roll. Regardless of the rolling mill equipment used and the scale of its complexity, the roll has a significant impact on the quality of the product. Its quality, design and features allow maintaining high dimensional tolerances. Roll and its features are a conglomerate of factors which give the greatest possibilities in the field of narrowing obtained dimensional deviations, and thus improve the quality of cold rolled products. It seems that control the roll deflection is the simplest and most effective way to improve the quality of cold rolled products

Jeng and Chiou [3] observed the surface pits, cracks and spalling marks on First Intermediate roll, the main causes of deformation are fatigue, contact stresses, metallurgical microstructure and chemical & physical characteristics of contact surface.

Shen et al [4] have shown the importance of rolling lubrication and coolant used in the process of Cold rolling. They have conducted their study on laboratory simulation and actual temper rolling process. The use of new rolling lubricant as rolling chemical RL1B and RL1C were shown enhanced results of rolling lubricity and cold rolled surface cleanliness by 20- 40%.

Mackel [5] published in his paper about the vibration and torque effect and their analysis in the rolls in cold rolling mill. In his research the tendency of vibration and torque is explained. Under very high speed rolling mill the tendency of vibration occurs and results in chatter marks on the strip. The vibration control system monitor the vibrations in the work roll and control the chatter marks on the sheet. The torque measuring and monitoring system helps in the predictive maintenance schedule for rolling mills which are running on very high speed with continuous operation condition under very rough conditions.

Seeligeret al [6] have published about the defects in sheet due to roll stand vibrations. The major defects which are considered as chatter marks, flatness and strip rupture. The main findings are related to the speed of rolling mill and according this the main causes for sheet defect are due to speed proportional indications are material damage by chatter, roll shape, balance error, roll bearing and drive irregularities. The causes of speed independent indications are as natural vibrations, front tension jerks, inhomogeneous material, slip, vibrations due to drive and free motion .In very high speed rolling mill the lubrication, type of lubricants, roll shapes, front and back tension are the parameters but due the shape and chatter problem in sheet which is common in high speed rolling mill the vibration are need to be analyzed and calculated. The author also suggested the mechanism and system for vibration control.

Saboonchi & Aghili [7] have discussed about the role of temperature in rolling mill and on rolls. The temperature is one of the important parameter which is being constituted by various researchers for analyzing the performance of the roll. The study conducted on the headers having series of nozzles, which are responsible for the cooling and expansion of the work rolls.

Anand S. Nilewar, et al [8] have discussed in their review article about the study of lubrication and its effect on steel in cold rolling mill .Lubrication plays an integral role in the production and it is considered one of the important parameter by various researchers for analyzing the performance of the roll. They initiate by discussing the effect of cold rolling oil properties. They further emphasize on the improvement of rolled sheet quality due to lubrication. In this section they review around 11 articles and put in their analysis. They further suggest improvements in rolling productivity due to lubrication. They also showcase their concern for environment by highlighting the effect of rolling oils on the environment.

CAO Jian-guo, et al [9] they discuss the hydraulic roll-bending device, which is widely used in modern cold rolling mills to regulate the strip flatness. The loaded roll gap crown mathematic model and the strip crown mathematic model of the reversing cold rolling process are established, and the deformation model of roll stack system of the 6-high 1 250 mm high crown (HC) reversing cold rolling mills built by slit beam method. The simulation results show that, the quadratic component of strip crown decreases nearly linearly with the increase of the work roll bending force, when the shifting value of intermediate roll is determined by the rolling process. From the first pass to the fifth pass of reversing rolling process, the crown controllability of bending force is gradually weakened. Base on analyzing the relationship among the main factors associated with roll-bending force in reversing multi-pass rolling, such as strip width and rolling force, a preset mathematic model of bending force is developed by genetic algorithm. The simulation data demonstrate that the relative deviation of flatness criterions in each rolling pass is improved significantly and the mean relative deviation of all five passes is decreased from 25.1% to 1.7%. The model can keep good shape in multi-pass reversing cold rolling process with the high prediction accuracy and can be used to guide the production process.

Katsumi et al [10] this paper described rolling mills for aluminum and copper, among other non-ferrous metal materials. The development of society and the diversification of industry are driving the continued increase in the demand for non-ferrous metal materials such as aluminum and copper. Quality requirements for the products are also rising. IHIMT has developed an automatic strip shape control system and automatic set-up system in our push to increase the value added to rolling equipment for non-ferrous metal materials. Our company intends to continue its contribution to the development of the non-ferrous metal rolling industries by mobilizing its advanced technology and rich experience.

Atkins [11] this paper summarizes the effects of roll flattening and to the inlet zone of pressure build up in the determination of lubricant film thickness in cold rolling. It shows that under present day practical conditions, the thickness of the lubricant films relative to surface roughness are insufficient to maintain full fluid film lubrication. Although the mathematical model predicts a “speed effect” for rolling, the speeds involved are much faster than present commercial rates. Thus speed effects in the literature must have been caused by a change over from boundary to mixed lubrication and lubricant puddle entrapment in surface micro crevices. The non-dimensional form of the solutions shows that laboratory experiments rarely approach full-scale mill conditions, thus reflecting the notoriously difficult problem of evaluating commercial metal-working lubricants.

Schindler et al [12] the impact of various cold deformation size in combination with several modes of heat treatment on mechanical properties of the QStE 420 steel strips was ascertained. The new experimental equipment of the Institute of modelling and Control of Forming Processes at VŠB – Technical University of Ostrava in the sphere of cold rolling was exploited, i.e. laboratory rolling mill Q110 as well as vacuum annealing furnace CLASIC 1812 VAK . By the described combinations of cold deformation and recrystallization annealing it is possible to homogenize microstructure of the hot rolled strip and gain a major share of ferritic grains, but an average size of resulting grains is not smaller in comparison with that one after hot rolling. It was confirmed that by a suitable set of size of previous cold reduction and parameters of the following heat treatment it is possible to influence a complex of mechanical properties of individual strips. Trends of the particular obtained curves in all graphs reflect the well-known relation between strength and plastic properties. Formability of the studied HSLA steel rises and vice versa strength properties fall with an increasing temperature of recrystallization annealing. Demands of the client on resulting mechanical properties of the HSLA steel strip can vary a lot. With regard to this fact it is of course not possible to establish a general-purpose optimal annealing mode. The experimentally obtained particular trends of strength and plastic properties may be utilized for optimization of conditions of heat treatment of the investigated HLSA steel QStE 420 in a cold rolling mill, reflecting the specific requirements for a relation between strength and plastic properties of the given steel strips. The experiment should be supplemented by additional TEM analyses explaining the behavior and role of precipitates during recrystallization annealing.

Limei Jing [13] has reviewed some previously published experimental and theoretical studies of hot rolling. A thorough understanding of the available roll design methods; and conditions of their application is extremely important in order to achieve the objective of producing high quality rolled products. Successful hot roll design is dominated by the calculations of some important parameters, which describe two-dimensional (2D) or three-dimensional (3D) deformation in the work piece. These parameters, such as roll separation force, torque, elongation, spread and draft, are discussed in detail. The method or formula for the calculation of each parameter is different for each set of different application conditions. A thorough study of these methods in different application cases will lead to the optimized design of hot rolled products .Finite Element (FE) is an important method which has been employed in the study of hot rolling. Design theory, commercial software and application cases have been described. 2-D and 3-D Finite Element Methods (FEM) for hot rolling simulation have also been discussed within the work. The current techniques and the problems of using the Finite Element system in hot roll design have been presented briefly. Possible solutions to these problems have also been discussed and there need to be considered in order to successfully apply Finite Element theory in hot roll design. An important alternative approach for hot roll design has been introduced in this thesis. A Matrix-based roll design system has been developed. It includes a Matrix-based system for flat and section roll designs. The realization of the Matrix-based system is discussed. All the methods and formulae considered previously can be integrated in the proposed roll design system. The approach emphasizes the need for teamwork. The design procedure allows both less experienced designers and senior designers to benefit from participation. It is suggested that high quality rolled products could be achieved from optimized designs produced using this systematized the approach compared to the ad-hoc use of existing techniques, formulae and methods.

Jiang [14] in his paper has developed successfully a new model for rolling mechanics of thin strip in cold rolling when the work rolls edge contacts. A strip plastic deformation-based model of the rolling force was employed in the calculation, and a modified semi-infinite body model was introduced to calculate the flattening between the work roll and backup roll, and the flattening between the work roll and strip, as well as a Foppl model was employed to calculate the edge contact between the upper and down work rolls. Based on the theory of the slit beam, the special rolling and strip deformation was simulated using a modified influence function method. The calculated results show that the specific forces such as the rolling force, intermediate force and the shape and profile of the strip for this special rolling process are significantly different from the forces in the traditional cold rolling process, and those form a new theory of metal plasticity in metal rolling. The edge contact of the work rolls can improve the strip shape when no work roll bending force is applied. With an increase of reduction, the rolling force, intermediate force and edge contact force increase significantly, however the strip shape becomes poor. Strip width has a significant influence on the edge contact force and edge contact length of the work rolls, which can result in an unstable work roll edge wear. When the friction coefficient increases, the edge contact force between the two work rolls increases, this can improve the strip profile. The transverse friction has a significant effect on the rolling force, edge contact force and the length of edge contact. It affects the strip shape and profile significantly, which is helpful in improving the strip shape and profile by modifying transverse friction. The calculated rolling force increases when the strip width increases and the rolling speed decreases, and it is in good agreement with the measured value. At lower rolling speeds, the work roll edge contact force becomes higher as a percentage of the total rolling force.

Hanoglu[15] has in his paper described the mathematical and physical modeling of flat rolling process. Here he gives us a detailed account of Flat rolling process 1.Plasticity of material during rolling and compression 2. Roll deformation 3. Roll separating force, roll pressure, shear stress, and friction 4. Friction factor and coefficient of friction 5.Schey's model, sim's model, Orowan model and refinements to Orowan model 6.Temperature gain and loss during rolling 7.Static, dynamic and meta dynamic recrystallization 8.Roll torque and power calculations 9. Influence of physical quantities on rolling 10.Temper, accumulative roll bonding, and flexible rolling 11.Comparison of some calculations 12.Base of computational simulation to be done

Malvezzi et al [16] has in his article proposed procedure that includes a mathematical model for lubricant flow based on Reynolds equation and a mathematical model for plastic deformation process based on Orowan approach. In this way was determined a free boundary problem with a choice of boundary conditions proposed by authors in a precedent paper .The improvement in this paper consists the authors have studied the introduction of the plastic deformation more advanced than slab analysis. The results gave better approximations. Other improvements can be obtained by introducing the deformation of the rolls or the pressure and thermal effect on the lubricant.

Durovsky et al [17] the mathematical relation between friction force on single stand rolling mill derived by using genetic algorithm. The Bland ford method used for tandem rolling mill. The main objective of the research paper is to use the results obtained by the model to superimpose the thickness, flatness, speed and tension with the value of flatness for different hardness materials.

Jian et al [18] has given finite element analysis for strip rolling mill. The main findings of the research paper related to the spalling (metal loss in rolls) of Back up roll in the rolling mill. As the hot rolling mill process works above the recrystallization temperature and the cold rolling mill process is below the recrystallization temperature. The temperature plays a vital role in the rolling process. The Finite element analysis used 3D ANSYS software for full analysis of Back up roll. Stress distribution on the contact of work roll and back up roll could be estimated by strip width, rolling force and thermal stresses can be analyzed. The results shows that when the strip width and rolling force per width changing the peak of the surface contact between work roll and back up roll is dissymmetry then the changing stresses will be maximum and above certain level it tends to the roll deformation.

Wendt et al [19] have discussed about the sticking problem after annealing process in cold rolled steel. The coil of cold rolled steel when uncoiled after annealing face sticking. The sticking is termed as welding and the cause may be diffusion or sintering or other adhesion mechanism. Basically in sticking the role of roll and their attributes are having no significance but as the heat increases due to hard material and high speed rolling mills. The types of stickers are Ridge Stickers – Due to strip profile which can cause high radial pressure inside the coil. Spot Stickers – These are localized spots caused by the high pressure and undesired foreign particles. Edge Stickers – These are on the edge of the coil, due to damage of the coil at the edges these stickers are formed, the sheet thickness is important because more thinner sheet will be having more edge stickers if the coil is damaged by external means. General Stickers – These are the irregular lines at the centre of the strip. Due to the crowning in the roll the roll pressure is centralized on the strip and due to this high pressure the general sticker marks occurs on the centre. Before annealing the factors which are affecting the sticking are Steel grade, hot strip profile, Coiling tension, Strip roughness, Strip Cleanliness, Strip dimensions, Coil dimensions. The factors affecting the sticking during annealing are Cooling rate, heating up gradient, Coil position. The factors affecting the sticking after annealing are Uncoiling speed, Uncoiling tension and Uncoiling geometry.

David [20] has given the analysis of thermogravimetry used to evaluate the burn off residue and decomposition of rolling oil system. A Dupont 9900 thermal analysis system used to conduct the experiment at a heating rate of 20 ^{o}C /min from ambient to 780^{o}C under a N2 atmosphere at a pure rate of 70 cm^{3}/min. The oil sample is mixed with carbonyl iron powder by 1 percent to interact with the oil. The TG technique used to find out the residual stresses in the rolling after annealing.

III. CONCLUSION

The main reasons for the deformation in the roll according to the past researchers identified from the manufacturing of the roll to the using the in the rolling mill. The following reasons are responsible for a roll deformation:

1. Thermal breakages:

Three factors are important for thermal breakage:

- Thermal gradient
- Strength
- Residual stress

2. Torsional Breakage of driven roll neck
3. Fire Cracks
4. Local Overload
5. Fatigue
6. Spalling
7. Damage of steel roll due to hydrogen
8. Wear and Friction of rolls
9. Bite angle and coefficient of rolls
10. Design parameters

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