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Finite Element Analysis of Evolution of Defects During Rolling

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ABSTRACT

Plastic strain and residual stresses are the two parameters influencing the life of the rolled products. Higher plastic strain is the source of crack formation and propagation and residual stress is the deciding factor for influencing the load carrying capacity. In the present works, three models of defect free, cracking and surface defects are considered to find the structural safety parameters like plastic strain, contact pressure, vonmises stress and load requirements. The finite element simulation shows uniform spread of contact in case of no defect. Also requirements are less as represented the report. In the defects components, plastic strain is high at the centre of crack as well as at the top of the crack. Contact pressure is abnormally varying with defect component. So using finite element analysis, one can fix the dimensions of the roller for maximum capacity of the defect. Also simulation helps in giving results at each stage of motion. A fine mesh is used in the region of stress concentration. Nonlinear geometrical and material conditions are considered for analysis. Through reaction development, the load required for the given process can be obtained. The implicit simulation carried out in the rolling process gives insight into stage by stage contact pressure, vonmises stress, and load requirements helps the designer to improve the product design. With the defects in the sheet metal, a load requirement of 33% can be observed through simulation which will increase the requirements of stronger rollers and higher inventory.

I INTRODUCTION

Rolling research over the past half century to improve the dimensional quality of rolled metal strip has focused primarily in two interrelated areas.The first general area has dealt with the problem of determining the requiredrolling force and rolling torque for a specified plastic strain in the thickness of the metalstrip. The problem of force and torque determination has been studied extensively sincethe 1940s . It is an elastic-plastic problem that involves the metal strip, the work rolls,and the interfacial lubricant, as depicted . Major early attempts at solving theplain strain problem were made by Von Karman, Orowan, and Jortner . Hitchcockrecognized the occurrence of elastic flattening of the work rolls and developed a widely used relationship to estimate the magnitude of a larger effective diameter .Due to the requirements for more practical, real-time calculation of rolling forceand torque with less sophisticated solutions, many theorists, including Trinks, Tselikov,Nadai, and Stone applied various simplifying assumptions to the original modeldeveloped by Von Karman in 1925 . For similar reasons, Orowan's more generalmodel of 1943 was simplified by Bland & Ford, Underwood, Sims, Ford & Alexander,among others . The simplifications and assumptions generally related to contactarc form, friction model, yielding criterion, and deformation type (homogeneous or nonhomogeneous).Hypothesizing that the flattened work roll may not remain circular in the arc ofcontact, and to improve the accuracy of rolling force models for thinner gauges, morerecent attempts to solve the plane strain problem were made, for example, by Fleck andJohnson who studied foil rolling. To overcome some of the simplifying assumptionsof previous investigators, Wilkund employed the plane-strain slab method and Gratacosused the elastic-plastic finite element method to determine required rolling force and torque.The second general area of focused rolling research has been to study the problem of the non-uniform deflection of the rolling stand and components (housing, rolls, and strip). This involves the phenomenon that leads to non-uniformities in the strip thickness reduction (with respect to the direction transverse to rolling) and is thus the cause of the strip thickness profile and flatness characteristics introduced.

Dr. YU Hai-liang et al [1]: In this paper, the research reports on the appearance and the propagation of cracks in rolled steel during rolling were investigated. Considerable investigations have been carried out on applying FEM for simulation of the propagation and closure of cracks in materials during rolling. A self-healing shape memory alloy (SMA) composite was simulated via a finite element approach that allows crack to propagate in a brittle matrix material. The SMA wires were carefully modeled using a one-dimensional SMA constitutive model and implemented into user-defined truss elements. Loading of the composite allowed a crack to propagate from an initiation site and the wires bridge the crack as detwinned martensite forms with the applied loading

Hyuck-Cheol Kwo et al [2]: In this paper, the defect formation was investigated in terms of the location and type. The temperature variations were determined experimentally and numerically to better understand the mechanism of surface cracking phenomenon.

Hai-liang Yu et al [3]: In this paper, the authors present a new type of finite element model using constrained node failure method to simulate the occurrence of surface defects on strips during rolling. Finally, he focus on the surface quality of rolled steel for various reduction ratios.

Heon Son et al [4]: In this paper the deformation behavior of intentionally generated surface defects with notch shapes was focused in order to investigate the effect of notch size and initial locations using the numerical simulations. For this purpose, FE program to handle contact treatment was developed to simulate the multi-pass rolling.

Shinohara and Yoshida et al [5]:In this paper, the growth and disappearance of surface scratches are examined by applying FEA to the analysis of billet rod rolling where scratches are artificially made on billet surface.On the basis of result obtained, the possibility of recovering surface defects by means of rolling by FEA.

S. Abdul Rajak et al [6]: In this paper internal defects are analysed on the basis of larger initial thickness of workpiece, low slab reductions during rolling and due to smaller roll radius.

Rebecca Nakhoul et al [7] In a thin strip cold rolling problem, the temperature increase in the roll bite may reach 100 K, and, due to the differential reduction, may not be homogeneous. Thickness at the edges is less than centre this leads to flatness defect

Awais and Son et al [8] :In this paper employed the two-dimension FEM and Processing Map to analyze the closure and growth of surface crack in bars in the rolling process.

Ervasti, et al [9]: In this paper, simulated the closure and growth of longitudinal and transversal cracks in flat rolling process, and analyzed the closure and growth of cracks under a variety of the crack sizes, roll radii.

Tang et al [10]:In this paper, used the FEM to simulate the crack propagation in oxide scale under hot rolling conditions for different profile parameters of the oxide scale layer. Simulation results indicated that the larger was the initial profile surface roughness, the larger the crack width remaining after rolling.

Kawano et al [11].In this paper used thermal and mechanical finite element (FE) simulations for calculating the temperature change in five different roll pass designs. They discussed that temperature was the most significant processing parameter to control surface cracks and recommended roll pass design with least temperature drop during rolling for reducing surface cracks.

Sychkov et al [12]:In this paper, classified various types of the surface defects of the wire rods transformed from defects in steel making process. They pointed out that accurate classification of surface defects on rolled products in terms of their causes and where they were formed in the rolling process was not easy. For example, it is sometimes confusing to distinguish laps from rolled-in cracks or to distinguish rolled-in scabs from folds.

II. METHODS AND METHODOLOGY

Finite Element Method:

In this method of analysis, a complex region defining a continuum is discretized into simple geometric shapes called finite elements. The material properties and the governing relations are considered over these elements and expressed in terms of unknown values at element corner. A rolling process, duly considering the loading, results in a set of equations, solution of these equations gives us the approximate behavior of the continuum. The analysis which uses FEM is known as FEA. A general purpose FEA program consists of three modules; a pre-processor, a solver, and a post processor. Commercial FEA programs can handle very large number of nodes and nodal degrees of freedom provided a powerful hardware is made available. User's manual, theoretical manual, and verification problems manual, document a commercial FEA program.

1. Geometrical modelling of the rolling process(Half model built up due to symmetry)
2. Plane stress with thickness approach due to complexity in the nonlinear geometrical and material nonlinearity of the problem
3. Map meshing of the geometry to obtain better results
4. Contact pairs creation
5. Nonlinear material and geometrical analysis through iterative solver
6. Analysis for defect free rolling process
7. Analysis of crack in the rolling material
8. Analysis for surface defect in the rolling process
9. Analysis results

III. MATERIAL SPECIFICATIONS:

Material Specifications:

Material: Mild Steel, Young's Modulus: 200Gpa, Poision's ratio=0.3, Density=7800kg/mm^3.

YieldStress:250 N/mm^2,
Tangent Modulus: 780N/mm^2.

A.MODEL SPECIFICATIONS

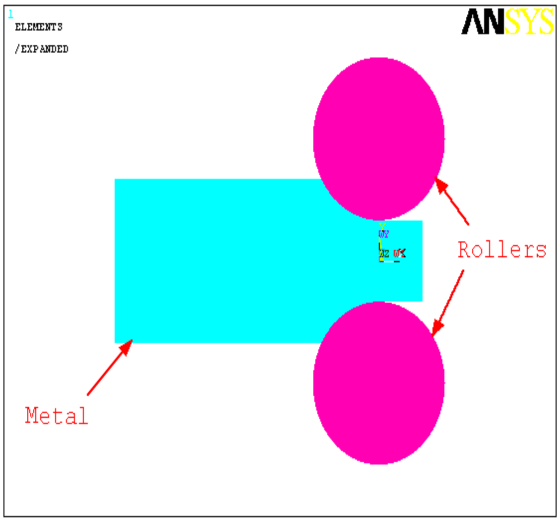

Fig3.1: Component Part

The figure3.1 shows components in the rolling process. Metal to be rolled along with rollers are represented in the problem. Due to symmetry , only half geometry will be considered for the analysis. Ansys mixed approach is used to built the geometry to the required shape. The component names are represented through annotation utility. The output section is taken equal to the half of inlet section.

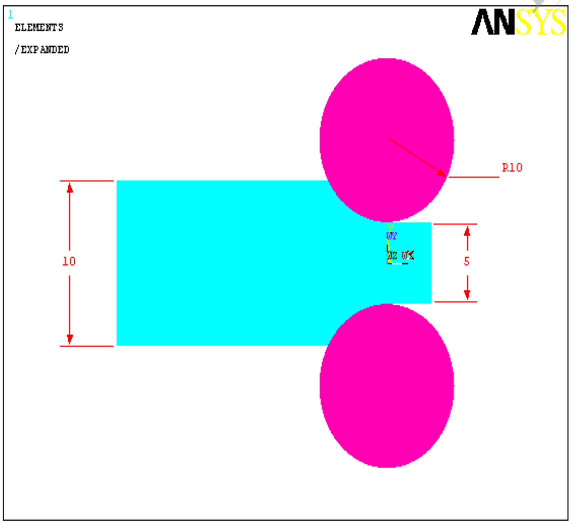

Fig3.2 : Dimensional details

The figure3.2 shows dimensional details of the problem. The rolling metal thickness is taken as 10mm at inlet and 5mm at outlet. Rollers with a diameter of 20mm is considered for the process. Colour representation is done to represent the rollers and sheet metal for rolling process. Thickness of the sheet is taken as 25mm. Plane stress with thickness option is considered for the analysis.

B.MESH SPECIFICATIONS

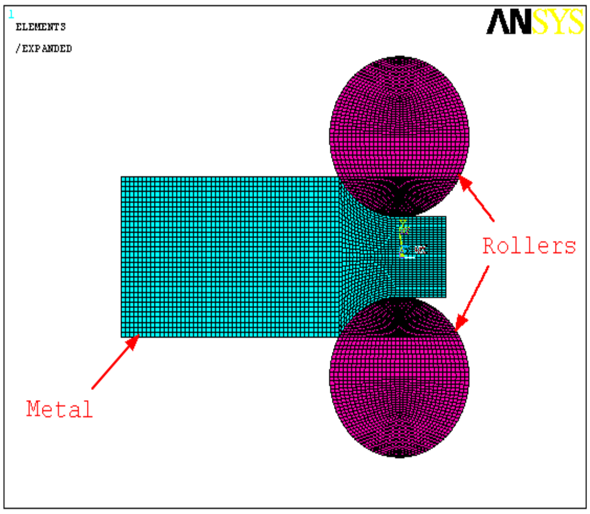

Fig3.3: Mesh Parts

The figure3.3 shows meshed geometries of the problem. Due to symmetry, half the members are meshed and reflected for view purpose. Half section is considered for analysis. The geometry is split to ease map mesh of the geometry. Map mesh gives better results compared to the free mesh. In the free mesh, elements are in disorder and graphical plots are difficult for representation. In map mesh, graphical plots can be represented in the required direction. Also mesh control is possible to capture the stress concentration regions. Plane182 element is used for 2 dimensional plane stress representation . Plane 182 element has the good capability for rolling simulation. It is having the support of plasticity and consideration for high plastic strains. 3137 elements with 3258 nodes are considered for analysis. Different colors are represented to identify the parts.

C.RESULT

The analysis for rolling is carried out in three stages using nonlinear material and geometrical domain. Initially the boundary conditions are applied using symmetrical boundary conditions are the bottom and displacement boundary conditions to the left side geometry for 2mm. The solver options are set for proper convergence in the problem. More number of steps are given with reduction of penetration tolerance settings. The analysis is done for the following cases.

1. Normal rolling application without any defects in the sheet metal to be rolled
2. Sheet metal with crack in the geometry

In all the analysis, the results for deflections, stresses, plastic strains and contact pressure are captured. Plastic strain and contact pressure are the main parameters for rolling simulation for defect free and lesser press requirements.

Case 1: Defect free sheet metal formation:
The simulation results in steps are represented in the following diagrams. The pictures are captured to show the change in the parameter (displacement, vonmises stress, contact pressure, and plastic strain) during the rolling process. The results are as follows.

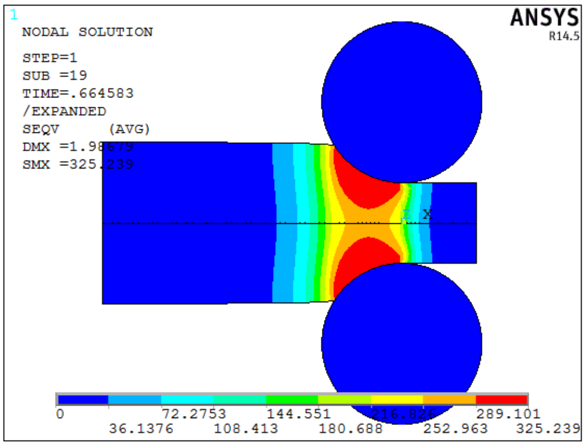

Fig1: maximum Stress condition

The figure 1 shows maximum vonmises stress developed in the rolling process. Maximum stress of 325.239Mpa can be observed in the process. Since the material is reaching to the yield point the stress is spreading as shown by red colour in the picture. Vonmises stress is considered for analysis, as the Vonmises stress represents equivalent stress of the structure. Also vonmises failures match with most of the ductile material failures.

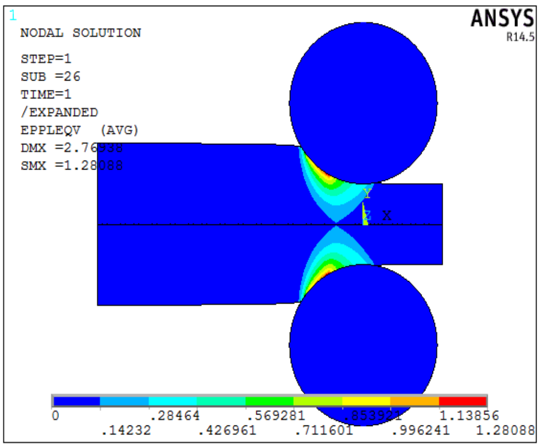

Fig 2: Maximum Plastic strain plot

The figure 2 shows maximum plastic strain in the problem. The plastic strain is almost 128% of the original structure. Higher plastic strains are not desirable in the structures as they are the sources of residual stress and source for tensile cracks. They will reduce the life of the rolled structures. So the process should be always to reduce the plastic strain and residual stresses. Maximum plastic strain can be observed by red colour region in the problem. The maximum value of 1.28088 can be observed in the status bar at the bottom and red colour region in the picture.

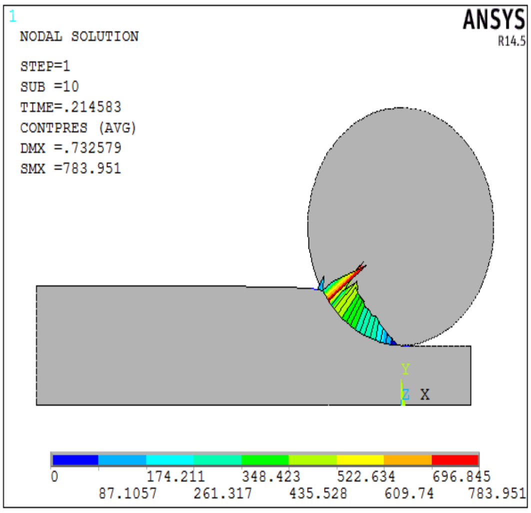

Fig 3: Maximum Contact Pressure

The figure 3 shows maximum contact pressure plot in the problem. Maximum contact pressure is 783.951 Mpa as shown with red colour arrows. The contact region spread is shown in the figure with zero contact pressure at the exit and higher contact pressures at the entry. Contact elements are defined to obtain the status of contact at the rolling interface. Target elements are defined for the rollers and contact elements are defined on the rolling surface.

Case 2: With Rolling Defects:

Crack in the material:

Simulation is carried out to find the effect of crack on the rolling process. So a crack is officially introduced through finite element modelling. The region of crack is shown in the figure. This helps in finding the cracksin side the rolled products due to variation in stress, contact pressure and plastic strain measurements along with load requirements.

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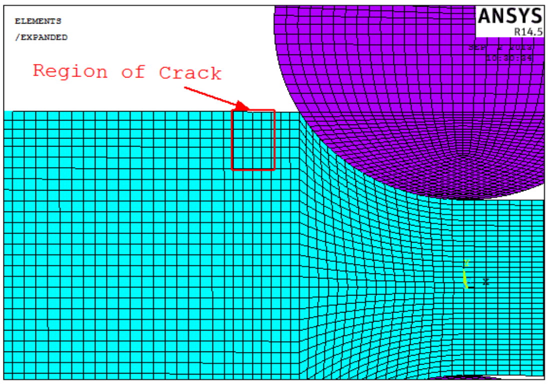

Fig 4: Geometrical model for Crack

The figure 4 shows introduction of crack of 1mm depth in the geometry. This is done unmerging the nodes at the interface. Roller elements and sheet metal elements are separated with different colours. Map mesh is used for better convergence. Plane182 elements with contact elements at the interface are defined.

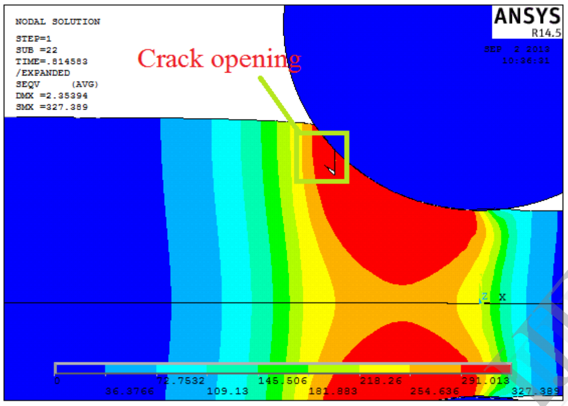

Fig 5: Crack Opening (Vonmises stress plot)

The figure 5 shows crack opening during the rolling simulation process. The crack region is indicated in the figure. So rolling simulation helps in identifying the crack propagation and changes in the surrounding regions. Maximum stress level is 327Mpa as shown in figue. This value is higher then the defect free rolling process.

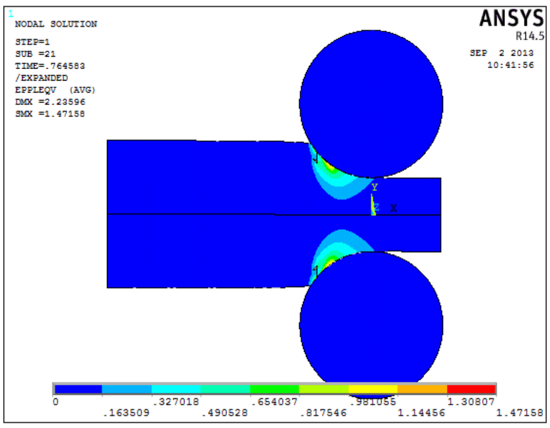

Fig 6: Increase of Plastic strain in the vicinity of crack.

The figure 6 shows plastic strain development of around 1.47159 which is higher then the normal deflect free rolled product. This higher strain is the cause of strain concentration and opening of the crack during the tensile load and causes the members for premature failures. Even crack region also can be observed.

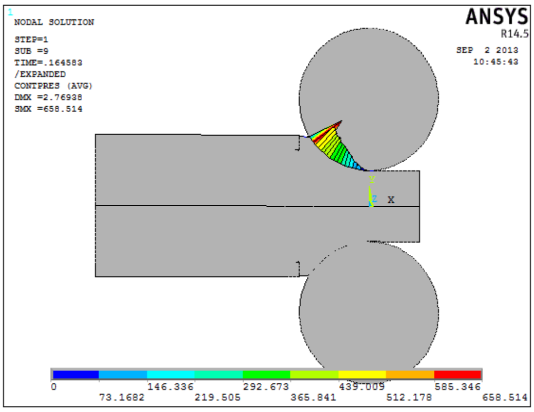

Fig 7: Normal contact Pressure in the plot

The figure 7 shows contact pressure when cracking region is not in the rolling process. Maximum of 658.514Mpa can be observed during rolling. The contact pressure spread is almost uniform and maximum at the inlet. Crack also can be observed in the figure. The spread of contact pressure is almost uniform which indicates no defect in the region of contact between roller and the sheet metal.

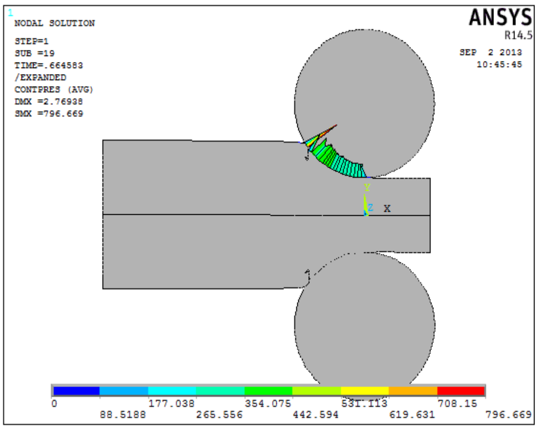

Fig 8: Contact pressure in the vicinity of the crack

The figure 8 shows the increase of contact pressure can be observed as the cracked region is entering the rolling process. The pressure is increased to 796.669Mpa at the crack tip region. So this increase in contact pressure requires stronger roller materials and support systems. Also uneven contact pressure causes the vibrations in the rolling process. Also this uneven contact pressure indication is the measure of the defect in the sheet metal.

D.GRAPHICAL PLOT

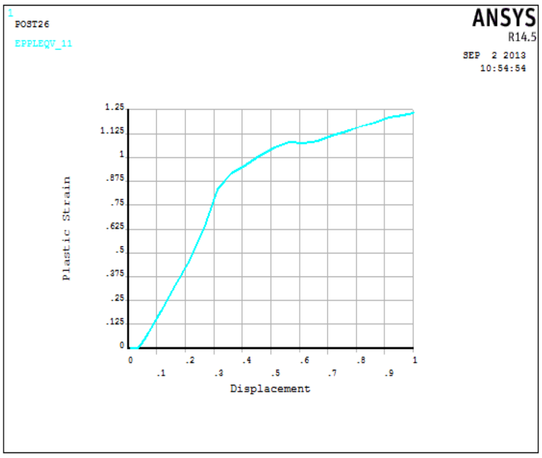

Fig 9: Plastic strain development at the top node away from crack tip

The figure 9 shows plastic strain change in the rolling material particles which are away from the crack regions. Almost uniformity can be observed for the rolling process. A smooth increase of plastic strain indicates, defect free region.

Table 1: Comparison of rolling process with and without defect.

Process Description	Vonmises Stress (Mpa)	Plastic Strain	Contact Pressure (Mpa)	Load Requirement (N)
Defect Free Rolling	325	1.28	783.951	44011
Crack in the Sheet Metal	327.3	1.471	796	58707
Surface defect on the rolling material	327	1.31	3167	58590

The table 1 shows stress, plastic strain, contact pressure and load requirements for the rolling process with defect and without defects. The table gives an idea of how a defect changes the pattern of stress, contact pressure and load requirements.

E.EXPERIMENTAL VALIDATION:

The load values are measured using load cells connected through extensometer. The load values are recorded using the panels provided in the machine. Totally 15 samples are experimentally tested and load values are recorded.

Table 2: Experimental values for 15 samples

Sl. No	Experimental Load (KN)
1	48.4
2	46.2
3	47.5
4	49.1
5	46.8
6	47.6
7	45.8
8	49.4
9	47.9
10	46.8
11	48.3
12	49.1
13	48.4
14	47.9
15	48.6

Average value of load for all the samples is 47.85Kilonewtons. Since finite element software does not have variation like practical values, finite element calculation is compared with the calculated average value to check the validity of the software.

Table 3: Comparative results between numerical and experimental values

Process Description	Load Requirement (N)-Numerical Results	Experimental Results(N)	Error Percentage
Defect Free Rolling	44011	47850	8.7

IV.CONCLUSION

In this present work the rolling is simulation is carried out for different configurations using Finite element analysis. The analysis summary is as follows.

1. The results shows stress increase from 325Mpa of defect free model to 327 Mpa with defect models.
2. The analysis shows plastic strain increment from 1.28 of regular component to 1.471 of defect component. This strain raise is the source weakness and eventual crack formation and failure. Plastic strain is the source of residual stress and any increase in residual stress reduces the life of the component by crack propagation.
3. Similarly the contact pressure of 783Mpa of defect free structure is increased abnormally to 3167Mpa which requires stronger roller material. This increases the cost of the rolling process.
4. Even the load requirement of 44011 N is increased to 58707 N with defect components. So a load increase of 33 % can be observed. So higher requirement of hydraulic cylinders and in turn increases the space requirements along with higher inventory.
5. Steep increase of plastic strain can be observed at the crack region which is not good for rolling process as it is the source of crack formation and propagation.
6. Higher loads requires stronger rollers and higher pneumatic circuits;

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