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ROLL SPEED MAPS FOR HOT ROLLING PROCESS DESIGN

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ABSTRACT

In metal forming processes, the behavior of the metal undergoing large plastic deformation is affected by the dynamic or strain rate effects of the material. Since both of' the material and mechanical effects are correlated with each other in the forming processes, they are effectively treated by the computer simulation which can take account of strain rate effect. The dynamic material modeling (DMM) is a proven technique for studying constitutive behavior of materials. In this study Roll Speed Maps (RSM) are generated using simulation and DMM, which are used to select the optimum roll speed for different frictional conditions.

Keywords: *Hot Rolling, Dynamic Material Modeling and Finite Element.*

1. Introduction to Wear

Hot rolling is widely used metal forming process. Due to recrystallization, hot rolling reduces the average grain size of a metal while maintaining an equiaxed microstructure. In this process control of microstructure evolution during rolling operation is difficult due to lack in knowledge of optimum processing parameters. This results in undesirable microstructure in the product. During the hot rolling, the strain rate, rolling temperature, pressure of roller, friction condition and percentage thickness reduction have important effects on the microstructure evolution in the final product. [3] investigated the importance of the initial rolling temperature on the microstructure evolution during and after hot rolling of AA6082 using FE package FORGE3. A physical model based on dislocation density, sub grain size and disorientation was used to calculate the grain size evolution and the recrystallized volume fraction after hot working. [8] proposed an analytical method for predicting the exit cross sectional shape of work piece for the oval-round pass rolling, which is most widely used in the role mill around world. A rolling speed dependent spread model was proposed for predicting the exit cross sectional shape in oval-round pass rod rolling process when the rolling speed was very high. [2] conducted the analysis of strip rolling using FEM and numerical integration techniques. Incremental approach was adopted for obtaining required elasto-plastic stress-strain matrix. Similar analysis has been carried out by means of numerical integration method considering the pressure before and after neutral point. [5] emphasized unsteady state heat transfer equation with time-dependent boundary conditions, as well as a two-dimensional finite element method, to determine work-roll temperature variations during continuous hot strip rolling.

The aim of the present work is to generate roll speed map for different percentage of thickness reduction and to determine an optimum roll speed using these roll speed maps (RSMs). For this purpose rolling process of aluminum 6061 alloy of 20 mm thickness in plate form, at recrystalization temperature of 550 ^{0} C is carried out using dynamic material modeling technique and stress, strain rate and contact pressure are assessed to generate rolling speed maps (RSMs).

2. Dynamic Material Modeling (DMM)

DMM is based on relationship between the deformations, which include visco-plastic heat generation, and the energy dissipation associated with the microstructural mechanisms occurring during deformation. DMM uses a non-dimensional iso-efficiency index (η), which is given as [4],

$$\eta = \frac{m}{1+m} \qquad (1)$$

Where m is the strain rate sensitivity of the material. The plot of iso-efficiency (η) values on the temperature-strain rate axes with the interpreted deformation mechanism mapped on to the plot constitutes the 'processing map'. The regions of high efficiency regime are the desirable regions for the processing. The true stress – plastic strain values, at

**Corresponding Author - E- mail: kkpathak1@rediffmail.com* different strain rates, are required for computing the efficiency factor (η). The procedure of generating the map is presented elsewhere [4]. In Fig.1, processing map for Al 6061 is shown. It can be observed, maximum efficiency is corresponding to 550^0 C and $0.03s^{-1}$ strain rate. The highest efficiency corresponds to dynamic recrystalization, which implies good workability of material. DMM has been successfully used for designing of metal forming processes [4]&[7].

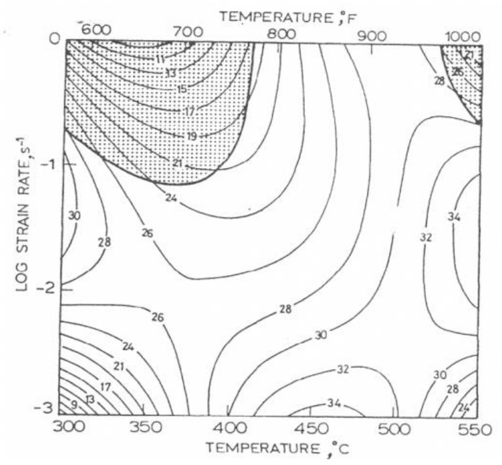

Fig. 1 Processing Map of Steel AL 6061

3. Rolling Process Simulation

The rolling simulation of aluminium alloy 6061 is carried out using MSC.SuperForge software [9]. The roller diameter and plate thickness are considered as 150 mm and 20 mm respectively. Twenty-seven cases are simulated considering varying friction, roll speeds and % thickness reduction. The processing temperature is 550° C as per the DMM. The flow stress used for hot rolling, σ is a function of effective strain rate, $\dot{\varepsilon}$ and given by,

$$\sigma = C\dot{\varepsilon}^n \qquad (2)$$

where the material constants C and n are strength coefficient and rate hardening exponent. The values of C and n for Al6061 are adopted from the software database as 40.00 MPa and 0.126 respectively [9]. Three values of friction (Coulomb) viz. 0.3, 0.4 and 0.5 and three roll speeds viz. 1, 3 and 5 rpm are considered in the simulation. The CAD model is shown in Fig.2. The CAD model is generated in I-deas software and exported to MSC.SuperForge. The maximum values of flow stress, flow strain, effective strain rate and contact pressure for 10, 15 and 20 % reductions in thickness are given in Table 1, Table 2 and Table 3. Typical distributions of strain rate, stress, strain and contact pressure in the rolling process are shown in Fig.3, 4, 5 & 6 respectively.

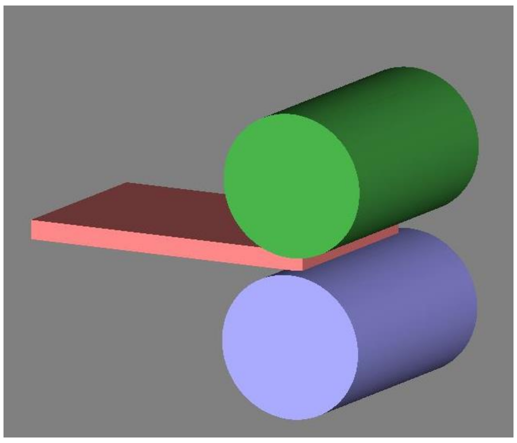

Fig. 2 CAD Model of Rolling Setup

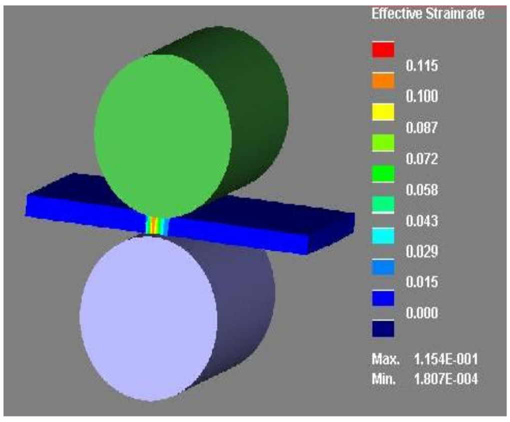

Fig. 3 Contour of Effective Strain Rate Distribution

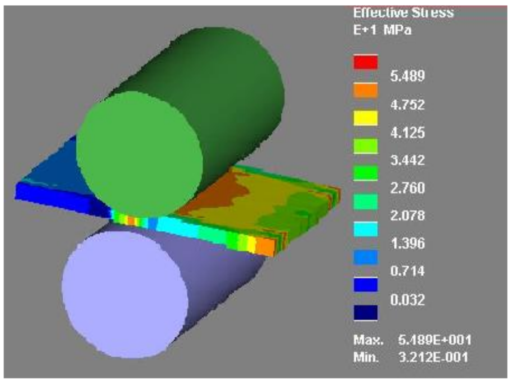

Fig. 4 Contour of Effective Stress Distribution

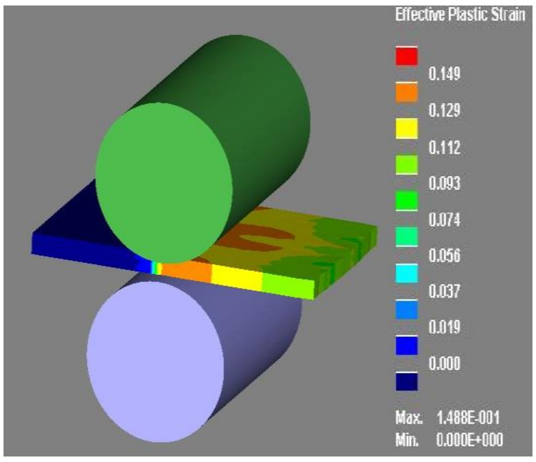

Fig. 5 Contour of Effective Plastic Strain Distribution

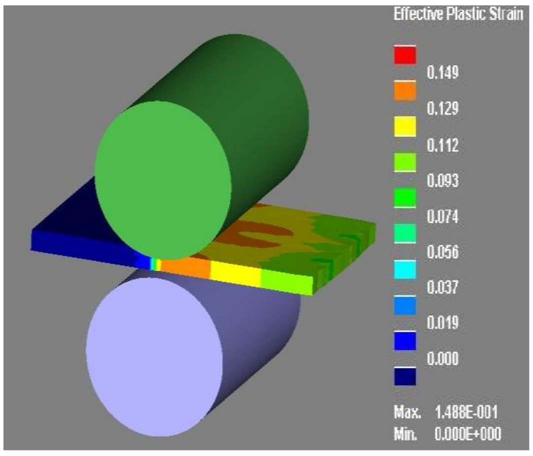

Fig. 6 Contour of Contact Pressure Distribution

Table 1: Simulation Results (10% Reduction)

S.No	Friction	Roll speed in RPM	Effective Strain	Effective Stress (MPa)	Effective Strain Rate s^{-1}	Contact pressure (MPa)
1	0.5	1	0.0416	25.53	0.022	16.79
2	0.4	1	0.0409	29.01	0.0171	18.06
3	0.3	1	0.04	31.12	0.0132	20.42
4	0.5	3	0.0399	18.22	0.047	12.04
5	0.4	3	0.0376	17.04	0.057	12.69
6	0.3	3	0.0393	20.9	0.031	13.1
7	0.5	5	0.0414	16.76	0.073	11.4
8	0.4	5	0.0396	16.49	0.063	11.23
9	0.3	5	0.0386	16.55	0.051	11.6

Table 2: Simulation Results (15% Reduction)

S.No	Friction	Roll speed in RPM	Effective Strain	Effective Stress (MPa)	Effective Strain Rate s^{-1}	Contact pressure (MPa)
1	0.5	1	0.064	27.31	0.0274	19.29
2	0.4	1	0.062	30.71	0.024	28.53
3	0.3	1	0.065	27.63	0.0273	21.77
4	0.5	3	0.064	18.64	0.078	17.15
5	0.4	3	0.063	20.38	0.057	14.44
6	0.3	3	0.065	18.64	0.06	19
7	0.5	5	0.065	16.21	0.103	15.45
8	0.4	5	0.061	17.51	0.07	15.2
9	0.3	5	0.056	21.3	0.457	16.23

Table 3: Simulation Results (20% Reduction)

S.No	Friction	Roll speed in RPM	Effective Strain	Effective Stress (MPa)	Effective Strain Rate s^{-1}	Contact Pressure (MPa)
1	0.5	1	0.09	31.35	0.035	30.14
2	0.4	1	0.083	35.64	0.0329	46.7
3	0.3	1	0.063	31.92	0.0081	27.95
4	0.5	3	0.089	21.56	0.074	21.82
5	0.4	3	0.083	24.33	0.053	21.65
6	0.3	3	0.069	32.1	0.0391	33.45
7	0.5	5	0.092	18.41	0.09	16.15
8	0.4	5	0.084	20.59	0.088	18.28
9	0.3	5	0.074	27.6	0.058	26.27

4. Roll Speed Maps

Using the simulation results given in Table 1, 2 & 3, roll speed maps are generated using Surfer software [10]. These maps for 10,15 and 20% reductions in plate thickness are shown in Fig. 7, 8 and 9. From the processing Map of Al 6061, as shown in Fig. 1, optimum strain rate is $0.03s^{-1}$. For this strain rate and given friction, optimum roll speed can be selected for the given % reduction in plate thickness. For 10% thickness reduction and coefficient of friction of 0.3, the optimum roll speed should be 3 rpm. For 15% reduction in thickness, required roll speed should be more than 5 rpm at al friction values. For 20 % reduction in thickness and coefficient of friction 0.4, the optimum roll speed should be 2 rpm. These maps will prove to be handy tool for design engineers in the selection of optimum roll speed.

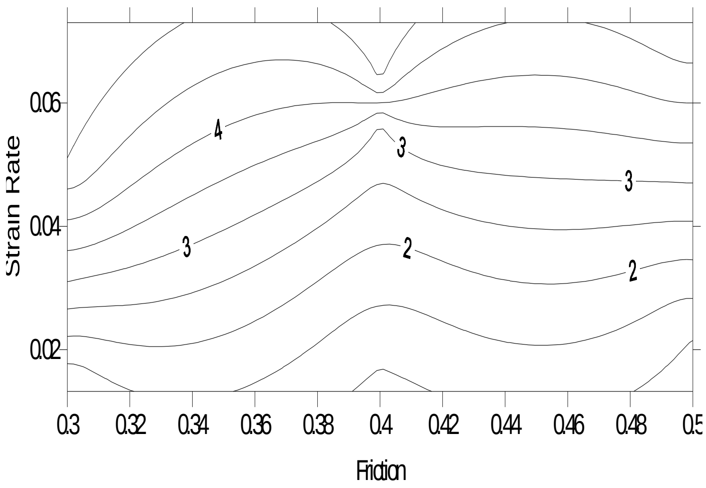

Fig. 7 Roll Speed Map (10 % Reduction in Thickness)

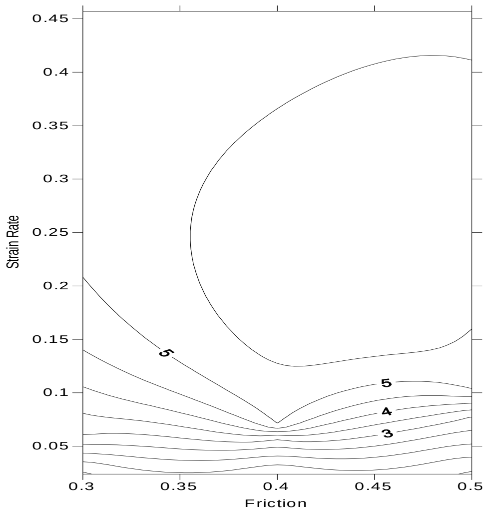

Fig. 8 Roll Speed Map (15 % Reduction in Thickness)

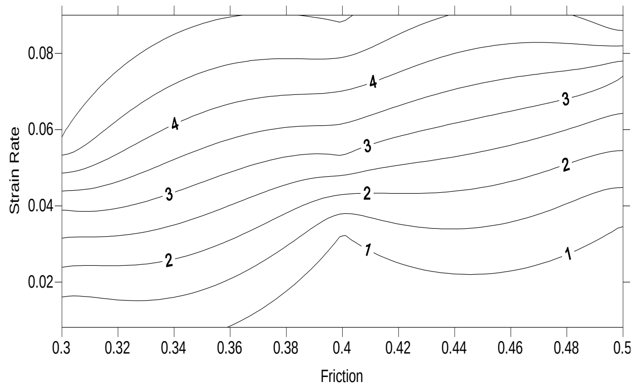

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Fig. 9 Roll Speed Map (20 % Reduction in Thickness)

5. Conclusion

In this study roll speed maps are proposed for selection of optimum roll speed using computer simulation and DMM. For given friction and plate thickness reduction, roll speed may be selected to result in desirable microstructure in the rolled product. These maps can be extended to other materials as well. Such design tools will be very useful for industries in taking quick decisions on critical design issues.

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