CRITICAL REVIEW ON DESIGN OF ROLLING PROCESS

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ABSTRACT

Rolling is one of the important forming processes used in steel industry. During rolling process because of overdraft, poor die design and defects in the rolling die material, breakage of rolls takes place, leading to shutdown of rolling mill. There is a need for proper deign of rolling dies based on work piece material. In the present paper an attempt is made to summarize the various works reported by earlier researchers on certain specific areas of rolling like Finite Element Analysis (FEA), die and rolling material and summarize the results , so that the gaps can be identified, which in turn helps the researchers to carry their research in rolling.

KEYWORDS: *Rolling, Die Design, FEA*

1.0 INTRODUCTION

Rolling is a metal forming process in which metal stock is passed through one or more pairs of rolls to reduce the thickness and to make the thickness uniform. Rolling is the most widely used forming process, which provides high production and close control of final product. Higher reduction is possible in hot rolling when compared to cold rolling, however good surface finish can be achieved in cold rolling when compared to hot rolling (Alejandro Rivera Muñiz 2007), (Shahani et al 2008), (Befekadu Zewdie T Mariam 2015), (Jordan Keith Ogak, 2013), (Bauer et al ,2016).

Rolling finds application in manufacturing engineering and military equipment, ships, bicycles, pipes, railway cars, bridges, boiler containers, automobile industry, factory structures, construction industries, infrastructure projects, elevators, household utensils, electrical machinery. Practically all metals, which are not used in cast form, are reduced to some standard shapes for subsequent processing. Manufacturing companies producing metals supply metals in form of ingots which are obtained by casting liquid metal into a square cross section such as Slab (500-1800 mm wide and 50-300 mm thick),Billets (40 to 150 sq.mm) and Blooms (150 to 400 sq.mm). These shapes are further processed through hot rolling, forging or extrusion, to produce materials in standard form such as plates, sheets, rods, tubes and structural sections.

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The material to be rolled is drawn by means of friction into the two revolving roll gap. The compressive forces applied by the rolls reduce the thickness of the material or changes its cross sectional area. The geometry of the product depends on the contour of the roll gap. Roll materials are cast iron, cast steel and forged steel because of high strength, wear resistance requirements. In rolling the crystals get elongated in the rolling direction. In cold rolling crystal more or less retain the elongated shape but in hot rolling they start reforming after coming out from the deformation zone (Figure.2). The peripheral velocity of rolls at entry exceeds that of the strip, which is dragged in if the interface friction is high enough (Figure.1).In the deformation zone the thickness of the strip gets reduced and it elongates(Andre Lim, Sylvie Castagne, Chow Cher Wong 2016, Yellappa M, Satyamurthy N, Uday M, Giriswamy B G and Puneet U 2014, Mohd Abdul Qayum, V. Vasudeva Rao, Manzoor Hussain, G. M. Sayeed Ahmed ,2015). This increases the linear speed at the exit. Thus there exist neutral points where roll speed and strip speeds are equal. At this point the direction of the friction reverses. When the angle of contact α exceeds the friction angle λ the rolls cannot draw fresh strip Roll torque, power etc. increase with increase in roll work contact length or roll radius.

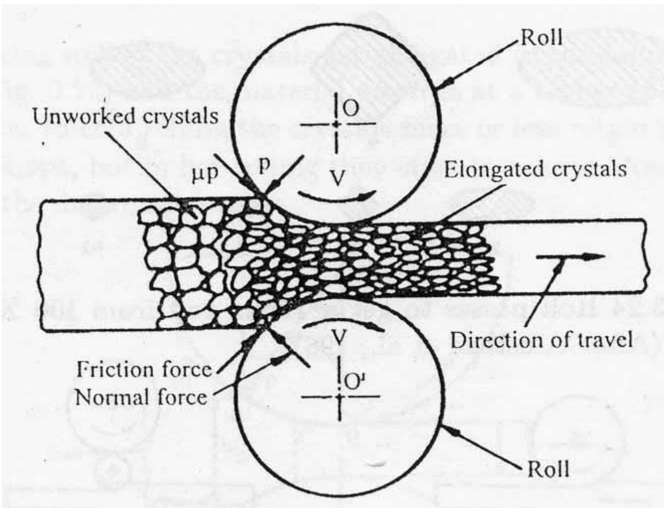

Figure 1. Deformation in rolling

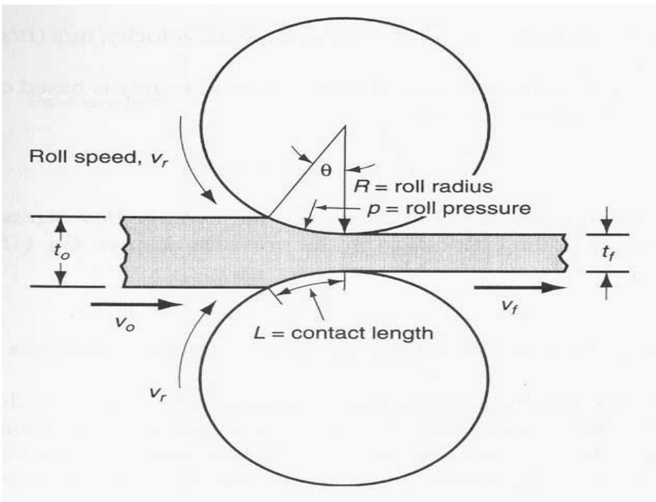

Figure 2. Rolling parameters

The objective of the paper is to present the works done by earlier researchers on certain specific areas like Finite Element Analysis (FEA), die and rolling material, identify the gaps, which helps the researchers to continue their research. A thorough review on rolling process in presented in section-2.

2.0 LITERATURE REVIEW

This section discusses about works reported by earlier researchers on certain specific areas of rolling like Finite Element Analysis (FEA), die and rolling material.

2.1 Literature review based on FEA analysis.

In this sub section works related to FEA are discussed. Bauer et al, (2016) discussed about the process of cold flat rolling is a widespread industrial technique to manufacture semi-finished products, e.g., for the automotive or home wares industry and calculated residual stresses with results of X-ray diffraction (XRD). He obtained a good agreement between the stress results of the FEA and the XRD was found in the center of the specimen. Andre Lim et al (2016), examined and studied the residual stress distributions caused by the deep cold rolling (DCR) process, with a focus on the distributions at the boundary of the treatment zone (Figure. 3). A three-dimensional finite-element (FE) model, validated with experimental residual stress data, is used to study the effect of the process. Other factors that cause a difference between the steady state and the transient zone of the burnished area are also investigated. It is shown that the net material movement causes larger plastic deformation in the boundary zone between the burnished and unburnished region of DCR.

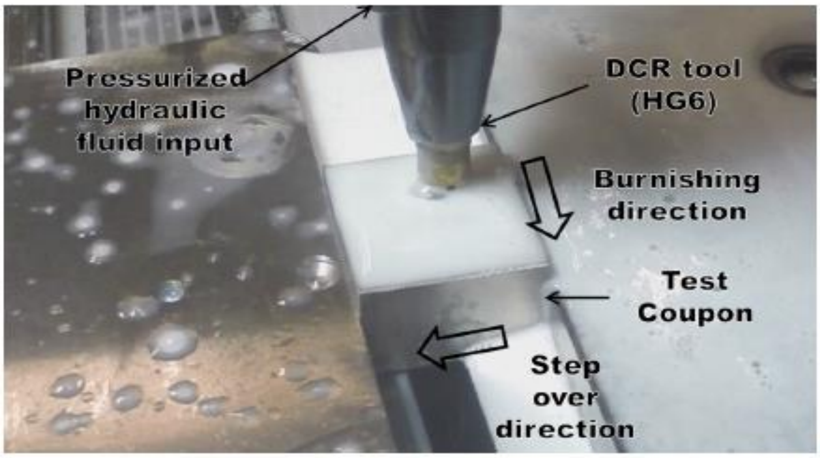

Figure 3. DCR Experimental set up

Kaixiang Peng, (2013) studied constant and reproducible production conditions of modern steel grades both in the hot strip mill and in the cooling section to achieve constant material properties along the entire strip length and from strip to strip. Finite element model is constructed for the temperature field in a rolling process. The temperature field of strip steel is modeled with a 3-D finite element analysis (FEA) structure, simultaneously considering the distribution of the work roll temperature. Tetsuo shinohara and kazunariyoshida (2015) carried out rolling and multi-pass drawing of a stainless steel wire with an artificial scratch and investigated the growth and disappearance of a scratch from both sides by experiments and Finite Element Analysis (FEA). When the scratch angle is small, the scratch side surfaces are pushed towards each other and the scratch becomes overlap defect. When the scratch angle is large, the bottom of the scratch rises and scratch is recovered. Alsamhan et al (2003) developed a FE models to simulate the cold roll forming CRF process, and to predict membrane strain distributions. The model was used to simulate CRF of a trapezoidal channel section, and the simulation results were compared to publish experiments. Two models were investigated in this paper. The first model involves closing the rolls over the undeformed stock to predict the initial deformed mesh, as a first stage, followed by rolling, as a second stage. The second model involved a rolling simulation with a pre-deformed mesh until the deformation was fully developed. Furthermore, to decrease the computation time and to continue the rolling simulation, a technique using dual meshes and re-meshing was applied to simulate roll-forming trapezoidal channel section. Chunlei et al (2000) developed generalized energy functional describing rigid–viscoplastic dynamic deformation is newly proposed. The Lagrangian multiplier method and the penalty method are introduced to enforce the incompressibility condition into the functional, respectively. The rigid–viscoplastic dynamic explicit finite element equation is established by employing the functional, where penalty method is used to remove the restraint of incompressibility. Then the rate-type explicit time integration formulation is given by the central difference method. (M.R. Forouzan,M. Salimi, M.S. Gadala, 2003) investigated the performance of the "Thermal Spokes Method" in modeling the effect of the guide rolls on the ring rolling process (Figure 4). Thermal spokes are introduced to withstand any unwanted moment of the resultant rolling forces at the roll gap and to maintain the ring in a centralized location in the mill. By employing the thermal spokes method, much closer predictions for the lateral spread and flow patterns are calculated. This method is able to predict the tilting of the ring with respect to the stiffness of the elements of the adjustment mechanism. It is also possible by this method to predict the point at which the ring changes its support from one guide roll to another one and to study the deformation mechanism outside the roll gap.

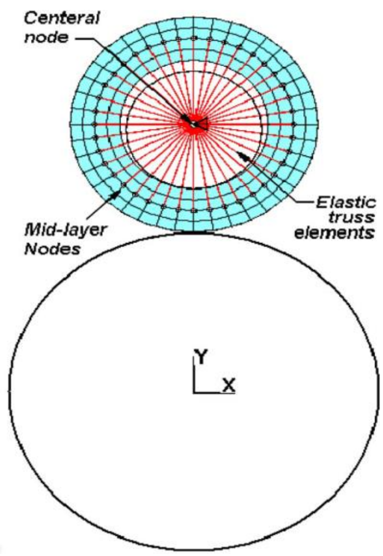

Figure 4. Thermal Spokes Method

Kumar et al (2013) analysed on reducing or minimizing the defects of rolling process. The analysis has been carried out for different temperature i.e. 100°C, 150°C, 200°C and 250°C. As the temperature goes on increasing correspondingly the residual stresses decreases. Hot rolling process helps in reduced residual stresses at high temperature & helps in formation of smooth granular structure of product. Due to the symmetry of the rolling components, half the model is built & the analysis is carried out with 4 roller sizes varying from 8mm to 20mm with 4mm increment & the results were tabulated by using ANSYS. This will helps in estimation of residual stresses. Nilam (2016) investigated reliable and efficient working of rolling mill it is necessary that all the components used in rolling mill should work properly without fail. Work roll assembly is very important part of the rolling mill. It has been observed that in hot rolling mill during the metal rolling at finishing mill (4-High mill Reversible) , work roll pair come out due to the axial crossing of work rolls and due to which uneven thickness of metal, strip breakage, bending of locking plate, metal shifting and equipment breakdown occurs. After the Study it has been observed that wear of the work roll liner is one of the reasons for the axial crossing of the work rolls. By modeling in Pro-E software and analysis in ANSYS13.0 (workbench) software it has observed that the wear is there in the liner.

Shaibu, (2012) investigated three dimensional heat equations and temperature fields of a roll using finite element method (FEM). For the estimation of thermal field on the work roll, mathematical modeling of moving heat sources approach is executed. The differences in the surface temperature of the roll during hot rolling process were illustrated. The effect of orientations of the water jets, heat transfer coefficient at roll surface and hot strip entry temperature also been deliberated by this model, and their effect on roll temperature has been analyzed. The change of angle of jet has shown that the effect of heat transfer coefficient is reduced. The computational dynamics of fluid flow with heat transfer variation and its characteristic are analytically modeled using the Finite volume Method (FVM). Wang et al (2015) analyzed some key technologies and gave out related solution schemes, in which the LS DYNA code and its mass scaling function is adopted to reduce the compute time, and a user-defined ANSYS Parametric Design Language program is developed to control the complex movements of the guide rolls and axial rolls. And this paper created the three-dimensional simulation models of a rear axle bevel gear blank, an aero-engine turbine casing blank and a great conical ring of the 600MW nuke reactor shell, and realized the entry virtual rolling process of these profile rings, respectively.

Nataliya Lyubenova and Dirk Baehre (2015) investigated the application of beneficial residual stresses in components is often used to increase their fatigue life and resistance to FOD (Foreign object damage). There are several production processes having the main aim to induce beneficial compressive residual stresses at the surface and on the sub-surface level in components. As examples can be mentioned the shot peening, auto frettage, laser shock peening, ultrasonic impact treatment and Deep rolling (DR) processes (Figure.5). The prediction and measurement of the induced residual stresses is always difficult and a time-consuming and therefore, the employment of the FEA (Finite element analysis) to model such processes can be very profitable. In this article the explicit module of the FE-Code ABAQUS 6.13 was applied to model the DR process on a plane geometry. The input parameters applied force, number of overturns and percentage of overlapping are varied and their influence on the resulted depth profile of residual stresses is commented on.

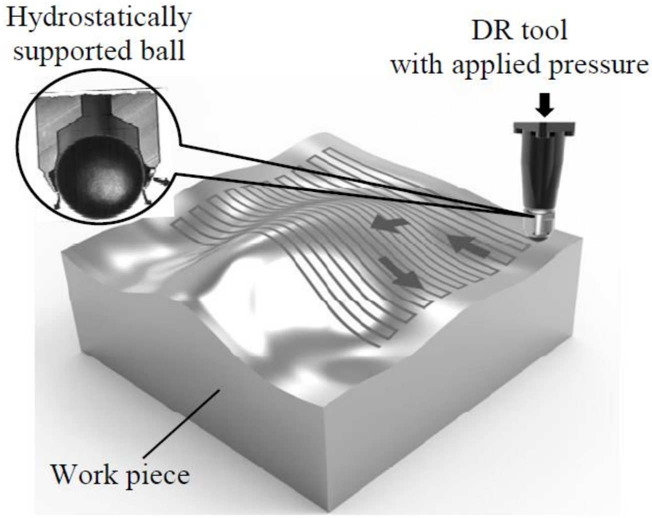

Figure 5. DR basic setup

Wen et al (2014) studied on Circle-to-square roll forming process of martensitic steel MS980. A 3D elastic-plastic roll forming finite element model was established with ABAQUS and the influence of material and process parameters was investigated. Four materials with different strengths include MS980, Fe360D, DP590, MS1500 were compared to study the effect of material strength. The result shows that as the material strength increase, the fillet radius of formed square tube decrease, corner thickness increase significantly, and the edge convexity is worse. Rolled compression amount distribution is an important parameter in roll forming process. Three distribution schemes were proposed, which were parabola distribution, decline distribution and equal distribution. The result shows that the equal distribution scheme can get good square shape and uniform force on each pass. Lanyun et al (2008) developed a method to control the guide rolls by the hydraulic adjustment mechanism is explored and realized in 3D-FE ring rolling model for the first time, and the key technologies, such as the parameter design of the linkage assembly and critical pressure of the hydraulic ram, are also proposed. Moreover, the difficulty in determining the liquid flow rate out of the hydraulic ram is solved by combining dichotomy with numerical simulation results. Based on the elastic–plastic dynamic finite element method under the ABAQUS software environment, the 3D-FE cold ring rolling model with hydraulic adjustment mechanism has been built, and the side spread of rectangular-section rings and the final section configuration of T-shaped ring have been analyzed. Good agreements between the calculating results and experimental ones prove the validity of the improved cold ring rolling model, and consequently the developed guide roll control method is also valid. Meanwhile, the circularity and oscillation of ring show that the rings are kept circular and stable very well during the process. Therefore the guide roll control method developed is suitable and reliable, particularly for rings complicated in shape or large in dimension or with high precision.

He et al (2006) determined the material properties of the ring blank have a significant effect on the quality of the deformed ring and the forming parameters. In this paper, the coupled influence laws of material properties parameters (hardening exponent n, yield stress σs and elastic modulus E) and forming parameters (rotational speed n1 of driver roll and feed rate v of idle roll) on the average spread, fishtail coefficient, degree of inhomogeneous deformation, roll force and roll moment have been investigated by using 3D-FE numerical simulation based on elastic–plastic dynamic explicit FEM under ABAQUS environment. The achievements of this study provide an important guide for selecting the material of the ring blank and determining the forming parameters according to the material properties of ring blank, and are very significant for the optimum design and precision control of the cold ring rolling process.

2.2 Literature review based on rolling material

Abrao et al (2014) studied the influence of selected deep rolling parameters (rolling pressure and number of passes) on the surface integrity of fully annealed AISI 1060 high carbon steel. In addition to the mechanical properties, a comprehensive investigation on surface integrity is carried out. The findings indicate that despite the increase in surface hardness and ultimate tensile stress, deep rolling can negatively affect the yield strength. The amplitude and functional roughness parameters show a considerable reduction after deep rolling, however, increasing rolling pressure and number of passes leads to poorer surface finish. Finally, the tensile residual stress generated by turning shifts to compressive values after deep rolling and the micro hardness and microstructure analyses indicate that the depth of the layer affected by deep rolling depends on both the rolling pressure and number of passes.

Nalawade (2016) examined deformation behavior of a hot rolled micro-alloyed steel bar of grade 38MnVS6 using an FEM model during the initial passes in a blooming mill, as a function of three different pass schedules, roll groove depth, collar taper angle and corner radius. The simulations predicted the effective strain penetration, load, torque, fish tail billet end shapes, and metal flow behaviour at a chosen temperature, mill rpm and draft. The model predictions were validated for typical groove geometry and a typical pass schedule. Lower collar taper angle, lower corner radius and higher depth of groove in hot rolling enabled achievement of higher strain penetration, higher mill load and lower fish tail formation. The present study establishes the capability of the model to improve the internal quality of the rolled billet as measured by effective strain which was corroborated to the rolled bar macrostructure and microstructure. The model enables yield improvement by the choice of draft to minimize fish tail losses. The surface quality is improved by the ability to avoid fin formation that occurs at certain conditions of rolling. Thus, the groove geometry, roll pass schedule and rolling mill parameters and temperature can be optimised for best product quality and yield. Xu et al (1997) investigatied the ring rolling of hot steel is simulated by using a three-dimensional thermo-coupled rigid-visco plastic finite element method. A new term is added to the functional in the variational approach to consider the influence of the frictional torque of the mandrel bearing, and the coupled thermal-mechanical simulation is performed by the iteration between the rigid –visco plastic finite element analysis and the thermal finite element analysis.

Kenji et al (1999) presented a new structure design to prolong the tool life for hot metal working. The tool surface deteriorates quickly when attacked under continuous severe sliding conditions by hot metal at a temperature above 1473 K. Observations were made on guide shoes used in seamless tube rolling to reach the conclusion that enlargement of the size and change in the structure of chromium carbide prolong the tool life. This is contrary to the structure design of high-speed steel for which small carbide is recommended. The validity of the new tool was verified both in laboratory tests and in the production line. Plicht et al (2010) used liquid nitrogen as a cooling medium for the final pass in the cold rolling of metal strip can increase production rates dramatically, in some cases by up to 50%. The liquid nitrogen replaces conventional water-based cooling fluids in wet rolling, and it works with dry rolling too (Figure.6). In the case of steel strip, it eliminates product losses caused by rust spots and can increase the life of the working rolls.

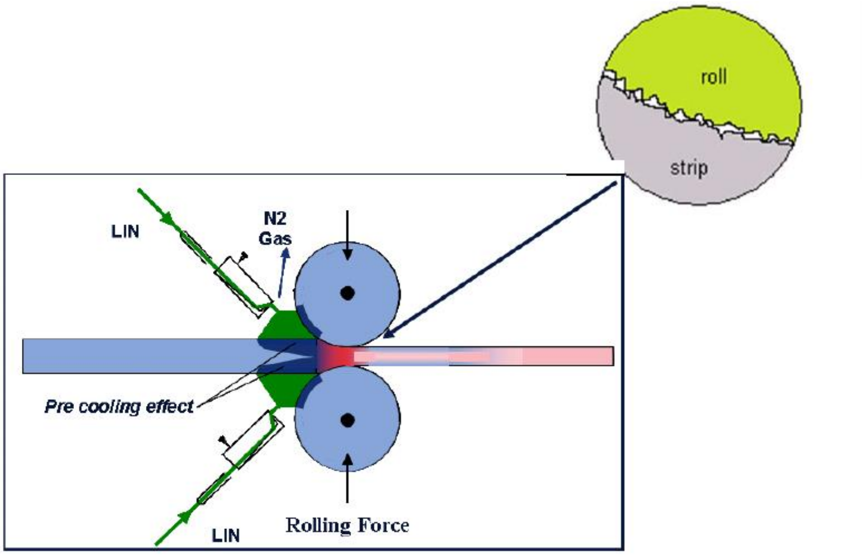

Figure 6. Liquid nitrogen sprays prevent oxidation during cold rolling through Pre cooling and keeping oxygen out of work area

Saral Dutta (2012) studied the metal forming process in which metal stock is passed through a pair of rolls. There are two types of rolling process - flat and profile rolling. In flat rolling the final shape of the product is either classed as sheet, also called "strip" (thickness less than 3 mm,) or plate (thickness more than 3 mm). In profile rolling, the final product is either a round rod or other cross sections shaped products such as structural sections (beam, channel, joist, rails, etc). The initial breakdown of ingots into blooms and billets is done by hot-rolling. The process involves plastically deforming a metal work piece by passing it between rolls. Rolling is the most widely used method of forming / shaping metals, which provides high production, higher productivity and close control of final product than other forming processes. This is particularly important in the manufacture of steel for use in construction and other industries. Vladimir et al (2012) investigated the causes of chatter by a literature review, the development and deployment of mathematical models, and a rigorous analysis of plant observations. The investigation suggests that the frictional conditions in the roll gap are the principal cause of chatter in this mill, though residual chatter marks on work rolls can occasionally cause it. The frictional conditions appear to be associated with the thickness and properties of oxide formed on rolls.

Sech et al (1990) evaluated the burn-off residue and decomposition profile of rolling oil raw materials and contaminants to the rolling oil system by Thermogravimetry (TG). The analytical method described in this report is able to simulate the interaction of the rolling oil with the steel surface, thereby offering insight into factors responsible for dirty burn-off during the annual stage of the cold rolling process. TG analysis of the rolling oil raw materials shows that the triglyceride component of a typical formulation is the major cause of high carbonaceous residue levels after anneal. Conversely, the hydrocarbon components evidence relatively clean burn-off. The TG technique also offers an explanation for the adverse effect of contaminants in the rolling oil system. Ganguly (2012) resolved the problems that are facing a large aluminum company in a) Developing Hot Rolling Mill Capabilities for Wider Widths Hard Alloys Rolling and b) Eliminate down time due to strip /coil slippage during hard alloys 5xxx rolling at Hot Mill. The challenge for the company was to cater the fast changing export demand for Flat Rolled products with its existing resources. By applying Six Sigma principles, the team identified the current situation that the rolling mills operations were in. Six Sigma DMAIC methodologies were used in the project to determine the project's CTQ characteristics, defining the possible causes, identifying the variation sources, establishing variable relationships and Implementing Control Plans. The project can be useful for any company that needs to find the most cost efficient way to improve and utilize its resources.

(V.Deepika Satya Bhanu and Dr P Mallesham, 2016) studied and analyzed different metals are been rolled by using two roller electrically powered rolling machine and its properties. The influence of rolling process parameters such as sheet thickness, sheet width, Elongation, Reduction in thickness on the Strip and shape and its profile have been investigated. (Dr.-Ing. J. Mackel , 2000) investigated 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 monitors 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.

(Zhao yang Gao, LinfaPeng, Peiyun Yi, Xinmin Lai,2013) analysed process design methods based on scale law cannot be directly used due to size effects. Its formability is greatly influenced by tool feature size and material grain size. In this study, a lab-scale R2P imprinting system was developed to fabricate the microstructures on the surface of metallic materials. The specimens of pure aluminum and pure copper with various size grains were prepared. Rigid die with geometric dimensions was fabricated and series of experiments were conducted. The micro feature height of the imprinted work piece was measured to evaluate the effects of tool feature dimensions (width, spacing, and fillet) and metal grain sizes. It is found that the groove width and fillet had more significant effect on the micro feature formation among the die cavity geometric parameters. Wider groove could enhance the micro forming ability and large fillet could improve the flowing ability. From the viewpoint of polycrystalline material, grain structures significantly affected the micro feature formation. When the grain size was smaller than the groove width, the material flowed more easily into the die cavity with increasing of the grain size because of the decrease of grain boundary strengthening effect. (Xiaoxin Ye, Zion T.H. Tse, Guoyi Tang, Xiaohui Lia, Guolin Song,2015) identified that the ductility of titanium materials is improved by electro pulse while remaining uniaxial tensile strength unchanged, with the increased volume fraction of fine recrystallized grains through electron back-scattered diffraction analysis. However, too high-frequency Electro pulsing treatment (EPT) brought in the coarsened grains and worsened mechanical properties (Figure 7). A mechanism for rapid recrystallization and grain growth in low temperature during EPT was proposed based on the reduction of nucleation thermodynamic barrier and enhancement of atomic diffusion and supposed that high-efficiency EPT could provide a highly efficient method for the intermediate-softening annealing of titanium sheet/strips within well-designed process.

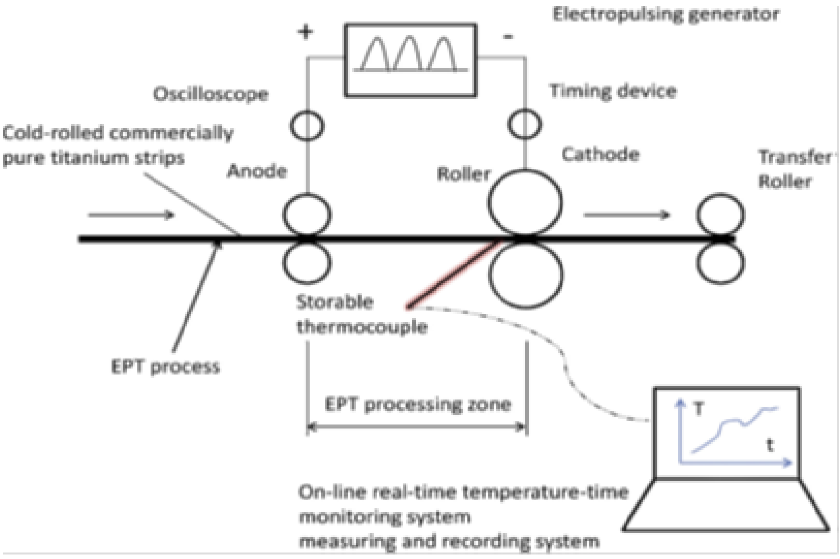

Figure. 7 Schematic diagrams of EPT process and relative on-line temperature Monitoring system

(Chow Cher Wong, Andry Hartawana, Wee Kin Teo, 2014) studied three cold rolling tool designs for feasibility on processing Titanium (Ti 6Al-4V) test coupons of different features. The effect of process variables (pressure, feed rate and overlap) on residual stress profiles were also investigated for one selected tool. Results showed that Deep cold rolling (DCR) is able to generate deep layer of compressive residual stress (up to 1mm depth) and process variables such as rolling pressure played a significant role in affecting the residual stress profiles. (Hongchum li , 2008) improved the evolution and tribological behavior of work roll surfaces for different grade materials of the roll and strip with different roughness and hardness in cold rolling because surface deterioration affects the quality of products and efficiency of production and an experimental Lateral Set-Testing (LST) mini-mill was developed to make use of Gleeble 3500 thermo-mechanical simulator functions to evaluate, the roll material surface features, surface roughness, fast Fourier transform (FFT) and Power Spectral

Density (PSD) of frequency distribution after single and multi-pass rolling. A low carbon steel war prepared for paired discs and experiments on disc-to-disc wear were carried out to test surface deterioration and friction. Surface defects of the work rolls including banding, stalling, marking, and welding in a cold strip plant, were investigated. It was found that early failures principally resulted from operational factors and roll material off-specification micro-structure defects rather than wear.

3.0 RESULTS AND DISCUSSIONS

Figure.8 represents the various works reported by researchers using FEA and analysis software's. It is understood that most of the works reported on FEA, in particular using ABAQUS software. Figure.9 represents the various works reported on rolling using different materials. It is understood that most of the works reported on steels. Figure.10 represents the various works reported by researchers based on research area. It is understood that most of the works reported on process parameter control. The data in Figures 8 to 10 are based on literature collected between years 2000 and 2016 from the limited database we are having. The data is only indicative.

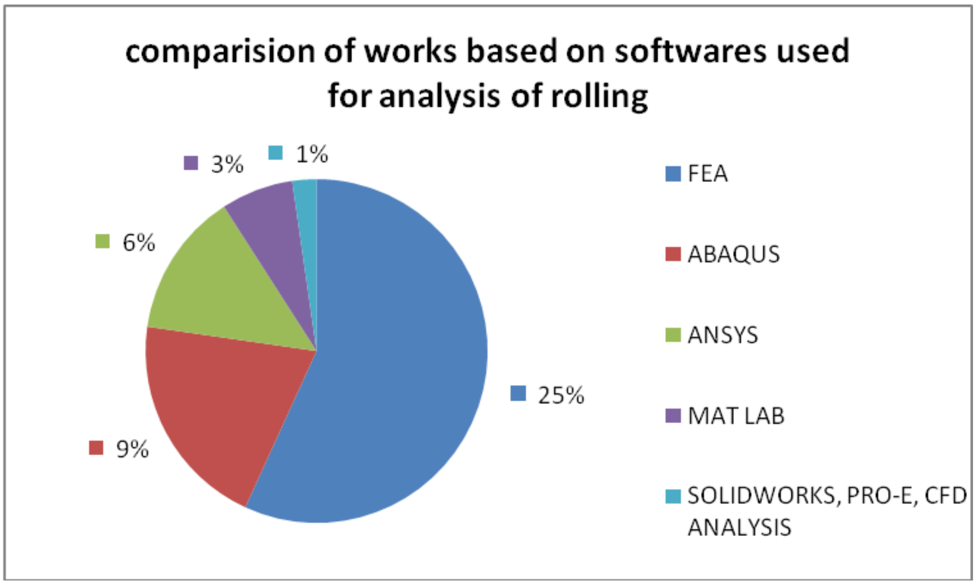

Figure. 8 Comparison of pie diagram on works based on software's used for analysis of rolling

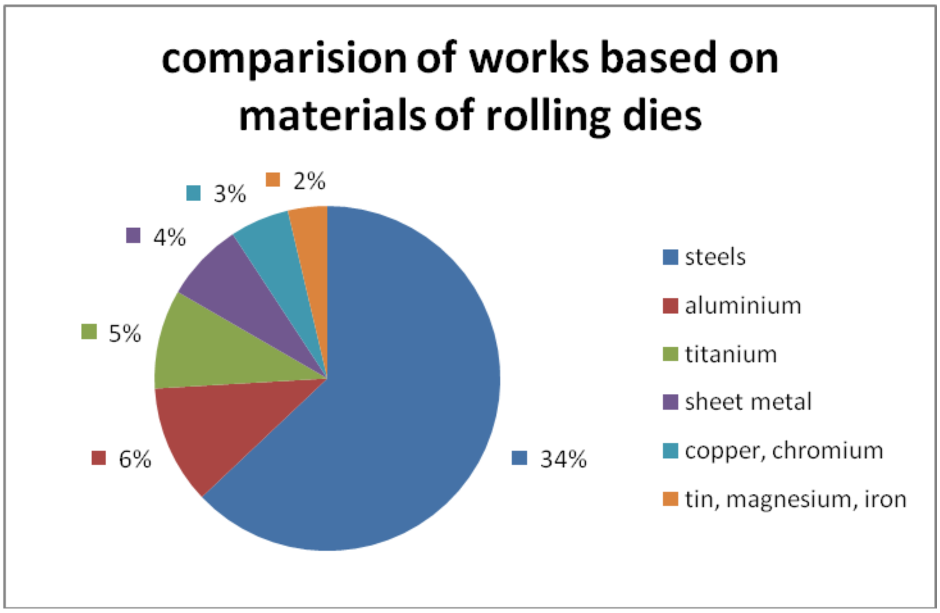

Figure.9 Comparison of pie diagram on works based on materials of rolling dies

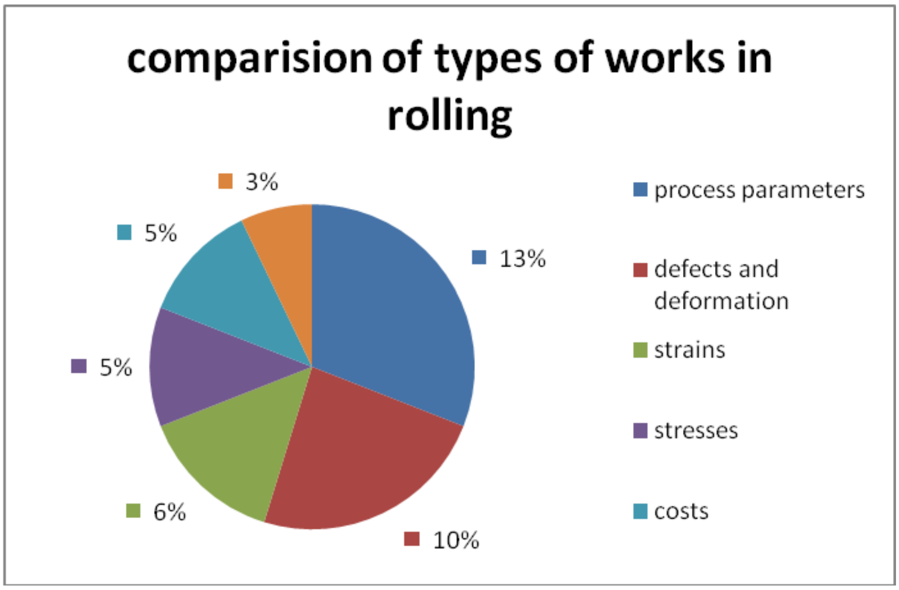

Figure. 10 Comparison of pie diagram based on types of works done in rolling

4.0 CONCLUSIONS

From the literature review it is understood most of the works reported on rolling process concentrated on FEA analysis using ABAQUS software, steel is considered as rolling material and the objective is to control the process parameters. Very few works are reported on material property evaluation after rolling, comparison of experimental values. Most of the researchers concentrated on Design of rolling Die's, however much focus is not done on metallurgical aspects. The researchers can focus on metallurgical aspects of roll and work piece material for better understanding of the failure of rolls.

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