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Analysis of the Rolling Process's Design

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Abstract

Rolling is a crucial shaping process in the steel industry. Overdraft and defective die design cause roll cracks and fractures during the rolling process, leading the rolling mill to shut down. Rolling dies must be properly manufactured depending on the material of the work item. This article explains the design techniques that many researchers use. Work on Finite Element Analysis (FEA) methodologies and material selection is evaluated and presented.

Keywords: *Finite Element Analysis, Rolling process, Die Design*

INTRODUCTION

Rolling is a metal shaping method in which metal stock is passed between one or more pairs of rolls to reduce thickness and homogeneity. Because it provides for great production and exact control of the completed product, rolling is the most often utilised shaping process. Although heat rolling produces greater reduction than cold rolling, cold rolling produces a superior surface polish than hot rolling. Engineering and military equipment, ships, bicycles, pipes, railway carriages, bridges, boiler containers, autos, manufacturing structures, construction industries, infrastructure projects, elevators, home items, and electrical apparatus are all manufactured using rolling. Almost all non-cast metals are converted to conventional forms for further processing. Metals are supplied by manufacturers in the form of ingots, which are formed by casting liquid metal into square cross sections, such as Slab (500-1800 mm broad and 50-300 mm thick), Billets (40 to 150 sq mm), and Blooms (150 to 400 sq mm). These shapes are subsequently hot rolled, forged, or extruded to produce

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standard materials including plates, sheets, rods, tubes, and structural sections. Friction draws the material to be rolled into the two spinning roll gaps. Roll compressive pressures reduce the material's thickness or change its cross sectional area. The geometry of the product is governed by the form of the roll gap. Roll materials include cast iron, cast steel, and forged steel because to the high strength and wear resistance requirements. Crystals lengthen in the rolling direction as a result of rolling. Cold rolling crystals retain their elongated structure, but hot rolling crystals begin to reassemble after departing the deformation zone (Fig. 2). If the interface friction is high enough, the peripheral velocity of the rolls at entrance exceeds that of the strip, which is pulled in (Fig. 1). The strip's thickness decreases as it elongates in the deformation zone. This improves the exit linear speed. As a result, there are neutral spots where the roll and strip speeds are equal. The direction of the friction reverses at this moment. When the angle of contact exceeds the friction angle, λ the rollers are unable to draw new strip. Roll torque, power, and so on rise as roll work contact length or roll radius increases.

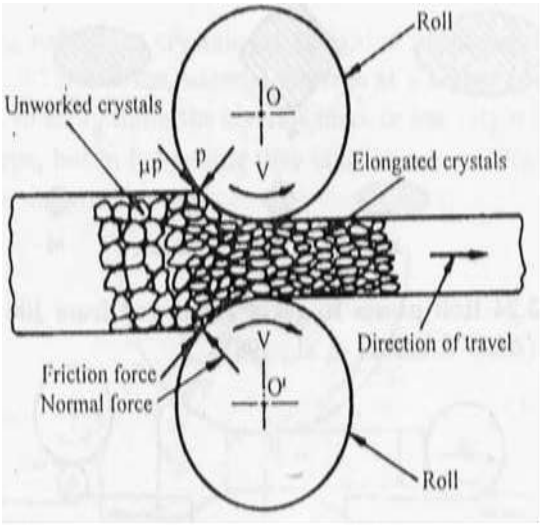

Figure 1: Deformation in Rolling

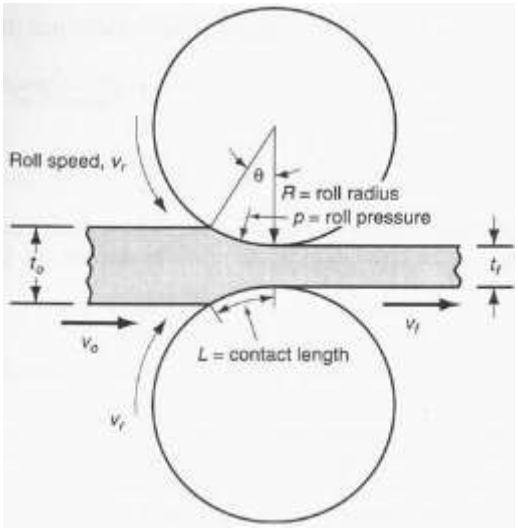

Figure 2: Rolling Parameters

The purpose of this article is to look at the work of numerous hot rolling researchers in order to discover the process elements that influence the surface quality of the rolled product.

LITERATURE REVIEW

The works reported by various researchers are presented below.

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Literature review based on FEA analysis.

Bauer A et al. addressed the process of cold flat rolling, which is a common industrial technique for manufacturing semi-finished items, such as for the automotive or home wares industries, and computed residual stresses using X-ray diffraction data (XRD). 1

He discovered a good agreement between the FEA stress findings and the XRD in the core of the specimen.

Lim A et al. investigated and analyzed the residual stress distributions induced by the deep cold rolling (DCR) method, with a particular focus on the distributions near the treatment zone's boundary (Fig. 3). 2 The influence of the process is studied using a three-dimensional finite-element (FE) model verified with experimental residual stress data.

Other elements that produce a difference between the burnished area's steady state and transient zone are also examined. It is demonstrated that net material flow generates greater plastic deformation in the boundary zone of DCR's burnished and unfurnished regions.

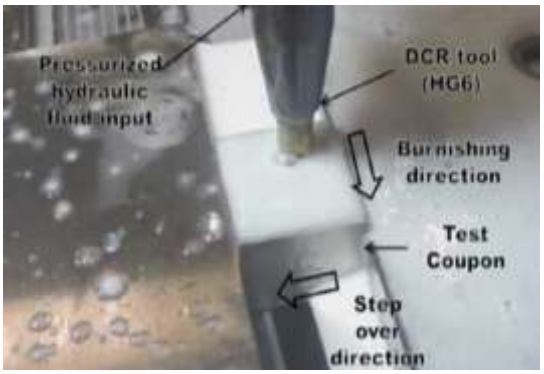

Figure 3: DCR Experimental Setup 2

Peng K investigated continuous and repeatable manufacturing conditions of current steel grades in both the hot strip mill and the cooling section in order to obtain consistent material qualities over the full strip length and from strip to strip.3 In a rolling process, a finite element model is built for the temperature field. The temperature field of strip steel is modelled using a 3-D finite element analysis (FEA) structure while the distribution of the work roll temperature is taken into account.

Shinohara T et al. explored the growth and disappearance of a scratch from both sides using tests and Finite Element Analysis on a stainless steel wire with an artificial scratch (FEA). 4 When the scratch angle is minimal, the scratch side surfaces are forced together, resulting in an overlap fault. When the scratch angle is high, the scratch bottom rises and the scratch is recovered.

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Alsamhan A et al. created FE models to simulate and predict membrane strain distributions during the CRF process. 5 The model was used to simulate the CRF of a trapezoidal channel segment, and the results of the simulation were compared to published experiments. In this article, two models were studied. As a first step, the first model involves closing the rolls over the undeformed stock to forecast the initial deformed mesh, followed by rolling as a second stage. The second model used a rolling simulation with a pre-deformed mesh to completely create the deformation. Furthermore, to save computing time and keep the rolling simulation going, a technique based on dual meshes and re-meshing was used to simulate a roll-forming trapezoidal channel segment.

Xie C et al. suggested a new generalised energy functional for modelling rigid-viscoplastic dynamic deformation. 6 To enforce the incompressibility constraint into the functional, the Lagrangian multiplier approach and the penalty method are introduced. The rigid-viscoplastic dynamic explicit finite element equation is created using the functional, where the penalty approach is utilised to eliminate the incompressibility constraint. The central difference approach then provides the rate-type explicit time integration formulation.

Forouzan MR et al. studied the "Thermal Spokes Method's" efficacy in predicting the influence of guide rolls on the ring rolling process (Fig. 4). 7 Thermal spokes are used to withstand any undesirable moment of the resulting rolling forces at the roll gap and to keep the ring centred in the mill. The thermal spokes technique yields substantially more accurate forecasts for lateral spread and flow patterns. This approach may forecast the tilting of the ring in relation to the stiffness of the adjustment mechanism's parts. This approach may also forecast the point at which the ring switches its support from one guiding roll to another and examine the deformation process beyond the roll gap.

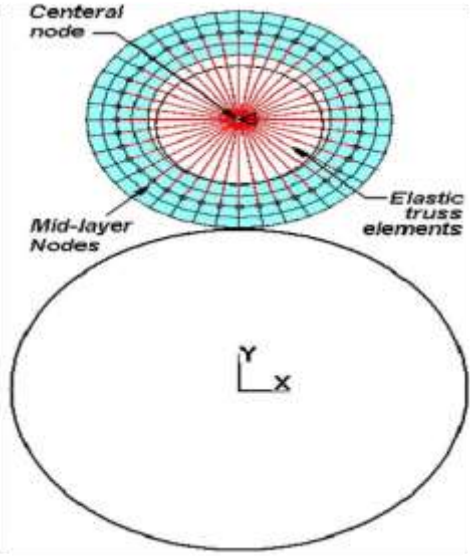

Figure 4: Thermal Spokes Method

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Kumar S, Kodli BS] investigated ways to reduce or minimize rolling process faults. 8 The analysis was performed at several temperatures, including 100°C, 150°C, 200°C, and 250°C. Residual tensions diminish as temperature rises. The hot rolling technique reduces residual strains at high temperatures and aids in the creation of a smooth granular structure in the result. Because of the symmetry of the rolling components, half of the model is produced, and the analysis is performed with four roller sizes ranging from 8mm to 20mm with 4mm increments, and the results are tabulated using ANSYS. This aids in the estimate of residual stresses.

Wankhade NK, Ikhar DR researched the dependable and efficient operation of a rolling mill. All of the components utilized in the rolling mill must function properly and without fail. 9 Work roll assembly is a critical component of the rolling mill. Work roll pair come out in hot rolling mill during metal rolling at finishing mill (4-High mill Reversible) owing to axial crossing of work rolls, resulting in uneven thickness of metal, strip breaking, bending of locking plate, metal shifting, and equipment failure. According to the findings of the study, one of the causes of axial crossing of the work rolls is wear of the work roll liner. The wear in the liner was discovered by modeling in Pro-E software and analysis in ANSYS13.0 (workbench) software.

Shaibu VB used the finite element method to explore three-dimensional heat equations and temperature fields of a roll (FEM). 10 The mathematical modeling of moving heat sources technique is used to estimate the thermal field on the work roll. The variations in the surface temperature of the roll during the hot rolling operation were depicted. This model included the influence of water jet orientations, heat transfer coefficient at the roll surface, and hot strip entry temperature, as well as their effect on roll temperature.

The effect of the heat transfer coefficient is lessened when the angle of the jet is changed. The Finite volume approach is used to study the computational dynamics of fluid flow with heat transfer fluctuation and its characteristics (FVM).

Wang ZW et al. investigated some key technologies and proposed related solutions, in which the LS DYNA code and its mass scaling function are used to reduce compute time, and a user-defined ANSYS parametric design language programme is developed to control the complex movements of the guide rolls and

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axial rolls11, and this article created three-dimensional simulation models of a rear axle bevel gear blank, an aero-engine turbine casing blank, and a great conica.

Lyubenova N, Baehre D examined the utilization of beneficial residual stresses in components, which is frequently employed to extend fatigue life and resistance to FOD. 12 Several manufacturing procedures exist with the primary goal of inducing advantageous compressive residual stresses at the surface and subsurface levels of components. As examples may be given the shot peening, auto frottage, laser shock penning, ultrasonic impact treatment and DR (Deep rolling) techniques. Because predicting and measuring generated residual stresses is usually complex and time-consuming, using FEA (Finite element analysis) to simulate such processes may be extremely advantageous. The explicit module of the FE-Code ABAQUS 6.13 was used in this research to represent the DR process on a flat geometry.

The input parameters applied force, number of overturns, and percentage of overlap are changed, and the impact on the resulting depth profile of residual stresses is discussed.

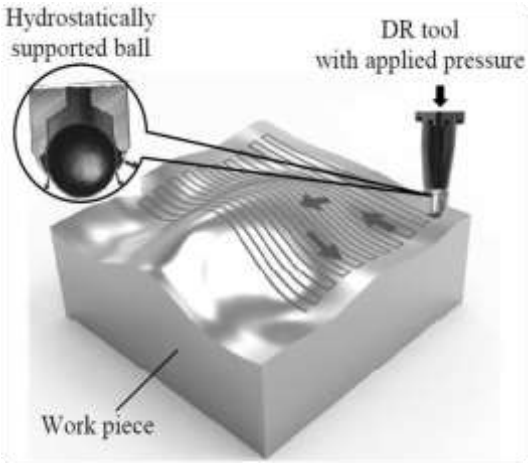

Figure 5: DR Basic Setup12

Kang W and colleagues investigated the circle-to-square roll forming method of martens tic steel MS980. With Abacus, a 3D elastic-plastic roll forming finite element model was created, and the impact of material and process factors was examined. 13 To investigate the influence of material strength, four materials with varying strengths were compared: MS980, Fe360D, DP590, and MS1500. As the material strength increases, the fillet radius of the produced square tube decreases, corner thickness increases dramatically, and edge convexity worsens. The distribution of rolled compression amount is a crucial component in the roll forming process. There were three distribution strategies proposed: parabola distribution, decline distribution, and equal distribution. The outcome demonstrates that the equal distribution strategy may achieve a decent

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square shape and uniform force on each pass.

Li L et al. studied and accomplished for the first time in 3D-FE ring rolling model a way to regulate the guide rolls by the hydraulic adjustment mechanism, and essential technologies such as the parameter design of the linkage assembly and critical pressure of the hydraulic ram are also provided. 14 Furthermore, by integrating dichotomy with numerical simulation data, the challenge in calculating the liquid flow rate out of the hydraulic ram is solved. The 3D-FE cold ring rolling model with hydraulic adjustment mechanism was created using the elastic-plastic dynamic finite element method in the ABAQUS software environment, and the side spread of rectangular-section rings and the final section configuration of T-shaped ring were examined. Good agreement between calculated and actual data demonstrates the viability of the revised cold ring-rolling model, and hence the suggested guide roll control mechanism. Meanwhile, the circularity and oscillation of the rings demonstrate that the rings are kept circular and stable throughout the operation. As a result, the proposed guide roll control system is appropriate and dependable, particularly for rings with difficult shapes, large dimensions, or high accuracy.

Yang H et al. discovered that the ring blank's material qualities had a substantial impact on the quality of the deformed ring and the forming parameters. 15 The coupled influence laws of material properties parameters (hardening exponent n, yield stress s, 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 were investigated in this article using 3D-FE numerical simulation based on elastic-plastic dynamic explicit FEM under ABAQUS. The findings of this study are highly essential for the optimal design and precise control of the cold ring rolling process because they give a vital guidance for selecting the material of the ring blank and calculating the forming parameters based on the material characteristics of the ring blank.

LITERATURE REVIEW

Based on Rolling Material

Abrão AM studied the influence of selected deep rolling parameters (rolling pressure and number of passes) on the surface integrity of fully annealed AISI

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1060 high carbon steel.16 In addition to mechanical qualities; a thorough analysis of surface integrity is conducted. The results show that, despite an increase in surface hardness and ultimate tensile stress, deep rolling can reduce yield strength. The amplitude and functional roughness parameters decrease significantly after deep rolling; nevertheless, increasing the rolling pressure and number of passes results in a worse surface quality. Finally, the tensile residual stress created by turning switches to compressive values after deep rolling, and micro hardness and microstructure investigations show that the depth of the layer impacted by deep rolling is affected by both rolling pressure and the number of passes.

Nalawade RS et al. investigated the deformation behaviour of a hot rolled micro-alloyed steel bar of grade 38MnVS6 as a function of three distinct pass schedules, roll groove depth, collar taper angle, and corner radius in a blooming mill using a FEM model. 17 At a given temperature, mill speed, and draught, the models projected effective strain penetration, load, torque, fish tail billet end geometries, and metal flow behaviour. For typical groove shape and a typical pass schedule, the model predictions were confirmed. Lower collar taper angle, corner radius, and groove depth in hot rolling permitted better strain penetration, higher mill load, and lower fish tail development. The current study demonstrates the model's capacity to increase the internal quality of the rolled billet as assessed by effective strain, which was supported by the rolled bar macrostructure and microstructure. The model allows for increased production by adjusting the draught to reduce fish tail losses. The capacity to avoid fin development, which happens under specific rolling situations, improves surface quality. As a result, the groove geometry, roll pass schedule, rolling mill settings, and temperature may all be optimised for the greatest product quality and yield.

Xu SG et al. examined hot steel ring rolling using a three-dimensional thermo-coupled rigid-visco plastic finite element approach. 18 In the variational approach, a new term is added to the functional to account for the influence of the mandrel bearing's frictional torque, and the coupled thermal-mechanical simulation is performed by iterating between the rigid-visco plastic finite element analysis and the thermal finite element analysis. Tsubouchi K et al. introduced a novel

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structural design for hot metal working tool life extension. 19 When attacked by hot metal at a temperature exceeding 1473 K under continuous severe sliding circumstances, the tool surface deteriorates fast. Observations on guide shoes used in seamless tube rolling led to the conclusion that increasing the size and changing the structure of chromium carbide extends tool life. This is in contrast to the high-speed steel structure design, which calls for tiny carbide. The new tool's validity was validated in both laboratory testing and on the manufacturing line.

Plicht G et al. discovered that using liquid nitrogen as a cooling medium for the final pass in cold rolling of metal strip may significantly enhance production rates, in certain circumstances by up to 50%. 20 In wet rolling, liquid nitrogen replaces traditional water-based cooling fluids, and it also works in dry rolling. It avoids product losses due by rust spots in the case of steel strip and can extend the life of the working rolls.

Dutta S investigated the metal forming method, which involves passing metal stock via a pair of rolls. Flat rolling and profile rolling are the two types of rolling processes. 21 The ultimate shape of the product in flat rolling is either sheet, often known as "strip" (thickness less than 3 mm,) or plate (thickness more than 3 mm). The ultimate product of profile rolling is either a round rod or various cross section shaped goods such as structural sections (beam, channel, joist, rails, etc). Hot-rolling is used to break down ingots into blooms and billets. By passing the metal work item between rolls, it is plastically deformed. Rolling is the most extensively used way of forming/shaping metals because it offers better output, more productivity, and greater control over the finished product than other forming processes. This is very significant in the production of steel for building and other sectors.

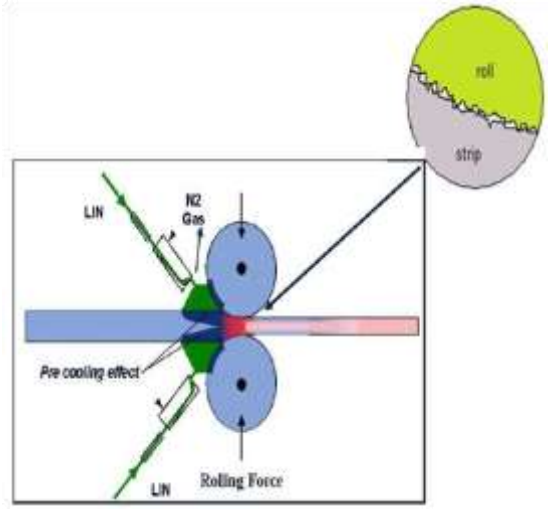

Figure 6: Liquid Nitrogen Sprays Prevent Oxidation during Cold Rolling through Pre-cooling and Keeping Oxygen out of Work Area

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Panjkovi' V used a literature study, the construction and deployment of mathematical models, and a systematic analysis of plant observations to examine the sources of chatter. 22 According to the analysis, the primary source of chatter in this mill is frictional conditions in the roll gap; however, residual chatter marks on work rolls might occasionally produce it. The thickness and characteristics of oxide generated on rollers appear to be related to frictional circumstances.

Michael Ker E used Thermogravimetry to assess the burn-off residue and decomposition profile of rolling oil raw materials and pollutants in the rolling oil system (TG). 23 The analytical approach presented in this study can mimic the interaction of rolling oil with the steel surface, providing insight into the causes that cause unclean burn-off during the yearly stage of the cold rolling process. According to TG analysis of rolling oil raw materials, the triglyceride component of a common formulation is the primary source of excessive carbonaceous residue levels after annealing. The hydrocarbon components, on the other hand, show reasonably clean burn-off. The TG approach also explains the negative influence of impurities in the rolling oil system.

Ganguly K addressed the challenges that a big aluminium firm was experiencing in a) developing hot rolling mill capabilities for wider widths hard alloys rolling and b) eliminating downtime due to strip /coil slippage during hard alloys 5xxx rolling at hot mill. 24 The company's task was to meet the rapidly changing international demand for Flat Rolled goods with its existing resources. Using Six Sigma techniques, the team identified the existing state of the rolling mill operations. Six Sigma DMAIC approaches were utilised in the project to assess the CTQ features, define potential causes, identify variation sources, develop variable linkages, and implement control plans. The project can be beneficial to any firm looking for the most cost-effective approach to enhance and utilise its resources.

Deepika Satya Bhanu V and Mallesham P investigated and examined the characteristics of various metals rolled using a two roller electrically powered rolling machine. 25 The effect of rolling process factors such as sheet thickness, sheet width, elongation, and thickness reduction on strip form and profile has been explored. Mackel IJ researched the vibration and torque effects, as well as their analysis, in cold rolling mill rollers. The inclination of vibration and torque is

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explained in his research. 26 Vibration occurs in very high speed rolling mills, resulting in chatter markings on the strip. The vibration control system monitors and controls the chatter marks on the sheet by monitoring vibrations in the work roll. The torque measurement and monitoring system aids in the predictive maintenance plan for rolling mills that operate at high speeds with continuous operation under harsh circumstances.

Due to size effects, the process design methodologies examined by Lai X et al. cannot be employed directly. 27 Its formability is largely impacted by the size of the tool feature and the grain size of the material. A lab-scale R2P imprinting method was created in this work to produce microstructures on the surface of metallic materials. Pure aluminium and pure copper specimens with varying grain sizes were created. A rigid die with geometric dimensions was created, and a number of experiments were carried out. The imprinted work piece's micro feature height was evaluated to assess the impacts of tool feature parameters (width, spacing, and fillet) and metal grain sizes. Among the die cavity geometric characteristics, the groove width and fillet had the greatest influence on micro feature creation. A wider groove might increase micro-forming ability, whereas a larger fillet could improve flowing ability. Grain structures have a substantial impact on the creation of micro features in polycrystalline materials. Because the grain boundary strengthening effect was reduced when the grain size was less than the groove width, the material flowed more freely into the die cavity as the grain size increased.

Through electron back-scattered diffraction examination, Ye X et al. discovered that electro pulse improves the ductility of titanium materials while leaving the uniaxial tensile strength unaltered, with an enhanced volume percentage of fine recrystallized grains. 28 However, too high-frequency EPT coarsened the grains and harmed the mechanical characteristics (Figure 5). Based on the reduction of the nucleation thermodynamic barrier and the enhancement of atomic diffusion, a mechanism for rapid recrystallization and grain growth in low temperature during EPT was proposed, and it was assumed that high-efficiency EPT could provide a highly efficient method for the intermediate-softening annealing of titanium sheet/strips within a well-designed process.

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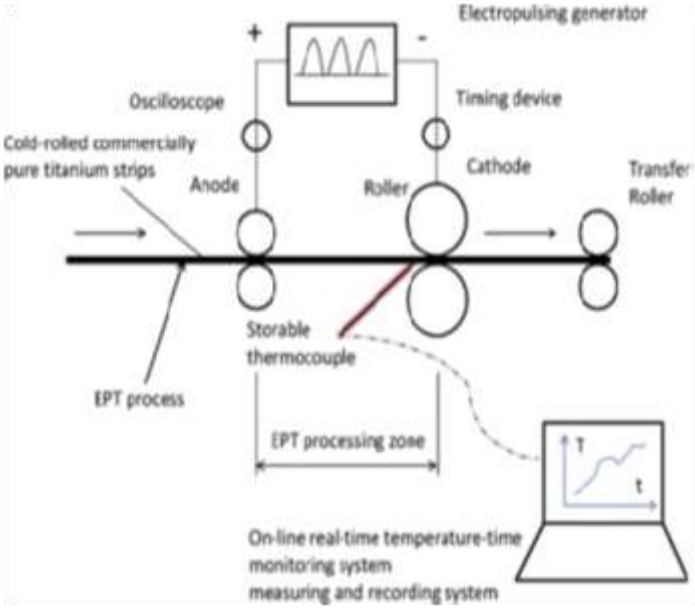

Figure 7: Schematic diagrams of EPT Process and Relative on-Line Temperature Monitoring System

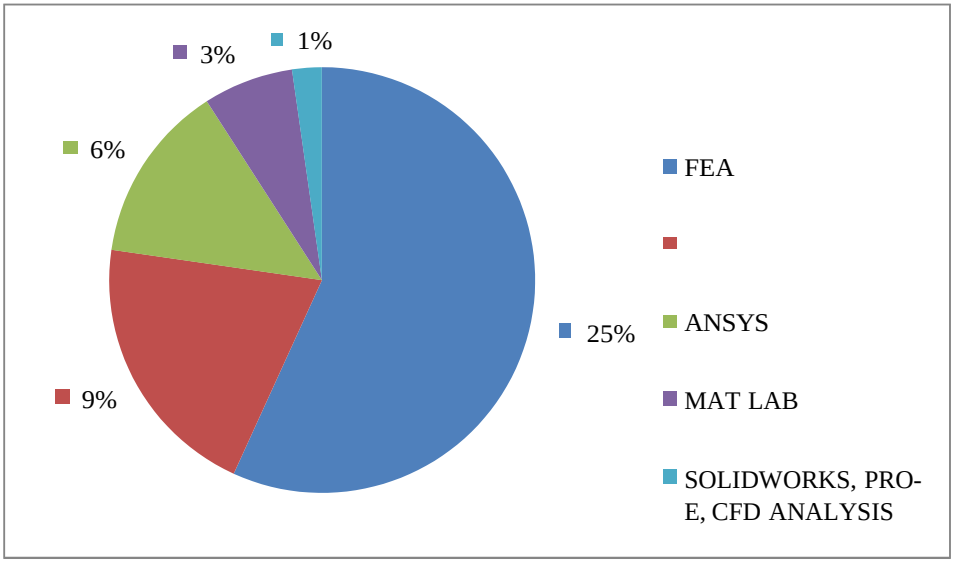

Figure 8: Comparison of Pie Diagram on works based on Software is used for Analysis of Rolling

Wong CC et al. investigated the feasibility of three cold rolling tool designs for processing Titanium (Ti 6Al-4V) test coupons with varying characteristics. 29 For one tool, the influence of process factors (pressure, feed rate, and overlap) on residual stress profiles was also examined. The results revealed that DCR

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may create a thick layer of compressive residual stress (up to 1mm depth) and that process factors like rolling pressure had a substantial impact on the residual stress profiles. Because surface degradation impacts product quality and production efficiency, Li H enhanced the evolution and tribological behavior of work roll surfaces for different grade materials of the roll and strip with varying roughness and hardness in cold rolling. The Lateral Set-Testing (LST) mini-mill was designed 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 using the Gleeble 3500 thermo-mechanical simulator functions. 30 To assess surface degradation and friction, a low carbon steel war was made for paired discs, and studies on disc-to-disc wear were performed. Surface problems of work rolls in a cold strip facility were studied, including banding, spelling, marking, and welding. Early failures were discovered to be the consequence of operational issues and roll material off-spec micro-structure flaws rather than wear. Figure 8 depicts the many papers published by researchers who used FEA and analytic tools. It is assumed that the majority of the works reported on FEA, specifically on Abacus software.

Figure 9 represents the various works reported on rolling using different materials. It is understood that most of the works reported on steels.

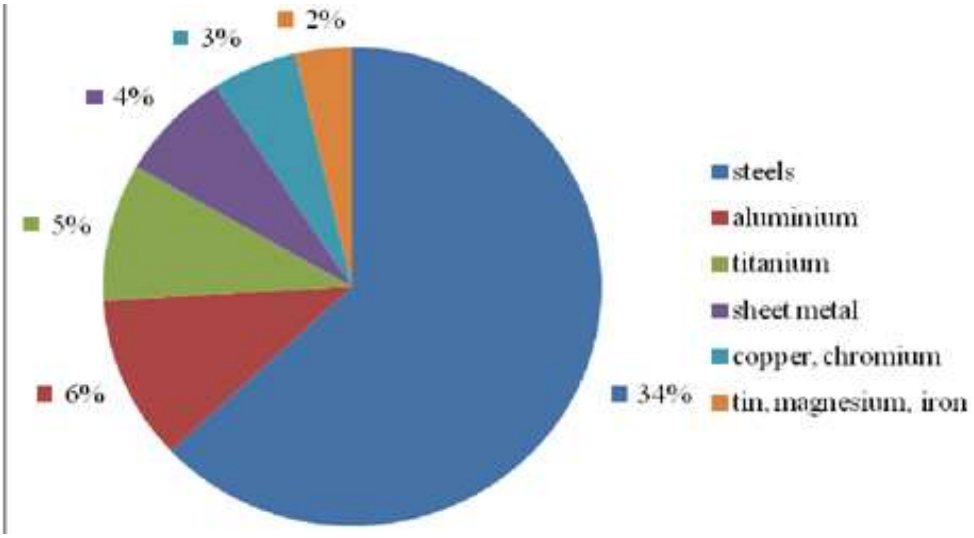

Figure 9: Comparison of Pie Diagram on Works based on Materials of Rolling Dies

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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.

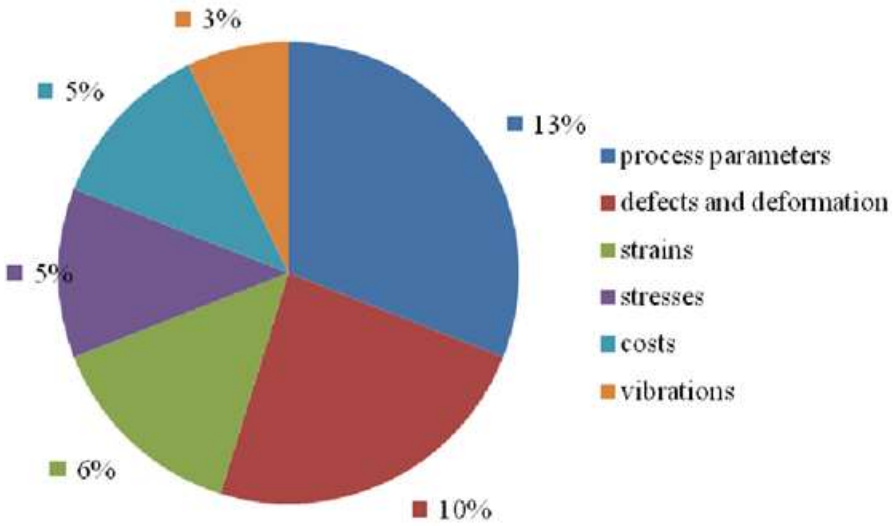

Figure 10: Comparison of Pie Diagram based on Types of Works done in Rolling

CONCLUSIONS

According to the literature, the bulk of the studies published on the rolling process focused on FEA analysis using ABAQUS software, with steel as the rolling material and the purpose of managing the process parameters. There have been very few research published on the evaluation of material characteristics after rolling and the comparison of experimental data. The majority of the researchers concentrated on rolling die design, with minimal emphasis on metallurgical considerations.

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