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Numerical modelling of hot roll bonding process

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Abstract

The roll bonding process is a preferable production method to manufacture multilayer sheets and it needs clear investigation because some industrial parts cannot fulfill all of the requirements of single-layer material. In this study, a numerical model of hot roll bonding of AlSi alloy has been explored using Marc Mentat 2020 finite element code. A uniaxial compression test experimental study was conducted using GLEEBLE 3500 thermo-mechanical simulator machine at different temperatures and strain rates to determine the thermomechanical properties of the material. In the finite element modeling of the process, the working temperature was set at 400 °C and only the flow cure of the material at a specified temperature was considered. The effect of contact pressure between the sheet and between the sheet and roller in the deformation zone of the process to analyze the bonding characteristics was defined. The simulation results indicated that the liner thickness and reduction ratio are important parameters to determine the total deformation zone and it affected the contact pressure. Unbonded length of deformation becomes a serious problem as increasing of the thickness ratio of the sheet. The good bonding strength was found at a higher reduction ratio of the process and at a smaller thickness ratio of the sheet.

1 Introduction

Some industrial parts cannot meet all the required properties of single-layer materials. Multilayer sheets are therefore in high demand in the automotive, aerospace, and electronics industries [1]. Flat rolling is suitable for manufacturing sandwich sheets because applying sufficient contact pressure between the layer is the best option to create a joint. This is a more efficient and economical method [2]. Flat rolling is a common continuous metal forming process that reduces sheet metal by passing it between a pair of rotating cylindrical rolls.

Da Silva and Laurie also studied the cold roll bonding of aluminum alloys and steel and discussed the effects of key process parameters on cold roll bonding and bond strength [3]. Advances in cold-rolled metal joining are described by Li Long, Kotobu Nagai, and Fuxing Yin [4]. The surface preparation-related process parameters that affect bonding were discussed and their potential to help handle roll bonding in the future. G Szabó also investigated an experimental study of hot roll bonding to optimize the bonding properties of clad aluminum sheets using a roll mill [5]. These were considered as AlMn1Si0.8 and AlSi7 core and liner materials, respectively. Both lap shear and T-peel tests were performed to determine bond strength. Pan SC and Huang studied the roll bonding of unbonded clad sheets under constant shear friction at both room temperature and elevated temperature [6]. The authors developed a new analytical approach for asymmetric roll cladding of clad sheets to find different stress distributions easily and quickly. Lee C.H. and Park J.P. studied the warpage behavior caused by the elongation mismatch in flat rolling of two-layer sheets based on differential analysis [7]. Use FORGETM as a finite element code to support the investigation. Han J and Niu H studied the effects of mechanical surface treatments on the joining mechanism of the cold roll joining process [8]. The authors used both lap shear and peel tests to describe the properties and bond-strengthening mechanism of cold-rolled Cu/Al clad sheets.

In this study, the effects of the rolling reduction ratio and liner thickness of the sandwich rolling process on the deformation region and bond strength of the sandwich roll bonding process were numerically investigated. A numerical model for hot-rolled joining of AlSi alloys was investigated using the Marc Mentat 2020 finite element code. A GLEEBLE 3500 thermomechanical simulation machine was used to perform uniaxial compression tests at various temperatures and strain rates to determine the thermomechanical properties of the materials.

2 Finite element modeling

Finite element models (FE) in this study were performed using Marc Mentat commercial FE software. reactions, The FE model developed for this study considered 2D axisymmetric fully Hermann-formulated quad elements and a finer mesh with assuming isotropic material model. The model consists of a rigid roller and three deformable workpieces. The half-section geometrical model of the multilayer rolling process is shown in Figure 1 The roller is completely arrested at all degrees of freedom and can only free to rotate counter-clockwise. The simulation work plan and process parameters are summarized in Table 1. All contact between the work and roll was treated as hard contact, an arctangent (shear) model with a coefficient of friction of 0.3 was used, and a coefficient of friction between sheets of 1 was assumed. The constant thermal parameters used in the simulation are shown in

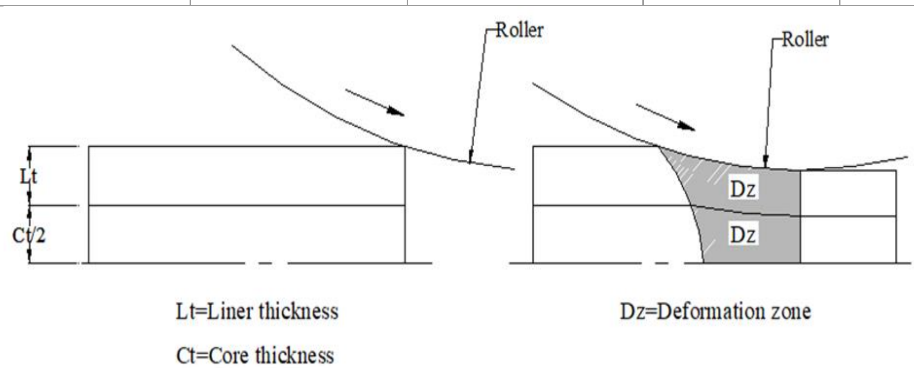
Table 2.

Table 1. *Simulation work plan summary*

Roller diameter, (mm)	*Liner thickness, (mm)*	*Roll speed (rad/sec)*	*Core thickness, (mm)*	*Percentage reduction (%)*
220	*2.5 & 7.5*	*2.272*	*20*	*1.25, 2.5, 5, 10, 15 and 20*

Table 2. *Constant thermal process parameters*

Workpiece temperature (°C)	*Roller temperature (°C)*	*Heat transfer coefficient (kW/m2·°C)*	*Film coefficient (W/(m2·°C))*	*Thermal Conductivity (W/m·°C)*	*Specific Heat Capacity (J/(kg·°C)*
400	*20*	*20*	*$25x10^{-3}$*	*154*	*893*



(a) *(b)*

Figure 1. Geometrical model of the multilayer rolling process: (a) before rolling, (b) after rolling

2.1 Material characterization

Material characterization has become an inevitable part of the development of modern manufacturing technology, in addition to mathematical modeling. It gives the material properties as functions of temperature and many other technological parameters to the modelling software as initial data for calculations.

An experimental series were carried out to give the material characteristic of the AlSi7 aluminum alloy. The effect of the temperature and the forming rate were studied on the formability especially the compression characteristic of the alloy performing on-heating compression tests.

The used system is the GLEEBLE 3500 is a fully integrated, digitally controlled thermomechanical testing scheme with software interface and data acquisition possibilities. It ensures the required conditions during the material characterization. Thermocouple at the middle of the sample gives the feedback to the temperature control and allows to keep temperature aberration less than 5°C during the whole test. A powerful hydraulic system proofs the piston speed up to 1000 mm/s, which gives the forming rate stable in wide interval.

Based on numerous preliminarily experiments the sample geometry and dimensions were established as cylinder with a diameter of ∅10 mm and a height of 18 mm. This specimen height was found to be sufficient to keep the forming rate stable at the test forming rates used.

Before fitting the specimen between the pressure jaws, two very important steps must be taken in order to ensure a successful test and to protect the equipment. Nickel based grease was used on the compression jaws to make easy the detachment of the sample after the test. In addition, graphite based plate was used to reduce friction between the jaw and the specimen surface during the forming. It is essential to avoid the barreling as it is possible and keep the diameter of the specimen almost constant along the longitudinal axis. Two pictures can be seen in Figure 2 of a specimen before and after the experiment fitted into the test equipment.

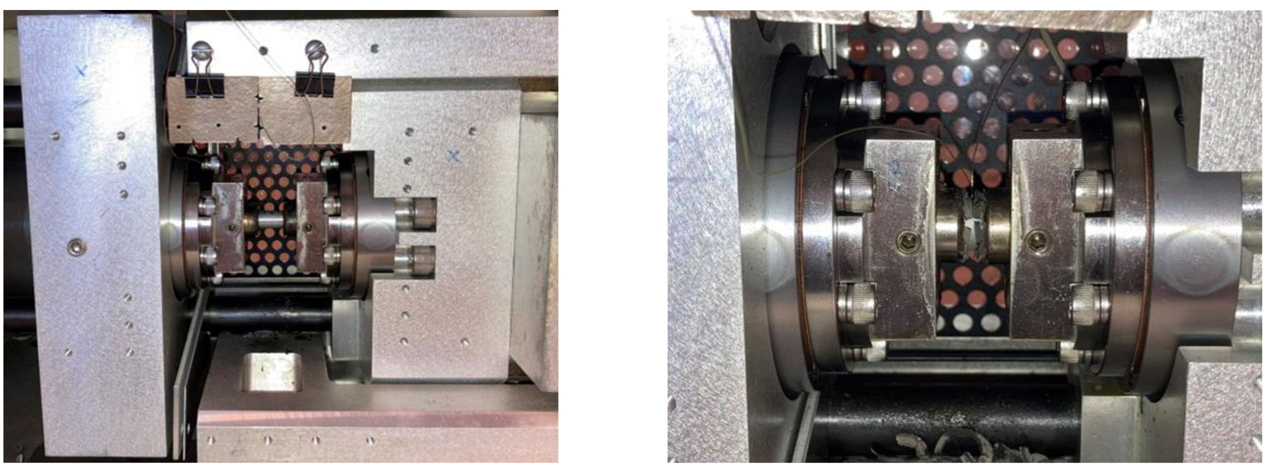


Figure 2. Experimental setup. The specimen before and after the experiment.

Five temperature levels, 350, 400, 450, 500, and 550°C and four different forming rates 0.001, 0.01, 0.1 and 1 1/s were applied during the experimental series. Therefore, twenty different test conditions were studied. All the experiments 1 mm/mm true strain, therefore 6.62 mm compression were applied on the samples.

The test begins with heating up to test temperature. The heating rate is 5°C per seconds. After that, 30 seconds soaking time is applied to make homogeneous the temperature filed alongside the specimen. Than the compression starts and finally the sample cooling down to room temperature. The temperature cycle can be seen in Figure 3.

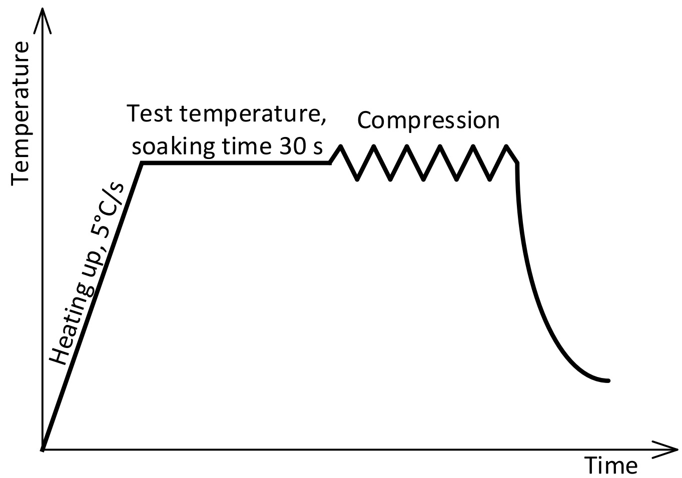


Figure 3. The temperature cycle during the investigation

The curves of the tests performed with a forming rate of 0.01 1/s and at 350°C can be seen in Figure 4 and Figure 5

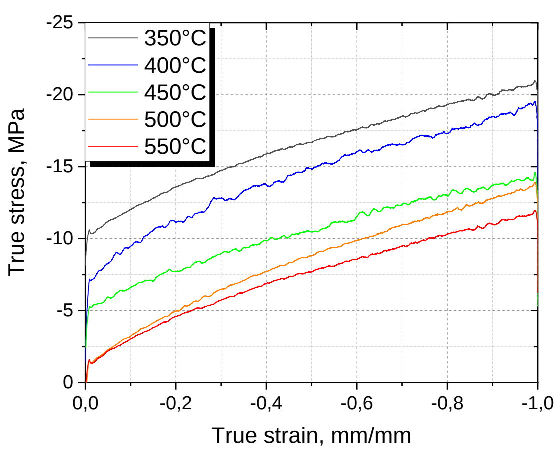


Figure 4. On-heating compression tests made with 0.01 1/s forming rates

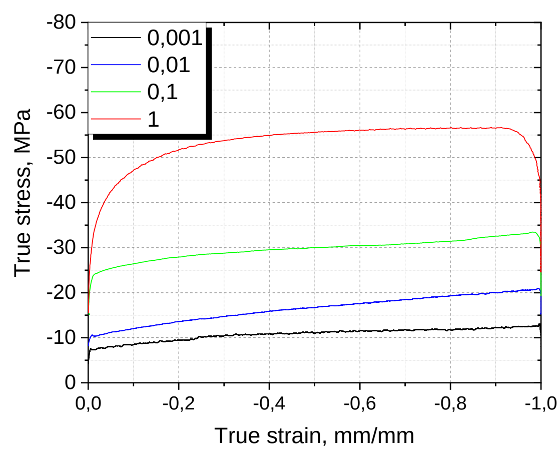


Figure 5. On-heating compression tests made at 350°C

In the case of tests carried out at different temperatures with the same forming speed, the effect of temperature is clear. As the temperature rises, the resistance of the material to compression decreases. In addition, opposite statement can be made in case of the forming rate. As the test carried out with different forming rate at same temperature the resistance of the material to pressure increases, as it can be seen in Figure 5.

3 Results

In this study, we considered the general assumption that bonding between sheets begins when the contact pressure reaches the yield strength of the weaker material. The contact pressure distribution from the FEM simulation is shown in Figure 6 Figure 7 graphically illustrates the effect of liner thickness and the reduction in normal contact pressure along the deformation length between sheets and between roll and liner sheet. The graph clearly explains that the normal contact pressure increases as the thickness of the liner and reduction ratio decreases.

The normal contact pressure between sheets approaches the normal contact pressure required between roller and liner at higher reduction ratios as liner thickness decreases. The effect of liner thickness on bond strength was assumed at the maximum contact pressure reaching the flow curve of the material. Increasing the thickness of the liner reduces the strength of the bond. It also decreases as the reduction ratio increases due to the large threshold area of the contact interface.

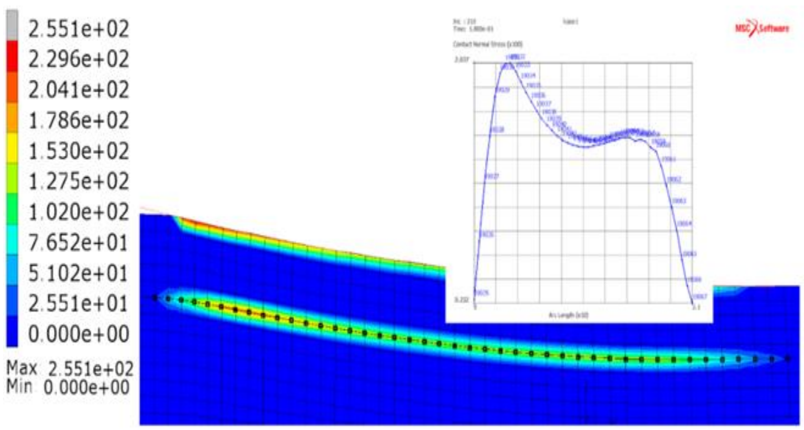
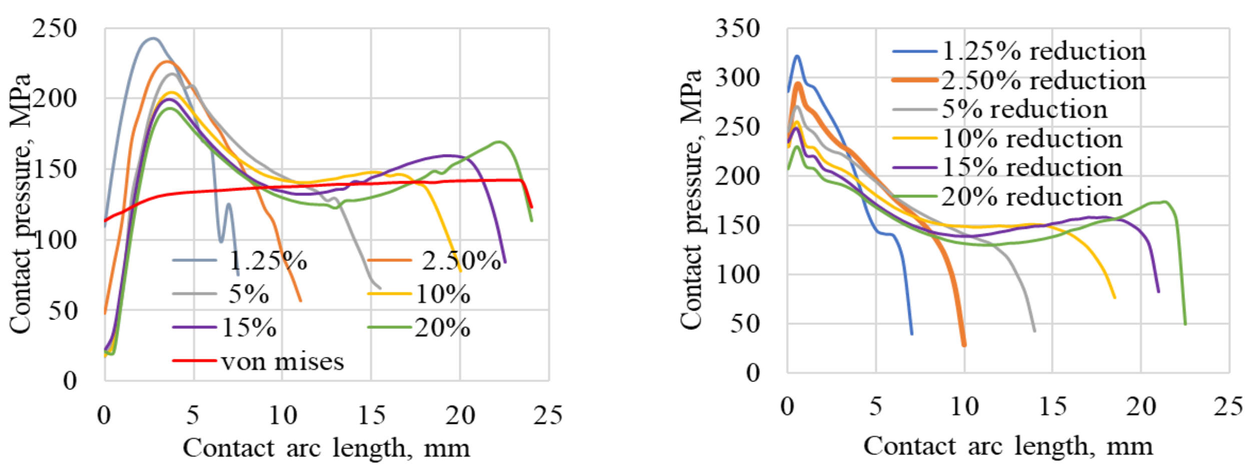
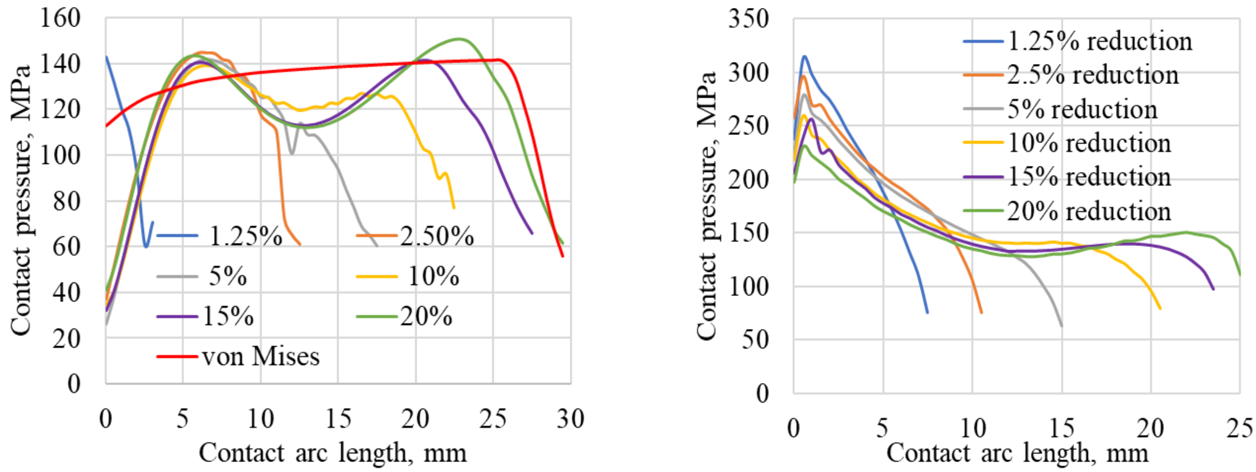


Figure 6. Contact pressure distribution during the rolling process.



(a) (b)



(c) (d)

Figure 7. Normal contact pressure distribution along the deformation length: (a) between sheets at 2.5 mm liner thickness, (b) between roller and sheet at 2.5 mm liner thickness, (c) between sheets at 7.5 mm liner thickness, (d) between roller and sheet at 7.5 mm liner thickness.

4 Summary

Numerical modeling and simulation can be used to understand and predict deformation zones in hot roll bonding of multilayer sheets. The normal contact pressure required between the roller and liner and between each sheet interface requires accurate calculations to analyze the bonding state of the deformation zones. The magnitude of the liner thickness has a significant impact on the magnitude of contact pressure transmission from the roller-sheet interface to the interface of both sheets. Finally, this study establishes that liner thickness and reduction ratio are important parameters that influence the required contact pressure in the deformation zone of the process.

5 Acknowledgement

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