ANALYSIS OF TEAR-OFF OF BONDED LAYERS IN FURTHER ROLLING 3-LAYERED ALUMINUM SHEETS

Gábor SZABÓ [1], Tamás MIKÓ [2], Csaba PUSKÁS [2], Máté SZŰCS [2]

[1]Institute of Metallurgy, University of Miskolc, Miskolc, Hungary, EU
szabogabor@uni-miskolc.hu

[2]Institute of Physical Metallurgy, Metallforming, and Nanotechnology, Miskolc, Hungary, EU
femmiko@uni-miskolc.hu, fempcs@uni-miskolc.hu, femszmat@uni-miskolc.hu

Abstract

Aluminum plating technology is used worldwide, not only in the automotive industry but also in household items. The essence of the technology is that a layer with a certain property is plated with another layer with different properties. The understanding of the bond development is highly important, because these sheets have high added value. In this study the tear-off of three layer-plated aluminum sheets are investigated. The alloys applied in specific layers were as follows: AlMnMg025Si08 (core alloy) and AlSi12 (liner). The bonding was performed on a Von Roll experimental roll stand mill using hot rolling. The experimental temperature was 300 °C, respectively. Furthermore, this study covers the analysis of tear-off of bond of 3-layered aluminum sheets, for dynamically hardening liner layer and less dynamically hardening core sheets. In the simulation the core material was an AlMnMg025Si08 alloy, the liner was AlSi12. The material properties for the calculations come from material databases. Analyses were backed by means of finite element method as well as experimental way. The applied softwares were Simufact forming 14 included Simufact Material database and MSC Marc. The tear-off of bond was tested in one pass with various reductions, which were 1.33, 1.99, 2.66, 3.32, 6.64, 9.97, 13.29, 16.61, 19.93, 23.26 and 26.58 %, respectively, the deformation temperature was 300 °C. From the calculations we get six differential zones where the layers prolongation is different. It has a different effect on tear-off of bonded layers. If all passes are kept in the optimal reduction zones to avoid the tear-off of bonded layers.

Keywords: Adhesives, rolling, plasticity, computer simulation, brazing, roll bonding, aluminium

1. INTRODUCTION

The main issue in the fabrication of multi-layer Al plates used in the automotive and aircraft industry is the matter of plateability, the classification of bond development between layers. The purpose of plating is to roll aluminum alloys of various properties and thicknesses together so that a bond is formed between the specific layers and by rolling further, the desired layer thickness is obtained at the final thickness. Many international researchers have been dealing with this issue among whom roll bonding was the most widespread researched. In such a case 2 layers are rolled together in a way that the contact line of layers be located in the centre between the two rolls.

In contrast to this technology, the effect of layer thicknesses cannot be neglected in the rolling of 3-layered plate. The process taking place depends largely from the geometrical conditions.

The professional literature has covered several times the bond development of the so-called sandwich sheets with such a geometry, so did we earlier.

In some previous studies it was determined clearly that rolling by plating is a welding procedure where weld occurs due to surface pressure. It was also determined that bond strength is proportional to the volume of deformation for symmetrical and identical layer thicknesses. [1-6] Bond development occurs if deformation reaches a critical value and if not, the bond development cannot be ensured. [1-3, 6] However, if deformation has reached the critical value, by its increasing bond strength rises until the yield strength of the softer material. [1-2, 6-7] Of course, this threshold can be determined but this differs from material pair to material pair. [1-2, 4] Furthermore, bond strength and bond formation depend not only from these, but they do also a great deal from surface preparation and temperature. [1-2, 4-5, 8] We investigated bond formation in an earlier study of ours. We determined that on reaching a limit value, the bond strengthens but after attaining another value the bond is expected to tear off. [9] We determined in our further experiments that bond between layers is proportional to the volume of reduction applied in a pass that is the higher the reduction the larger the surface over which layers adhere to each other but the layers leaving the roll gap or near the exit part tear off immediately due to different elongation conditions as a result of tangential stress [10]. Considering these determinations we started to investigate processes around tear-off.

2. EXPERIMENTS

2.1. Equipment

The physical tests were carried out on a Von Roll roll mill located at the Institute of Physical Metallurgy, Metalforming and Nanotechnology at the University of Miskolc. The roll arrangement is in duo modus, whereas the duo mill can also run in reverse mode. The applied work roll diameter: 220 mm, whereas the roll body length: 220 mm. The surface roughness of rolls: R_a = 0.3 mm. The maximum achievable rolling force is: 1 MN, the maximum rolling torque is: 1 kNm, whereas roll speed can vary between 0 - 10 m min^{-1}.

2.2. Materials and the samples

The materials used for the experiments were the following. The core material was an AlMnMg025Si08 alloy, the liner was AlSi12. The tests were performed at 300 °C. The experimental packages had a width of 100 mm and a length of 200 mm. **Figure 1** shows the layer thickness. The duration of preheating was 120 min.

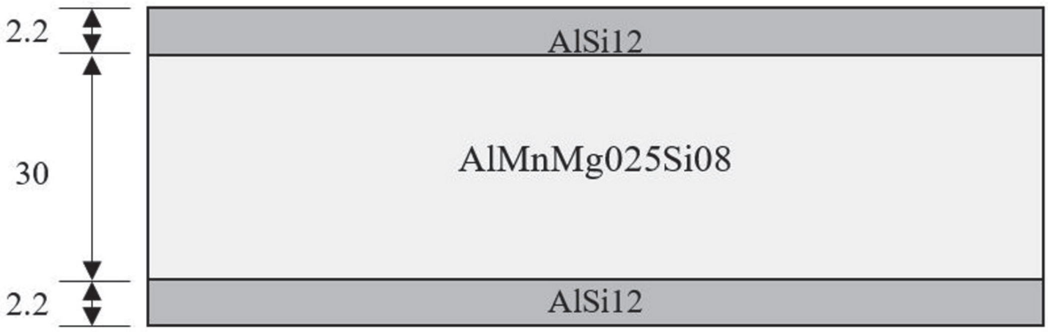
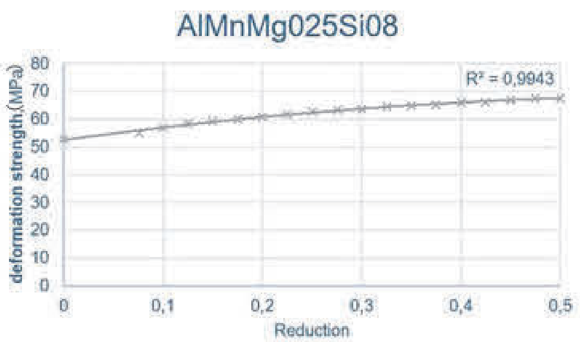


Figure 1 The layer thickness of package prepared for rolling

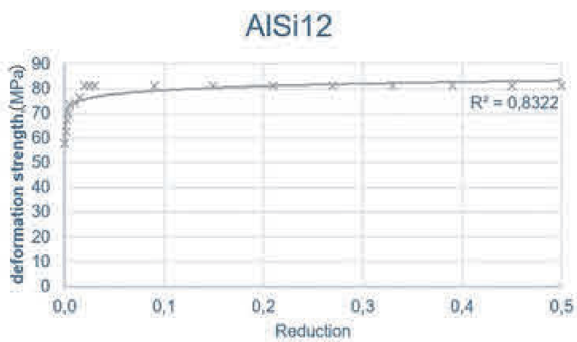
Table 1 lists the chemical composition of applied materials while the Yield strength of specific materials at 300 °C are shown in **Figure 2**.

Table 1 The chemical composition of the AlSi12 and AlMnMg025Si08 alloys (wg. %)

Alloy	Si	Fe	Mn	Zn	Mg	Cu	Al
AlSi12	12.0	0.6	0.3	0.2	0.1	0.05	rest
AlMnMg025Si08	0.8	0.3	0.6	0.1	0.25	0.05	rest



a.



b.

Figure 2 Yield strength at 300 °C

2.3. Procedure

During our experimental work, we created bond between layers of the experimental packages via „cementing“ passes. We rolled further the bond developed so in a warm state according to various pass plans. In specific cases, it was possible to roll without bonds tearing off, while in other cases layers tore off due to different elongations. Such a tear-off is shown in **Figure 3**.

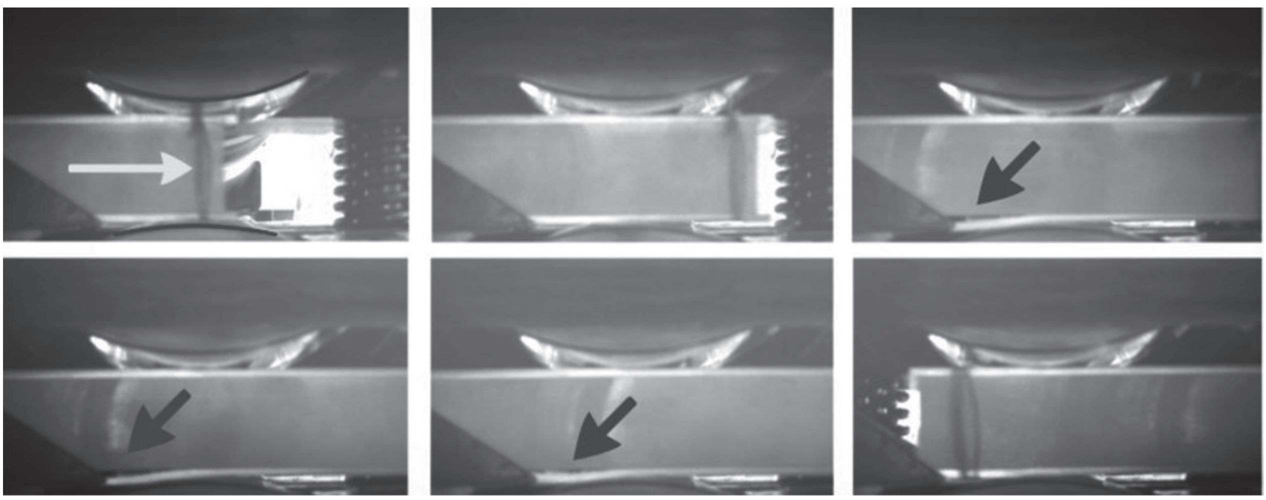


Figure 3 The bond already developed tears off already in the roll gap due to different elongation conditions (one-pass time sequence)

2.4. FEM model

It is important to define the pass plan as reductions to be applied in specific passes from the point of view of preventing bond tear-off as well as defects appearing at the final thickness, by means of which the sheets already having bond can be rolled further with bonds persisting at all times.

Simulation tests were carried out using the software MSC Marc based on the following approach. The roll in the model is an analytical circle, whereas the bond between the sheets in contact is provided by „glued contact type“ elements. The tangential stress needed for the break-up of bond can be calculated according to Equation 1:

$$\tau_{debonding} = \frac{k_{f,\min}}{\sqrt{3}} \qquad (1)$$

2.5. Prediction

As the thicknesses and deformation strengths of specific layers differ, because of different elongations expected in various reductions there is a reduction range where the elongation of layers is almost identical. In rolling in this range, the persistence of developed bond can be granted.

3. RESULTS AND DISCUSSION

We already proved in an experimental way earlier that the development of bond can be ensured with a reduction of 1 to 2% for a similar material pair [9, 10]. The 3-layered sheets produced this way were rolled in one pass at various reductions.

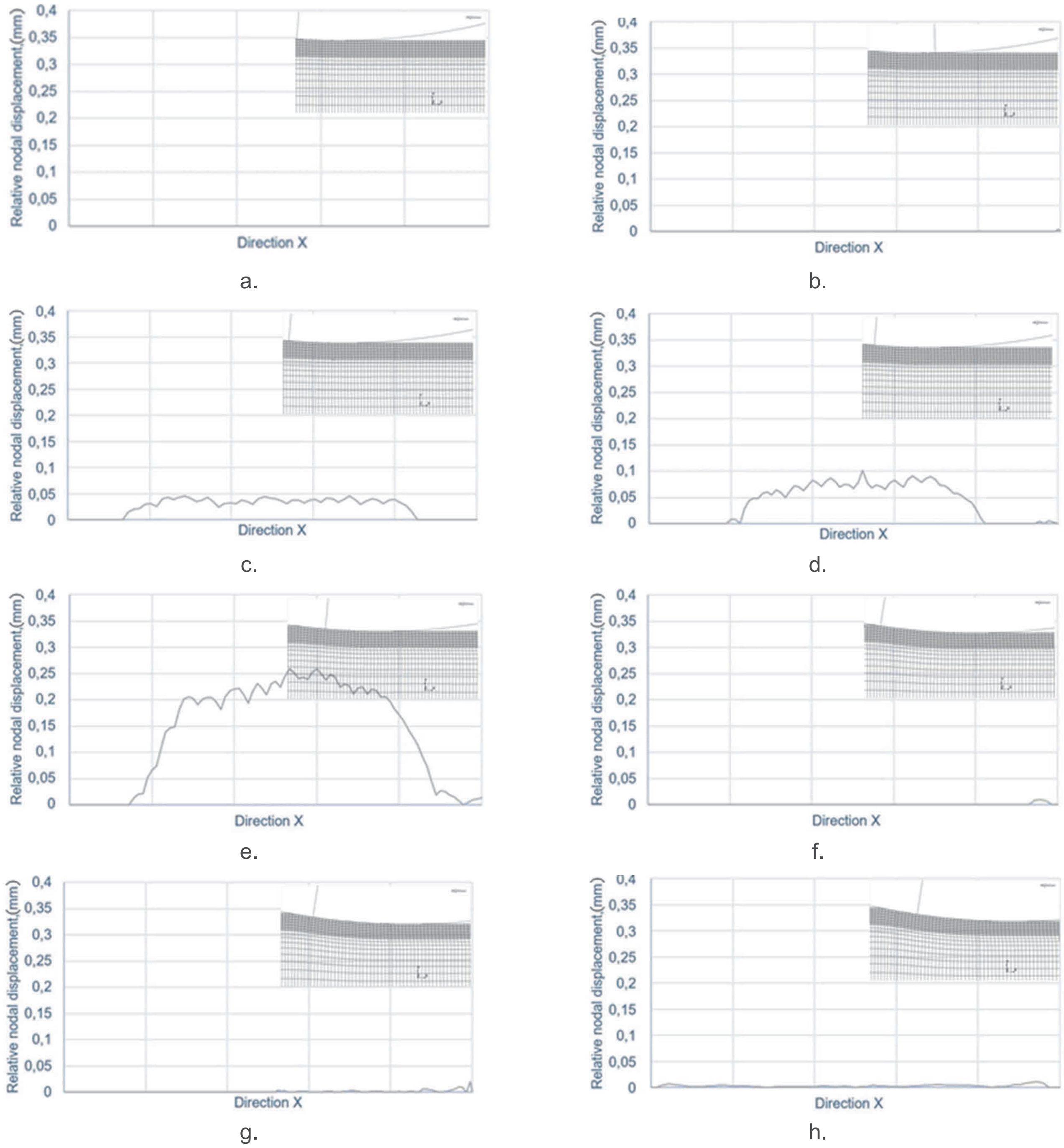
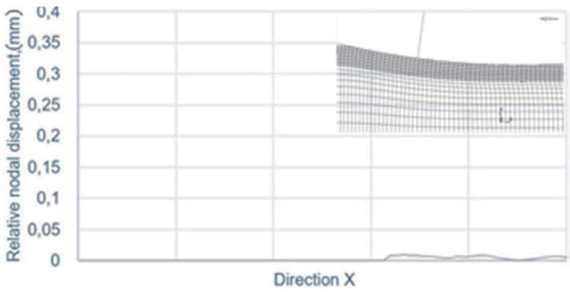
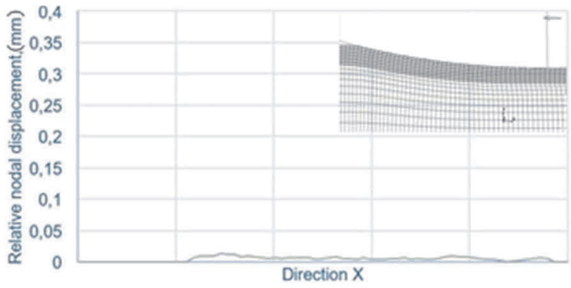


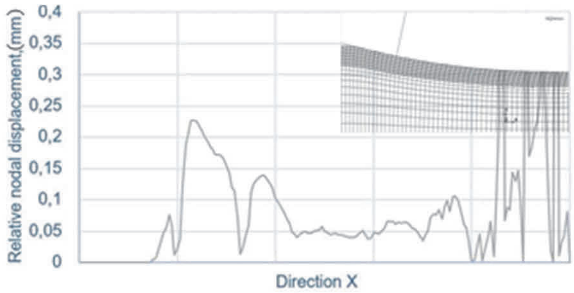
Figure 4/1 Relative displacement and nodal deformations in all passes



i.



j.



k.

Figure 4/2 Relative displacement and nodal deformations in all passes

Figure 4a reveals that the bond persists between the layers at all times and as a result the relative displacement of specific nodes is 0, too.

It can be observed that the point-like break-up between layers commences with 1.99% reduction on the output side but this appears only at nodes once in a while, locally. (**Figure 4b**)

By increasing the volume of deformation performed in the given pass it is well visible that the break-up between the layers commences in the roll gap and the layers detach technically over the entire contact surface. The relative displacement of the specific nodes as well. (**Figure 4c**)

By increasing the volume of reduction within the pass by 0.66% it is visible that the bond keeps breaking up and the relative displacement of the elements is almost doubled. (**Figure 4d**)

If the volume of reduction applied in one pass is increased further, it is visible that the bond also tears off and the relative displacement of the nodes of specific layers is higher than in the previous case. However, the start of tear-off shifts from the direction of input side towards the output side and the trend of relative displacement is turned as well. (**Figure 4e**)

By increasing the reduction by 1.5, it is visible that although layers tear off from each other but this tear-off can be observed on the output side of the roll gap only. The relative displacement of the contacting nodes can be observed on the output side of the roll gap, it can hardly be calculated technically. (**Figure 4f**)

If the volume of the reduction within one pass is further increased, it is well visible in **Figures 4g** to **j** that the bond technically persists between the specific layers at all times. It is also visible that the relative displacement of specific layers is almost 0.

By increasing reduction, the specific layers tear off from each other again, the relative displacement between the nodes starts as is shown in **Figure 4k**

If one examines the average displacement of nodes and depict these in function of reduction (**Figure 5**), 6 well distinguishable zones can be marked.

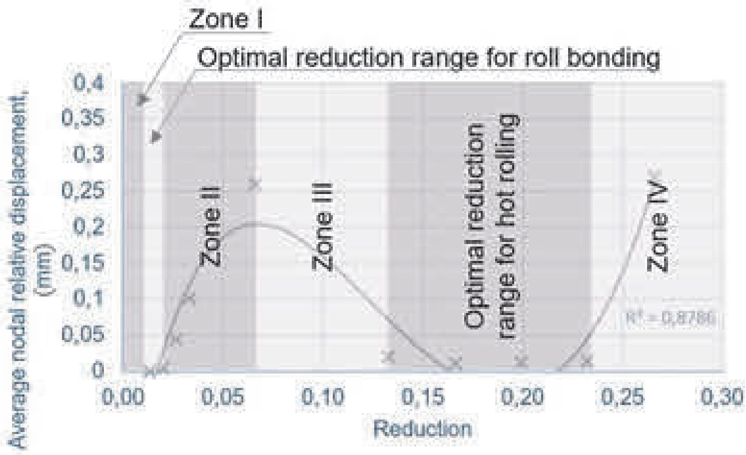


Figure 5 Average nodal relative displacement in function of reduction

In Zone I the reduction applied in one pass does not reach 1 %. In this case the desired bond cannot be established between the layers. If the reduction reaches 1 % but not 2 %, it can be proved in an experimental way that the bond develops under the selected geometrical ratios. In Zone II, the difference of elongation of specific layers keeps getting bigger namely in favour of the liner. If the volume of the reduction applied in one pass is 2 to 7 %, the elongation of the liner is larger than that of the core and as one increases the volume of reduction in this zone, the difference of relative elongations shall be larger between the layers, accordingly. In Zone III, it is still the elongation of liner that is bigger but in the zone of reduction of 7 to 13 % the higher the reduction the less large the relative slide between the layers that is the elongation of the core sheet in this zone gets more and more closer to that of the liner. The zone of reduction of 13 to 23 % can be called the hot rolling zone of the 3-layered sandwich sheet as layers in this zone elongate together. In Zone IV, where reduction attains or even exceeds 23 %, the relative displacement appears again but the elongation of layers shall be reverse. It is the core sheet that shall elongate more, this way it advances in relation to the liner in this zone.

4. CONCLUSIONS

As the thicknesses and Yield strengths of specific layers are different, we expected that a reduction zone existed where the elongations of layers are almost identical. The persistence of the developed bond can be ensured by rolling performed in this zone. We determined that outside the bond development zone defined earlier there is a reduction zone, in which the elongations of specific layers are almost identical, thus, the layers of sandwich sheet already with a bond can move together. Furthermore, it was possible to determine 6 reduction zones, in which the behaviour of layers can be well distinguished. These might serve as a proper basis for the design of various pass plans and technologies.

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