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Design and Analysis of Two Pass Rolling Dies

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Abstract: Sheet metal forming is widely used in automotive and aerospace industry. In this paper analysis of sheet metal forming process by deep drawing was discussed. Static analysis on the deep drawing operation was carried out to find the stresses, strains and total deformation of deep drawing cup. CAD models are generated using CATIA from the dimensions obtained by theoretical calculations and analysis is carried out using ANSYS software. The force required to develop the cup, deformation and defect like tearing, wrinkles etc. can be obtained through simulation. By using this method it is easy to make stress and strain analysis for different materials. From the analysis, it is observed that Titanium has the maximum stress with standing ability when compared to copper and Aluminum.

Keywords: ANSYS, CATIA, Rolling

Biographical notes: Kondapalli Siva Prasad obtained PhD from Andhra University, India, in 2014. He is currently working as Professor in Department of Mechanical Engineering, Anil Neerukonda Institute of Technology & Sciences, India. His current research interest includes Manufacturing and product design. He received research funds from UGC, DST, AICTE of Government of India. He has published 108 papers in various journals and 8 research scholars are working under his guidance. He served as Editorial Board member and reviewer for various international journals. **Vishnu Vardhan Reddy** is final year Bachelor's student in Department of Mechanical Engineering, Anil Neerukonda Institute of Technology & Sciences, India.

Research paper

1 INTRODUCTION

Rolling is a process to form metals where the metal strip is pressed by two or multiple rollers, thus the uniform thickness is formed. The rolling process is a metal forming process, in which stock of the material is passed between one or more pairs of rollers in order to reduce and to maintain the uniform thickness. This process is mainly focused on the cross-section of the ingot or the metal which is forming. Mainly by this process, we reduce the thickness of the metal workpiece. Now, the rolling processes are mainly focused on the increasing length and the decreasing thickness without changing the width of the workpiece. There are certain types of the rolling process, whereas, in the hot rolling process, the metal is heated at its desirable temperature, when the metal is properly heated then the metal should be passed between the one or more rolling mills to gain the proper desirable shape.

Mesay Alemu Tolcha, et.al [1], used numerical modelling to indicate a set of equations, derived from the contact principle, that transfer the physical event into the mathematical equations. Alexander Schowtjak, et.al [2] analysed the evolution of damage and voids in the sequence of caliber rolling to cold forward rod extrusion. The analysis is performed with the help of a variant of the Lemaitre model, microstructural analysis of the void area fraction and density measurements. Huiping Hong [3] used three dimensional elastoplastic finite element simulation with thermal mechanically coupled analysis which is applied to study the roll pass design of the hot continuous rolling of Φ100mm alloy steel round bar from 200mm×200mm square cast bloom.

Yavtushenko A.V, et.al [4], studied the possibility of application of the program complex called Mathcad Prime 5 for calculation of normal contact stresses in the centre of deformation during cold rolling of the strips. O.M. Ikumapayi, et.al [5] studied rolling techniques in metal forming operation, or as part of the industrial manufacturing process. Comparison in performance of different rolling methods, while analysing their defects, and areas of application of rolled products or components is presented. Yingxiang Xiaa, et.al [6] analysed the existing problems, e.g. cracking, many forming passes, difficult control of dimensional accuracy, in thin-walled pipe fittings hot extrusion forming process.

Mesay Alemu Tolcha, et.al [7] carried out modelling of rolling die contact with the slab primarily needs to describe the Tribology of contact phenomena. Jian-guo CAO, et.al [8] carried out finite element method for the behaviour analysis of mechanical, thermal, deformation and other characters of strip and rolling mills. Kondapalli Siva Prasad, M. Lalitha Kavya [9], made an attempt 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 summarized the results, so that the gaps can be identified, which in turn helps the researchers to carry their research in rolling. Andre Lim, et.al [10] 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.

In the present work, roller and billet assembly of dimensions are as 50mm and 40mm as diameter and width of the roller and 100mm, 15mm, 10mm as length, input width and output width, respectively. The rollers are made to rotate at 4 different speeds i.e. 0.24rad/s, 0.3rad/s, 0.46rad/s, 0.6rad/s and billet is made to move between the rollers. The temperatures are considered to be constant throughout the process. The contact stress between the roller and the billet, maximum equivalent stress and directional deformation can be found out. Simultaneously the material of the billet is changed. We have considered 4 different materials which are commonly used in the industry. Aluminium alloy, copper alloy, magnesium alloy and stainless steel are considered as workpiece materials.

2 MODELING & ANALYSIS

The materials used for blank, blank holder, die and punch are presented in “Table 1”

3D modelling was done using SOLIDWORKS software for roller and billet assembly is designed with the dimensions as mentioned in the “Table 1”.

Table 1 Dimensions of the roller and billet

	Volume (mm^3)	Surface area (mm^2)	Dimensions (mm)
Roller	74895.57	11787.26	Dia=50mm Width= 40mm
Billet	24892.41	7014.22	Input=15mm Output=5mm

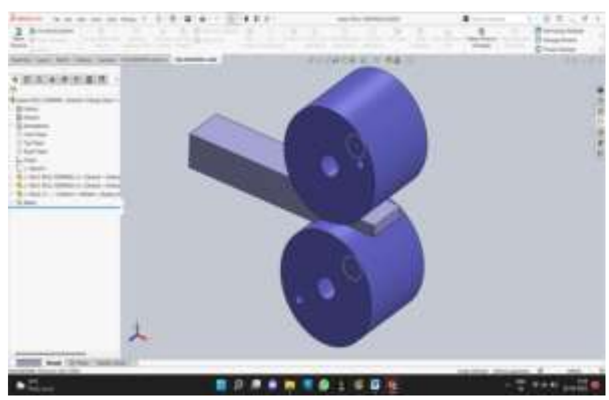

Fig. 1 Assembly of the roller and billet.

The roller and the billet are connected together by the use of mate option, eight mating are given for the complete assembly. The mating can be given in many ways. Here the curved surface area of billet and matching surface area of the billet are selected. The assembled roller and billet is as shown in the “Fig. 1”. It is saved in the ‘igs’ format to be used in the ANSYS WORKBENCH for the analysis work. The properties of the roller material and the four billet materials have been added to the ANSYS workbench for the analysis. The properties of materials are shown in the below tables. The load setup is given to the model as below. Rotation of rollers is given by selecting the joint rotation in the z-axis. Four different speeds are considered for the entire analysis. The chemical and physical properties of D2 material are presented in “Tables 2 and 4”.

Table 2 D2 steel metal composition (weight %)

Steel Grade	carbon	Mn	silicon	Cr	Nickel	S	P	Hardness HRC
D2	1	0.25	0.25	1	0.2	0.005	0.003	60-62

Table 3 Properties of D2 steel

Young’s modulus	2.09×10^11 pa
Poisson’s ratio	0.3
Bulk modulus	1.7417×10^11 pa
Shear modulus	8.038×10^10 pa
Coefficient of thermal expansion	1.04 ×10^-5 /c
Density	7700 kg/m^3
Tensile ultimate strength	2.4×10^9

Table 4 Properties of the Billet material

	Aluminium alloy	Copper alloy	Magnesium allly	Stainless steel
Young’s modulus	7.1×10^10 pa	1.1×10^11 pa	4.5×10^10 pa	1.93×10^11 pa
Poisson’s ratio	0.33	0.34	0.35	0.31
Bulk modulus	6.960×10^10 pa	1.1458×10^11 pa	5×10^10 pa	1.693×10^11 pa
Shear modulus	2.669×10^10 pa	4.10×10^10 pa	1.667×10^10 pa	7.366×10^10 pa
Tangent modulus	5×10^8 pa	1.15×10^9 pa	9.2×10^8 pa	1.8×10^9 pa
Density	2770 kg/m^3	8300 kg/m^3	1800 kg/m^-3	7750kg/m^3
Yield strength	2.8×10^8 pa	2.8×10^8 pa	1.93×10^8 pa	2.1×10^8 pa

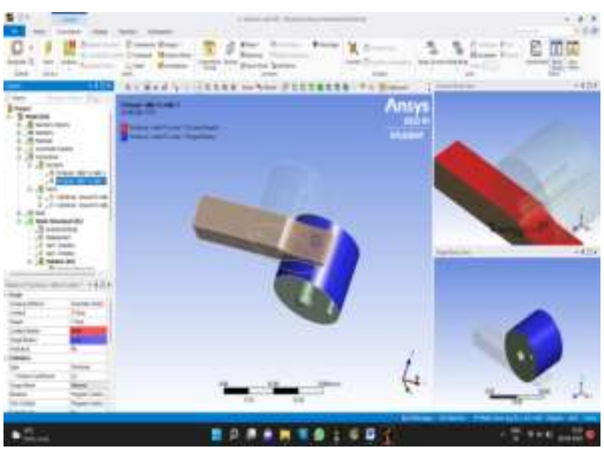

Fig. 2 Contact between the lower roller and billet surface.

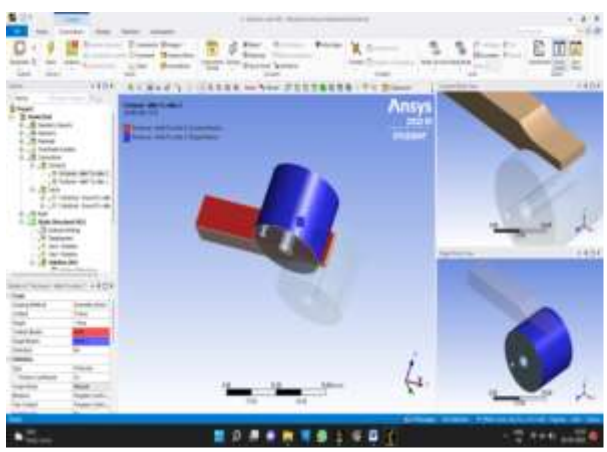

Fig. 3 Contact between the upper roller and billet surface.

The saved 3D model is imported into ANSYS workbench. In the static. structural module is selected from the Analysis system toolbox menu of ANSYS WORKBENCH. Contact regions are given as the 3D solid assembly consists of a roller and billet. A solid-solid bonded contact was given at the region as the bond strength of roller and billet and joints are given to the ground and roller, the contacts are shown in the "Figs. 2 and 3".

The 3D model is meshed in two different methods, the roller is meshed with the sweep method with automatic sizing quad/tri elements nodes and billet is meshed with body sizing method with 3mm, (See "Figs. 4 to 5").

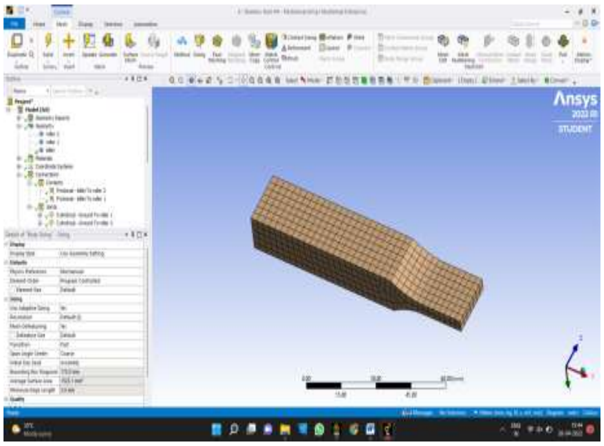

Fig. 4 Meshing of billet.

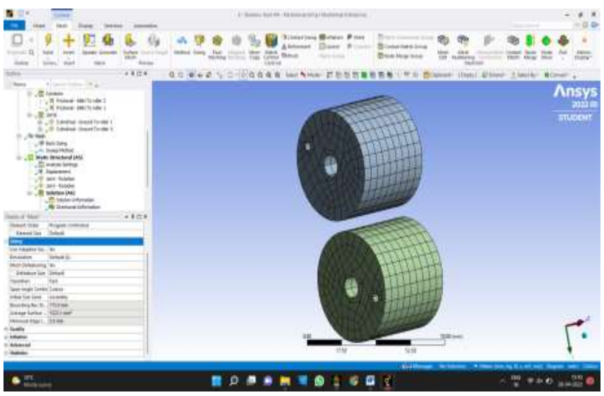

Fig. 5 Meshing of roller.

The rotation of the rollers is given as one roller in clockwise and another as Anti-clockwise direction. The roller speeds are given as 0.24, 0.3, 0.48, 0.6 rad/s. The solver module is used to obtain the solution for the given boundary conditions to the model. The required stress distribution and contact stress are evaluated for given loading conditions. The analysis for aluminium billet at different roller speeds has been presented in "Figs. 6 to 17".

1- At Roller Speed of 0.24 Rad/S for Aluminium Alloy

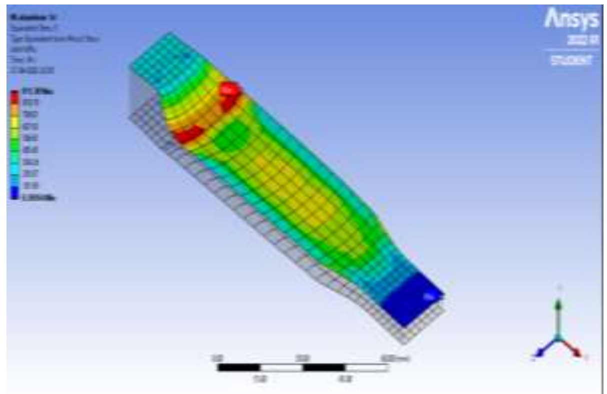

Fig. 6 Contact stress for aluminium alloy.

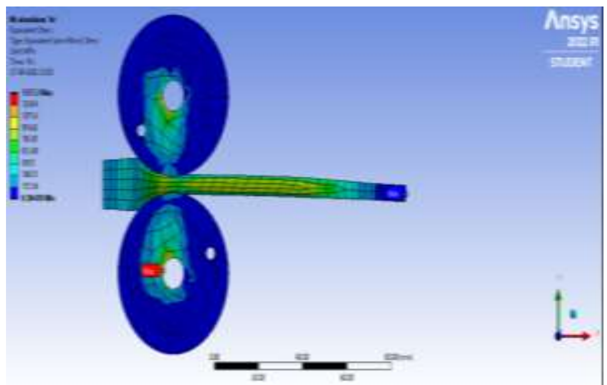

Fig. 7 Equivalent stress distribution for aluminium alloy.

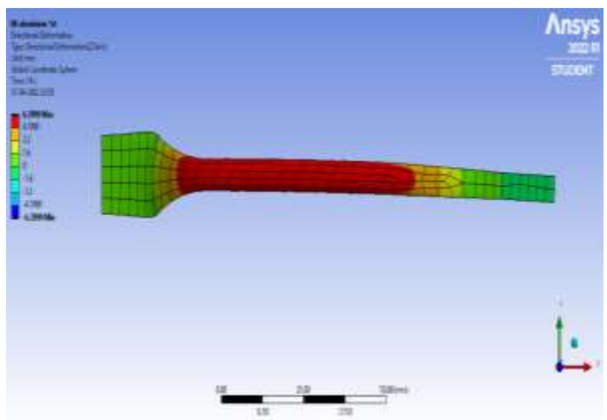

Fig. 8 Directional deformation for aluminium alloy.

2- At Roller Speed of 0.3 Rad/S for Aluminium Alloy

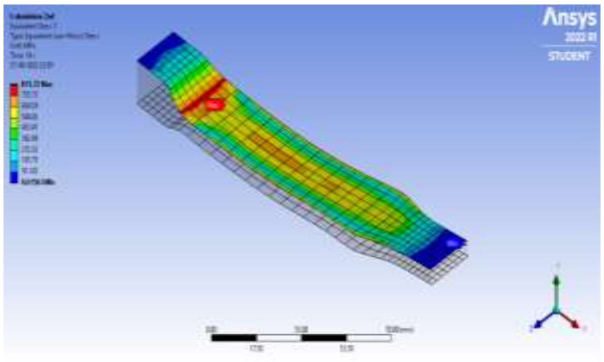

Fig. 9 Contact stress for aluminium alloy.

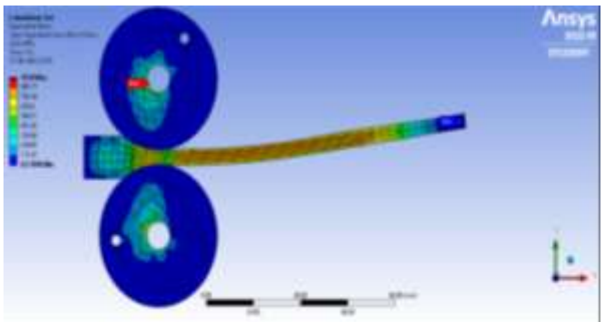

Fig. 10 Equivalent stress distribution for aluminium alloy.

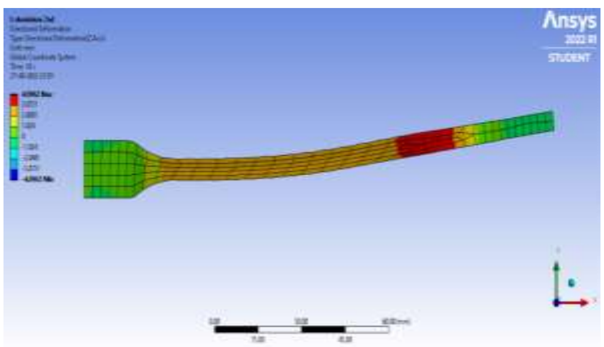

Fig. 11 Directional deformation for aluminium alloy.

3- At Roller Speed of 0.48 Rad/S for Aluminium Alloy

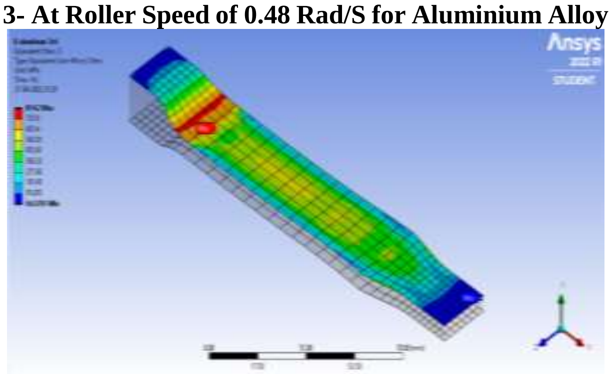

Fig. 12 Contact stress for aluminium alloy.

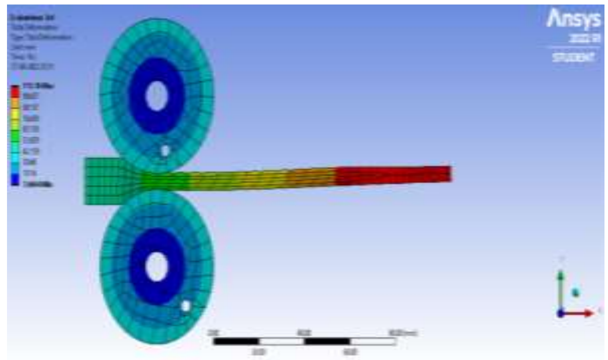

Fig. 13 Equivalent stress distribution for aluminium alloy.

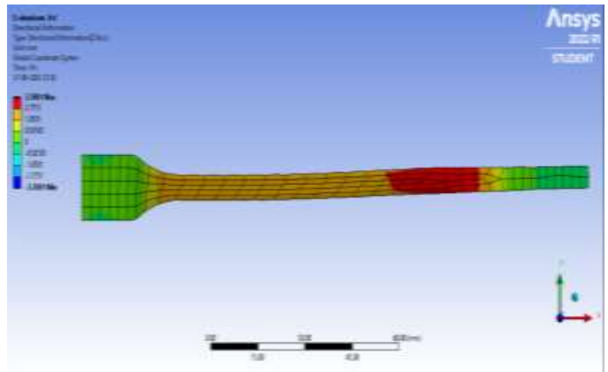

Fig. 14 Directional deformation for aluminium alloy.

4- At Roller Speed of 0.6 Rad/S for Aluminium Alloy

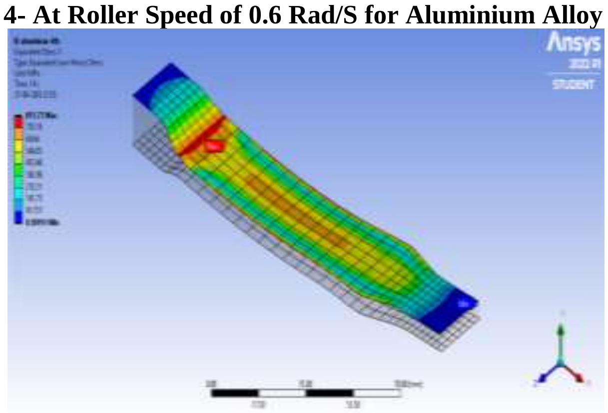

Fig. 15 Contact stress for aluminium alloy.

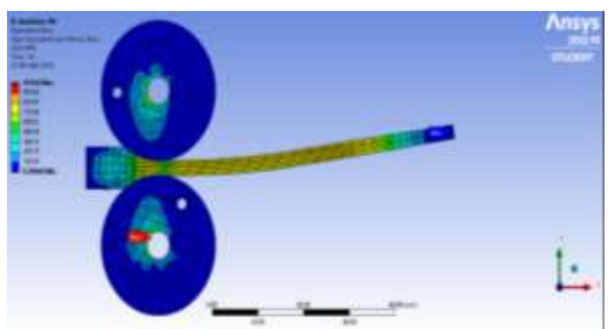

Fig. 16 Equivalent stress distribution for aluminium alloy.

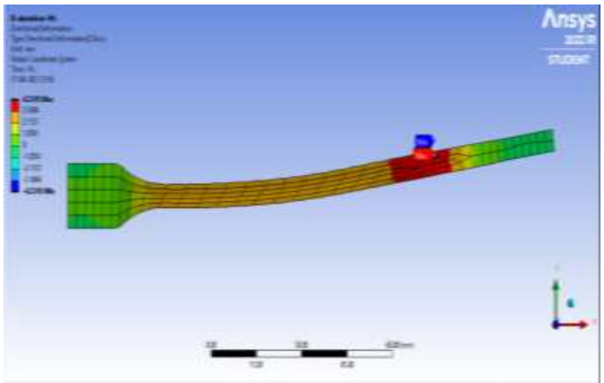

Fig. 17 Directional deformation for aluminium alloy.

Similarly for other billet materials, analysis is carried out at different roller speeds, which are presented in "Tables 5 to 7".

Table 5 Contact stresses

Speed (rad/s)	Aluminium alloy	Copper alloy	Magnesium alloy	Stainless steel
0.24	911.38	1738.4	1303.2	2640.1
0.3	814.2	1544.9	1197.1	2245.1
0.48	815.72	1560.1	1169.2	2296
0.6	815.75	1548.3	1169.3	2406.1

3 RESULTS & DISCUSSION

From the analysis carried out on different billet materials by varying the roller speed, the following observations are made. From the contact stresses Table 5, it is observed that maximum contact stresses were observed at 0.4 rad/s for stainless steel and minimum value was observed for aluminium alloy. Similar trend was observed for 0.3 rad/s 0.48 rad/s and 0.6 rad/s. Higher contact stresses was observed at lower roller speeds of 0.24 rad/s and minimum contact stresses were observed at 0.3 rad/s. From the directional deformation in Table.6, it is observed that the maximum directional deformation was observed for aluminium alloy at roller speed of 0.24 rad/s and the minimum directional deformation was observed for stainless steel at a roller speed of 0.6 rad/s. Directional deformation decreases with increase in roller velocity.

Table 6 Directional deformation

Speed (rad/s)	Aluminium alloy	Copper alloy	Magnesium alloy	Stainless steel
0.24	6.339	5.8974	5.6377	4.4164
0.3	3.7001	3.9951	3.8693	4.4539
0.48	4.0962	4.3762	4.224	4.6514
0.6	4.2245	4.5054	4.3644	3.587

From the directional deformation in "Table 7", it is observed that the maximum equivalent stress was observed for stainless steel at roller speed of 0.24 rad/s and minimum equivalent stress was observed for aluminium alloy at roller speed of 0.48 rad/s. Equivalent stress decreases with increase in roller speed from 0.24 rad/s to 0.48 rad/s.

Table 7 Equivalent stress

Speed (rad/s)	Aluminium alloy	Copper alloy	Magnesium alloy	Stainless steel
0.24	1377.3	2411.76	1712.6	4019.8
0.3	1136.7	1809.4	1407.3	2564.9
0.48	1019	1704.7	1266.1	2344.5
0.6	1079.8	1793.7	1335.4	3183.2

Graphs are drawn for contact stresses, Equivalent stresses and directional deformation for four different types of billet materials at different roller speeds as shown in "Figs.18 to 20".

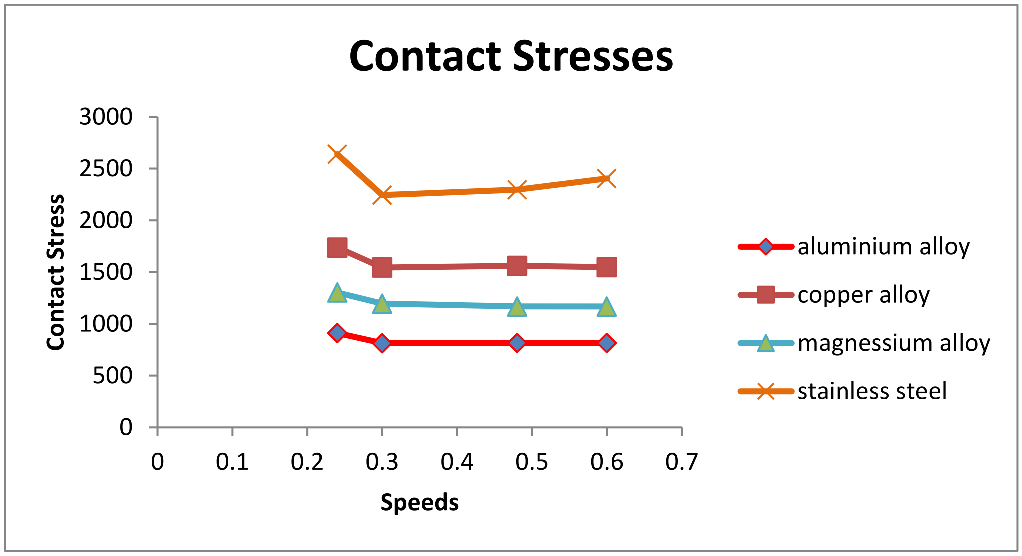

Fig. 18 Contact Stresses.

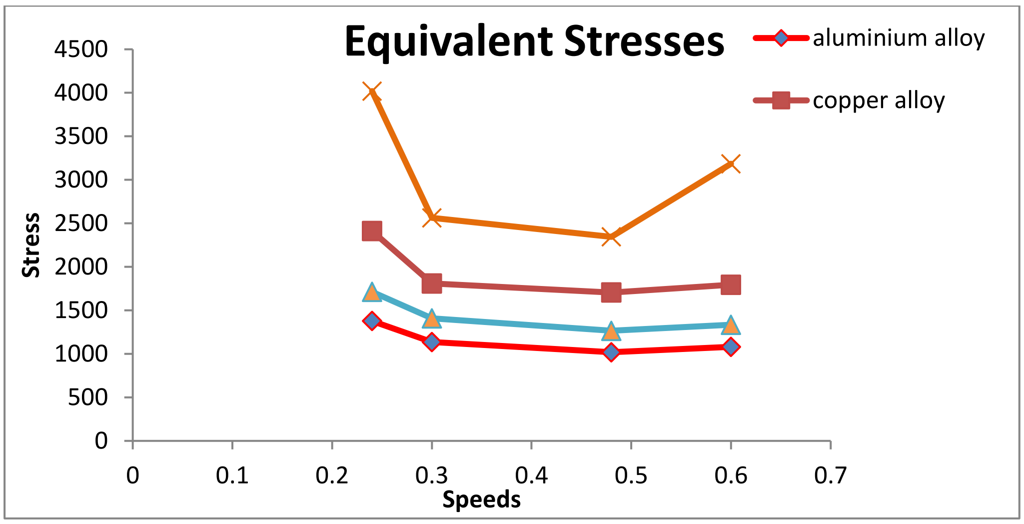

Fig. 19 Equivalent Stresses.

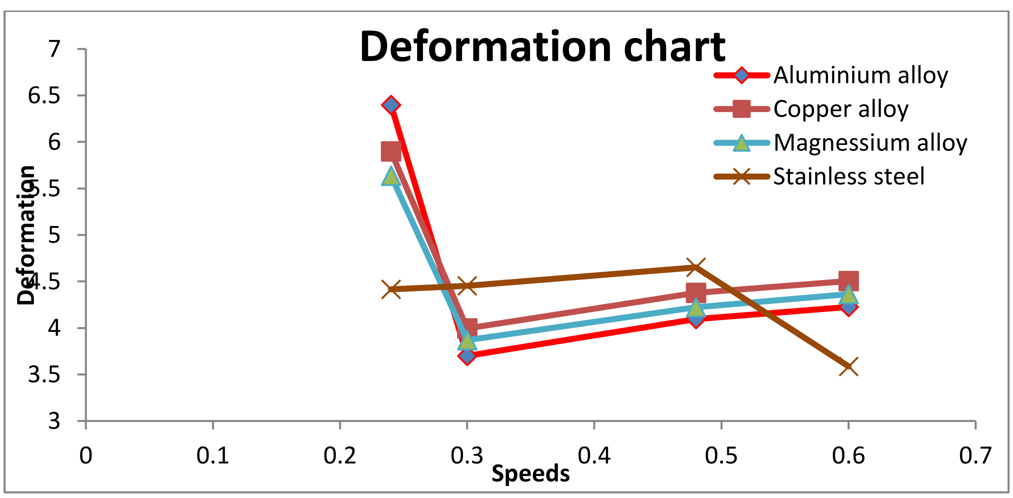

Fig. 20 Directional Deformation.

4 CONCLUSIONS

Based on analysis work carried on different billet materials, the following conclusions are drawn:
The optimal contact stress of 814.2 MPa is obtained for aluminium alloy at roller speed of 0.3 rad/s. The optimal equivalent stress of 1019 MPa is obtained for aluminium alloy at roller speed of 0.48 rad/s. The optimal directional deformation of 3.587 mm was observed for stainless steel at roller speed of 0.6 rad/s.

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