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Influence of Rolling Parameters on Hot Rolling of AZ31, AZ61 and AZ91 Mg Alloy

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ABSTRACT

Rolling of magnesium in industries is a challenging job because of its lower ductility and formability at ambient temperature. Magnesium metal possesses good energy absorption capacity and strength, hence it has higher demand in aerospace, automobiles and electronics sectors. Magnesium metal alloyed with Aluminum and Zinc has good yield strength and formability during application of tensile load. In this context an attempt has been made to study the influence of parameters on hot rolling of AZ31, AZ61 & AZ91 alloy for three different percentages of reductions. There are two important out come from the analysis, one is the ideal input parameters such as temperature, speed and co efficient of friction are identified for all the alloys to reduce 21%, 31% & 39% from its initial height. Second is the study of influence of the input parameters on von mises stress and roll force during hot rolling of Mg alloys. Finite element simulation using AFDEX software for the analysis of hot rolling and Taguchi Optimization technique to optimize rolling parameters for the three different reductions are applied for this study.

From the obtained results it is observed that Von mises stress decreases with the enhancement of initial temperature and coefficient of friction but increases when rolling speed increases. On the other hand roll force declines with the increase of rolling speed and initial temperature of rolling. Among materials rolling of AZ31 and AZ61 alloy at all reductions possess better product quality than AZ91 alloy.

Keywords: *Hot rolling, AFDEX, Taguchi Optimization technique, Percentage of reduction, Von mises stress, Roll force.*

1. INTRODUCTION

The decisive factor of rolling process is to reduce the height of the work piece through length wise. The work piece/ metal under rolling should have good formability and ductility property. Magnesium metal have major drawback of its poor formability and ductility to undergo rolling process. As such many attempts are made to employ magnesium in alloyed form by combining with Al and Zinc metals which improves its formability and ductility. Hot rolling of Mg alloys mainly depends on the stress, strain and force parameters obtained during the rolling process. We can find factors like temperature, speed, reduction percentage and co efficient of friction which could alter these process parameters. There are few attempts made over micro structural analysis of Mg alloys to identify the strain rate and stress variation during rolling. In that M Greger et al [1] provide information about magnitude of deformation, strain rate, and temperature of forming at different method of plastic deformation of Mg alloy AZ61. Peter Aiyedun et al [2] have numerical determination of friction co efficient for hot flat steel rolling. From the results friction co efficient can considered as function of process parameters during rolling. Author Se-Jong Kim et al [3] have given a research on Mg alloy sheet when embedded with steel sheet gives better impact on the strength in generating compressive stress along transverse direction in the mg alloy sheet. Xinsheng Huang et al [4] have given analysis on micro structural properties, textures, mechanical properties, stretch formability on differential speed rolling for large thickness reduction in sheet. Mahdi Bagheripoor et al [5] have also made a contribution in identifying the influence of process parameters such as rolling speed and percentage of reduction on fluctuation of roll force and torque in a steady state operating point. Charles Mansfield et al [6] have used Ansys and LS Dyna software to numerically simulate symmetric hot rolling. The thermo mechanical process parameters like temperature, roller speed and plate dimension can be altered to characterize how geometric and material properties confer a mechanical response for single pass isothermal rolling. Souvik Biswas et al [7] has given a study in developing a thermo

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mechanical model using commercial finite element code ABAQUS which predicts geometric parameters required to satisfy the customer requirements. Fei Guo et al [8] have shown that Dynamic recrystallization behavior during hot rolling of Mg alloys is controlled by both rolling speed and thickness reduction. Twinning was the dominant deformation behavior during hot rolling with small rolling reduction. For AZ31 alloy Tao Zhou et al [9] have given information about the effect of rolling speeds on the micro structures, textures, mechanical properties and stretch formability of AZ31 alloy. M.T. Pérez-Prado et al [10] have studied the effect of sheet thickness on the micro structural evaluation of Mg alloy AZ61 during large strain hot rolling. Seyed Reza Motallebi et al [11] has also made an attempt in identifying the influence of geometry of the slab, temperature, friction between work-rolls and slab, percentage of thickness reduction, rotational speed of work-roll to improve the product integrity and mechanical properties using finite element simulation. Another paper on AZ31 alloy from Lili Guo et al [12] has given the influence of rolling parameters on dynamically recrystallized microstructures. From this literature review, it can be noted that process parameters like temperature, speed, initial thickness, percentage of reduction, friction have major contribution in microstructure property of the rolled sheet or in improvising product formability. In this paper an attempt has been made to explore influence of percentage of reduction on three Mg alloys AZ31, AZ61 & AZ91 depending on the process parameters such as Von mises stress and Roll force. Also the dependency of temperature, speed and co efficient of friction for controlling the von mises stress and roll force has been identified. The analysis is carried out using AFDEX for finite element simulation method and Taguchi optimization technique for Optimization process.

2. METHODOLOGY

2.1 Materials

In present study AZ31, AZ61 & AZ91 alloy are taken to check for their rolling ability under the given input parameters. Compositions and Material properties of the alloys are given in table 2.1

Table 2.1 AZ31, AZ61 & AZ91 Alloys Composition

Alloy name	Mg %	Al %	Zn %	Si%	Mn %	Other metals	Material property
AZ31	96	3.5	1.3	<0.05	0.2	--	Wrought alloy, good strength and ductility, corrosion resistance, weldability & extrusion
AZ61	93	5.9	1.1	<0.01	0.02	Ni-- <0.005; Fe -- < 0.01	Wrought alloy, high tensile strength, superior corrosion resistance
AZ91	90.8	8.25	0.63	0.035	0.22	Cu – 0.003; Fe – 0.014; Be – 0.002	Sand casting alloy

2.2 Process Parameters

Percentage of Reduction: Thickness reduction is the major issue in flat rolling. The amount of metal to be reduced will decide the significance of input parameters like temperature, speed of roller, roller diameter and mean while it

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has keen effect on the outputs like von mises stress and roll separating force. Therefore it is very essential and effective factor during rolling process.

Von Mises Stress: This stress is widely used in engineering design since it will explain the capability of material to withstand the given load. It is used to predict the yielding of materials under any loading condition from results of simple uniaxial tensile tests. Also the plastic deformation of the material during rolling depends on the max Von mises stress factor. Therefore Von mises stress is an important factor to analyze the rolling process.

Roll Separating Force: Roll force is a key parameter in the process control of hot strip rolling, and its computational accuracy directly determines thickness precision, strip shape quality and rolling stability. The roll separating force pulls the rollers apart. It is important to see the roll force during rolling since it's a key parameter to have control over the flatness and geometrical accuracy, yield strength, and the hardness of the product.

2.3 Finite Element Analysis & Taguchi L9 Orthogonal array

AZ31, AZ61 & AZ91 alloys are hot rolled using AFDEX. The roller diameter and dimension of work piece are as shown in table 2.2. The input parameters temperature, speed, material and friction are taken as control factors as shown in the L9 orthogonal array table 2.3. Finite element simulation of Mg alloys are carried out for the 9 experiments given in table 2.4.

Table 2.2 Dimensions For Roller And Mg Alloy Sheet For Rolling Process

Component	Dimension
Sheet Height x width x length in mm	5.6 x 40 x 150 in mm
Upper and lower rollers	
Diameter of roller	200 mm
Width of roller	50 mm

Taguchi L9 orthogonal array matrix is created by considering temperature, speed, co efficient of friction, and alloys as control factors. The matrix of L9 orthogonal array for this analysis is as shown in the table 2.2.

Table.2.3 Control Factors & Their Levels

Control factors (rolling parameter)	Positions	Level 1	Level 2	Level 3
Temperature	A	300	350	400
Speed	B	35	23.5	16.62
Material	C	AZ31	AZ61	AZ91
Friction	D	0.2	0.25	0.3

Finite element simulation is carried out using AFDEX as per the combination of rolling parameters for each alloy in the matrix and is as shown in the table 2.3.

Table.2.4 Orthogonal array with control factors

Experiment no.	Temperature	Speed	Material	Friction
Exp 1	L1 – 300	L1 - 35	L1 - AZ31	L1 - 0.2
Exp 2	L1 – 300	L2 -	L2 –	L2 -

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		23.5	AZ61	0.25
Exp 3	L1 – 300	L3 – 16.62	L3 – AZ91	L3 - 03
Exp 4	L2 - 350	L1 - 35	L2 – AZ61	L3 – 0.3
Exp 5	L2 – 350	L2 - 23.5	L3 – AZ91	L1 – 0.2
Exp 6	L2 – 350	L3 – 16.62	L1 – AZ31	L2 – 0.25
Exp 7	L3 – 400	L1 - 35	L3 – AZ91	L2 - 0.25
Exp 8	L3 – 400	L2 - 23.5	L1 – AZ31	L3 – 0.3
Exp 9	L3 – 400	L3 – 16.62	L2 – AZ61	L1 - 0.2

3. RESULT & DISCUSSION

3.1 Effect of Percentage of Reduction

To understand the effect of percentage of reduction on process parameters Von Mises stress and Roll separating force, let us consider AZ31, AZ61 & AZ91 alloy with initial temperature 400^{0}C, roll speed 16.62 rpm and friction 0.2 to hot roll. The von mises stress and Roll force obtained during hot rolling are tabulated in the table 3.1.

Table3.1Effect Of Percentage Of Reduction On Hot Rolling Of AZ61 Plate

Material	%age of reduction	Temperature (0C)	Speed (rpm)	Frictioin	Von mises stress (M Pa)	Roll force (N)
AZ31	21%	400	16.62	0.2	73.2962	2206.53
AZ31	31%	400	16.62	0.2	75.6261	19468.6
AZ31	39%	400	16.62	0.2	78.1349	7213.7
AZ61	21%	400	16.62	0.2	99.427	14968.8
AZ61	31%	400	16.62	0.2	101.55	7205.6
AZ61	39%	400	16.62	0.2	110.54	4968.5
AZ91	21%	400	16.62	0.2	77.97	4048.2
AZ91	31%	400	16.62	0.2	81.83	1148.4
AZ91	39%	400	16.62	0.2	84.18	998.7

3.2 Von Mises Stress

When the material is checking for its ductility, it is important to observe the maximum value of von mises stress the material can with stand when tensile load is applied. In hot rolling many input parameters have found effect on varying the value of Von mises stress during the process. From the present work hot rolling of AZ31,AZ61 & AZ91 alloy to 21% reduction has taken with varied input parameters to observe the changes is in von mises stress. The of von mises stress based on different input temperature, speed and co efficient of friction is given from table 3.2 to 3.4. The variation in Von mises stress depending on changes in temperature, speed & friction are shown in figure 1, figure 2 & figure 3 respectively.

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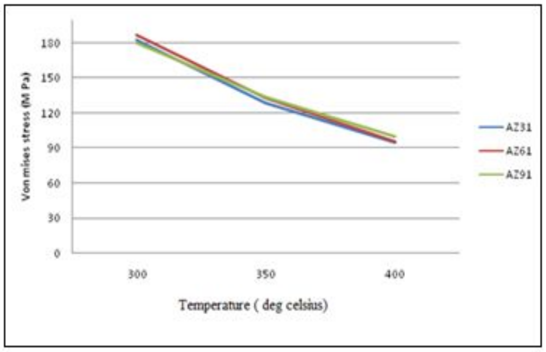

Fig. 1. Effect of initial temperature of workpiece on Von mises stress during hot rolling of AZ31, AZ61 & AZ91 alloy.

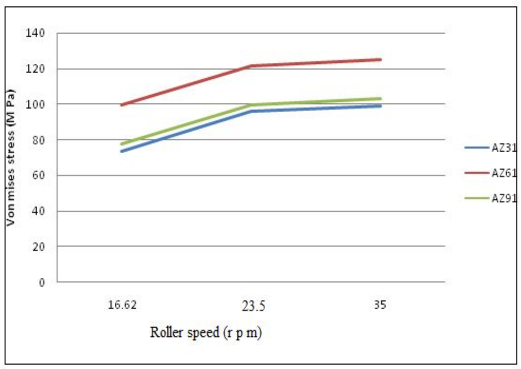

Fig. 2. Effect of roller speed on von mises stress during hot rolling of AZ31, AZ61 & AZ91alloy.

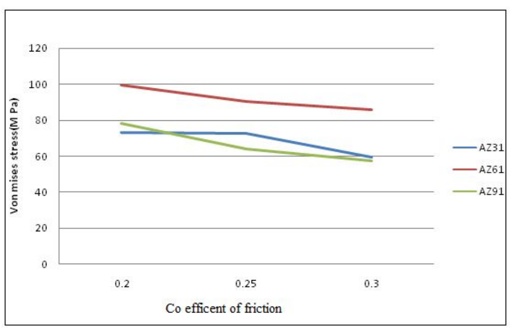

Fig. 3. Effect of co efficient of friciton on von mises stress during hot rolling of AZ31, AZ61 & AZ91 alloy.

3.3 Roll Force

Roll force is required to be minimized since it affects the contact between the roller and work piece throughout its length. To observe the changes in roll force results of hot rolling of AZ31 alloy for 21% reduction under varied input parametric condition are considered. The results of analysis on roll force based on temperature, speed and co efficient of friction are shown in the table 3.5 to 3.7. The variation of Rolling force depending upon the temperature, speed and friction are shown from figure 4 to figure 6.

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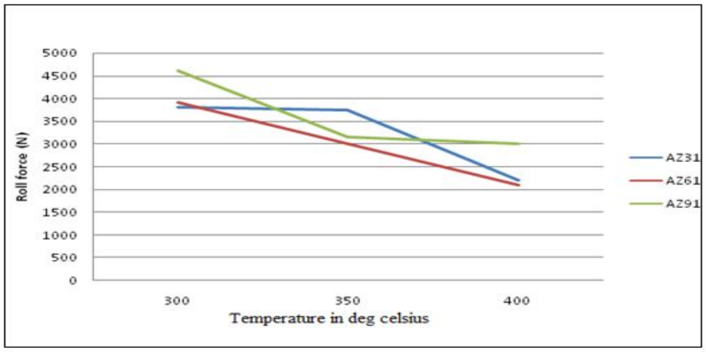

Fig.4. Effect of Variation in temperature on Roll force during rolling of AZ31, AZ61 & AZ91 alloy

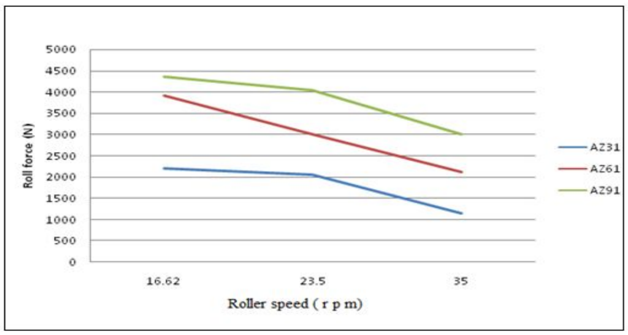

Fig. 5. Effect of roll speed on roll force during hot rolling of AZ31,AZ61 & AZ91 alloy.

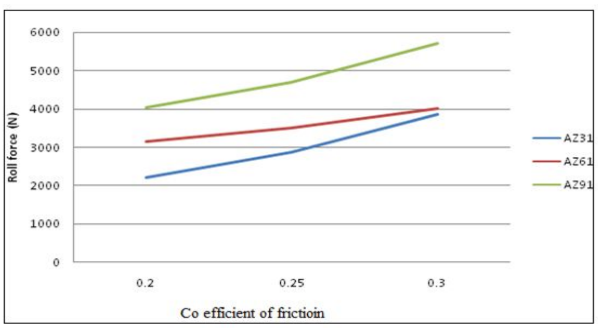

Fig. 6. Effect of roll co efficient of friction on roll force during hot rolling of AZ31,AZ61 & AZ91 alloy.

3.4 Ideal Input Parameters for AZ31, AZ61 & AZ91 Alloy To Hot Roll For Three Different Percentage Of Reduction.

From the results obtained by the simulation of hot rolling Mg alloys using AFDEX software and using the results of Von mises stress and roll force further analysis has been carried out to optimize the input parameters using Taguchi optimization method. The optimized input parameters for all the three alloys based on the maximum Von mises stress and roll force obtained are given table 3.8 to 3.10 for three different reductions.

Table3.8 Ideal Combination of Parameters During Hot Rolling of AZ31, AZ61 & AZ91 Mg Alloys For 21% Of Reduction

Material	Temperature	Speed (rpm)	Frictioin	V M S Stress	Roll Force

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	(^{0}C)			(M Pa)	(N)
AZ31	400	16.62	0.2	73.2968	494806.5
AZ61	400	16.62	0.2	77.971	4068.79
AZ91	400	16.62	0.2	499.427	2648.28

Table3.9 Ideal Combination of Parameters During Hot Rolling of AZ31, AZ61 & AZ91 Mg Alloys For 31% Of Reduction

Material	Temperature (^{0}C)	Speed (rpm)	Frictioin	V M S Stress (M Pa)	Roll Force (N)
AZ31	350	16.62	0.2	65.1834	7262.4
AZ61	400	16.62	0.2	78.575	4305.77
AZ91	400	16.62	0.2	101.988	4123.25

Table3.10 Ideal Combination Of Parameters During Hot Rolling of AZ31, AZ61 & AZ91 Mg Alloys For 39% Of Reduction

Material	Temperature (^{0}C)	Speed (rpm)	Frictioin	V M S Stress (M Pa)	Roll Force (N)
AZ31	350	16.62	0.25	84.4908	8313.5
AZ61	400	16.62	0.2	97.54	4968.7
AZ91	400	16.62	0.2	101.183	1187.8

4. CONCLUSION

The present analysis for hot rolling of Mg alloys AZ31, AZ61 & AZ91 provide the behavior of process parameters Von mises stress, and Roll force on three different percentage of reduction with varied input parameters. From the analysis following observations are made as shown below.

Considering the von mises stress and roll force obtained during hot rolling of AZ61 it has found as increase in percentage of reduction will enhance Von mises stress and roll force value. But comparatively roll force has maximum increase with the increase in percentage of reduction.

Analysis of influence of input parameters on von mises stress and roll force are made by taking AZ31 alloy hot rolled for 21% of its initial height. From which following observations are made

- ✓ Increase in initial temperature & co efficient of friction will decrease the von mises stress and in comparison with co efficient of friction have higher effect on changing von mises stress value. While Roller speed have direct effect over the von mises stress, i.e, if the roller speed increases von mises stress also increases.
- ✓ Input parameters roller speed and initial temperature have reverse effect on roll force. If we increase the roller speed or initial temperature roll separating force declines. In other case if we increase the value of co efficient of friction it will increase the rolling force during rolling process
- ✓ Also from all the results of Von mises stress and roll force obtained for three different reductions during hot rolling of AZ31, AZ61 & AZ91 we can conclude 4000C temperature, 16.62 rpm speed and 0.2 co efficient of friction are the ideal parameters from which minimal values of von mises stress and roll force obtained. This will improve the product quality and integrity after rolling.

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