

INVESTIGATION OF PRODUCING DIFFERENT METALLIC SHEET COMPOSITE STRUCTURES BY ROLLING

^{1,2}Ramóna VESZPRÉMI, ²Gábor SZABÓ

¹HUN-REN–ME Materials Science Research Group, H-3515 Miskolc-Egyetemváros, Hungary, EU, veszpremi.ramona@student.uni-miskolc.hu

²University of Miskolc, Faculty of Materials and Chemical Engineering, H-3515 Miskolc-Egyetemváros, Hungary, EU, gabor.szabo@uni-miskolc.hu

<https://doi.org/10.37904/metal.2026.5276>

Abstract

The production of metallic sheet composites by rolling is a manufacturing route in which the quality of the bond between the layers directly determines the integrity and further processability of the final product. This paper is based on laboratory experiments carried out on clad aluminium sheets and examines the conditions under which a reliable bond can be formed during rolling. The work focuses on the basic bonding tests performed with a Ford-type tool, the rolling of three- and multilayer packages, the metallographic evaluation of the layer interface, and peel testing used for the quantitative assessment of bond strength. The investigated systems included AlMnCu/Al99.7/AlSi10 and AlMnSi/Al99.5/AlSi10 layer arrangements. The experiments were performed mainly in the temperature range of 480-520 °C, with total reductions between 40 and 80 %. The results showed that bonding cannot be interpreted as the effect of a single technological parameter. Temperature, reduction, surface condition, deformation compatibility of the layers and the elongation ratio between the cover sheet and the core material all have a decisive role. Based on the T-peel tests and metallographic observations, a technological window can be identified in which the first bonding passes support both the closing of the layers and the bond reliability required for subsequent rolling. The presented approach supports the preliminary laboratory assessment of metallic sheet composite structures and the planning of stable rolling schedules.

Keywords: Metallic sheet composite, cladding, rolling, pass design, bond quality

1. INTRODUCTION

Roll cladding is one of the most important industrial methods for producing multilayer metallic sheet composites. The basic principle of the process is that layers with different chemical compositions and different functions are subjected to common plastic deformation in the roll gap, while a welded-type bond is formed between the contacting surfaces [1]. From a metallurgical point of view, this bond cannot be interpreted as simple surface adhesion. It develops as a result of the combined effect of surface pressure, frictional conditions, temperature, local plastic deformation and, in some cases, diffusion processes [2-4]. For this reason, the technological design of roll cladding requires the joint evaluation of material behaviour, surface condition and rolling parameters.

The practical difficulty of the cladding process is that the formation of a reliable bond is not determined only by the selected material pairing. Temperature, the surface oxide film, degreasing, surface roughness, friction between the rolls and the workpiece, as well as the compressive stress and deformation state developing in the individual passes all influence the stability of the layer interface. Previous studies on warm, cold and hot roll bonding also confirmed that bond formation is strongly affected by rolling temperature, reduction, surface preparation, deformation state and the mechanical compatibility of the joined layers [5-9]. If the first bonding

passes do not create sufficient contact and local plastic deformation, the layers may remain unbonded. In contrast, if the reduction is too large or the elongation of the individual layers differs significantly, the bond already formed may open locally during subsequent deformation.

The aim of this paper is to show, based on laboratory cladding and rolling experiments, under which technological conditions a reliable interfacial bond can be formed in different metallic sheet composite structures. The focus is placed on the basic tests performed with a Ford-type tool, the rolling experiments of three- and multilayer packages, the metallographic evaluation of bond formation, the role of surface condition, and the determination of bond strength by peel testing. The paper therefore discusses those results which are directly related to the rollability and preliminary laboratory qualification of metallic sheet composite structures.

2. MATERIALS AND METHODS

2.1 Experimental material systems and package design

The laboratory experiments followed two interconnected directions. In the first part, a rapid basic test had to be selected that could compare the bonding tendency of two aluminium alloys during deformation. Ford-tool deformation proved suitable for this purpose because the compressed zone and the deformation range could be controlled, while the bonded surfaces could be evaluated by both tensile and metallographic tests after deformation. The basic tests were carried out with AlMnSi and AlSi10 materials at a furnace temperature of 500 °C and a heating time of 60 minutes. The deformation range was 30-90 % relative reduction referred to the total package thickness.

In the second part, three- and multilayer rolling packages were prepared. The decisive part of the experiments was based on two sandwich structures. In the first system the core alloy was AlMnCu, the corrosion-resistant intermediate layer was Al99.7, and the remelting cover layer was AlSi10. In the second system the core alloy was AlMnSi, the corrosion-resistant layer was Al99.5, and the cover layer was again AlSi10. In addition, packages containing Mg-bearing cover sheets were also investigated in order to examine whether the magnesium content of the cover layer has a detrimental effect on bond formation. The main elements of the experimental programme are summarized in **Table 1**.

Table 1 Main elements of the laboratory test programme

Test part	Material/layer arrangement	Main parameter	Evaluation
Basic test with Ford-type tool	AlMnSi - AlSi10	500 °C furnace, 60 min heating, Relative reduction = 30-90 %	Tensile and metallographic examination
Hot-rolling packages	AlMnCu/Al99.7/AlSi10; AlMnSi/Al99.5/AlSi10	T = 460-530 °C, v = 5 m/min	Layer thickness, bonding defect, layer elongation
Peel test	Three- and five-layer sheets	480, 500 and 520 °C; Relative reduction = 40-80 %	T-peel, peel stress

2.2 Rolling conditions and evaluation principle

The rolling experiments were carried out on the experimental rolling mill of the University of Miskolc, manufactured by Von Roll. The maximum permissible rolling force of the mill is 1 MN and the maximum permissible rolling torque is 1 kNm. The equipment can be operated in both two-high and four-high arrangements; the roll diameter is 220 mm in two-high mode and 56 mm for the work rolls in four-high mode. This made it possible to produce laboratory packages and to evaluate the role of the first bonding passes under controlled conditions.

In the first rolling experiments the starting temperature was 480 °C and the rolling speed was 5 m/min. Before package assembly, the contacting surfaces of the sheets were degreased with denatured alcohol. Heating was carried out in a forced-air furnace at 500 °C for 1 hour. To reduce rapid heat loss from the surface, the rolls were heated before rolling. During the experiments, both the per-pass reduction and the total reduction were varied, because the objective was not only to reduce thickness, but also to create a sufficiently stable bond between the layers.

The bond was evaluated in several steps. Visual inspection gave only preliminary information, because visible bonding defects did not always appear on the surface of the sheets. Therefore, the interface had to be checked on metallographic sections, especially for air entrapment and local lack of bonding. Peel testing was used as a quantitative method. This was important because a bond that appears acceptable on a section is not necessarily strong enough for further rolling or for the reliable use of the final sheet.

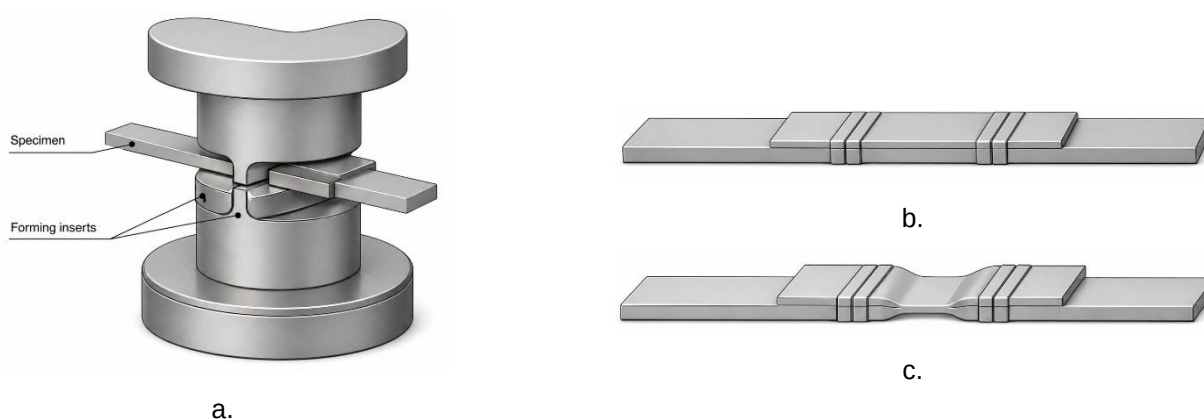


Figure 1 Arrangement of the basic Ford-tool test (a) and the position of the two layers before (b) and after (c) deformation

3. RESULTS AND DISCUSSION

3.1 Bond formation and deformation range

One of the most important observations of the Ford-tool basic tests was that the formation of the bond between the layers cannot be described by a single technological parameter. After heating for 60 minutes in a 500 °C furnace, the deformation range of 30-90 %, referred to the total package thickness, showed that the bond tendency changed with increasing deformation. At small reductions, the surface pressure and the real contact area were not sufficient for reliable bonding. At higher reductions, the bonded area became more continuous, but the stability of the layer interface still depended on the deformation compatibility of the two materials.

The laboratory rolling experiments further refined this interpretation. In the bonding passes, if the relative reduction was too small, the bond did not form because the surface pressure and the time of contact were insufficient. If the pass reduction was too large, the different elongation behaviour of the layers could open the bond that had already started to form. For this reason, the first rolling passes have a critical role: they must be large enough to initiate bonding, but not so severe that they create excessive relative displacement between the layers.

According to the experiments, a visually detectable bond formed when the elongation of the cover sheet was greater than that of the core material. This condition, however, could be maintained only within a narrow range, because the work hardening of the cover sheet during deformation modified the ratio of deformation resistance between the layers. The stability of the layer interface is therefore a process-dependent state, not a fixed material property. This explains why the pass design has to be built gradually and why the first bonding passes determine the success of the subsequent rolling steps.

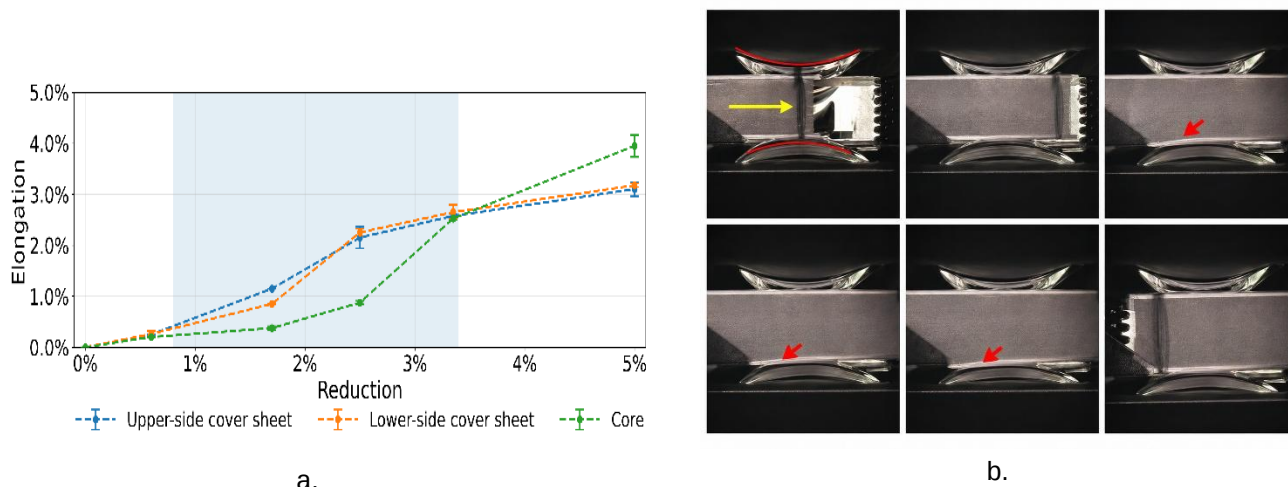


Figure 2 The role of the elongation of the cover sheets and the core material in the stability of the bond (a) and the rupture of the bonded layers due to the different elongation of the layers (b)

3.2 Surface condition, Mg-containing cover sheet and metallographic defect patterns

The microscopic examination of the rolled sheets showed that welding-type bonding was expected to develop at a total reduction of 60 % or higher and at a starting temperature of 500 °C. This, however, did not mean that every specimen was completely free from defects. Several sections contained air entrapment and local interface defects. These defects are especially important because they do not always cause immediate visible failure, but they may reduce the safety of subsequent rolling and the reliability of the final product.

The effect of the Mg content of the cover sheet was investigated on packages with identical geometry but different cover-sheet grades. In the literature, the presence of Mg is generally mentioned as an unfavourable factor in aluminium-based cladding [8]. In the laboratory experiments, however, no essential difference was found between AlSi10 and AlSi10Mg cover sheets under the applied conditions. The evaluation therefore indicated that, in this experimental range, the success of bonding was governed primarily by temperature, deformation, surface preparation and layer elongation rather than by the Mg content alone.

For this reason, metallographic images cannot be interpreted independently of the technological state. An interface that appears sound may still not represent a fully reliable bond because of local defects, while subsequent rolling may refine or eliminate some smaller discontinuities. Product qualification therefore requires the combined evaluation of geometrical accuracy, layer thickness uniformity, interface defects and peel strength. This complex evaluation gives a more realistic picture of rollability than any single observation method.

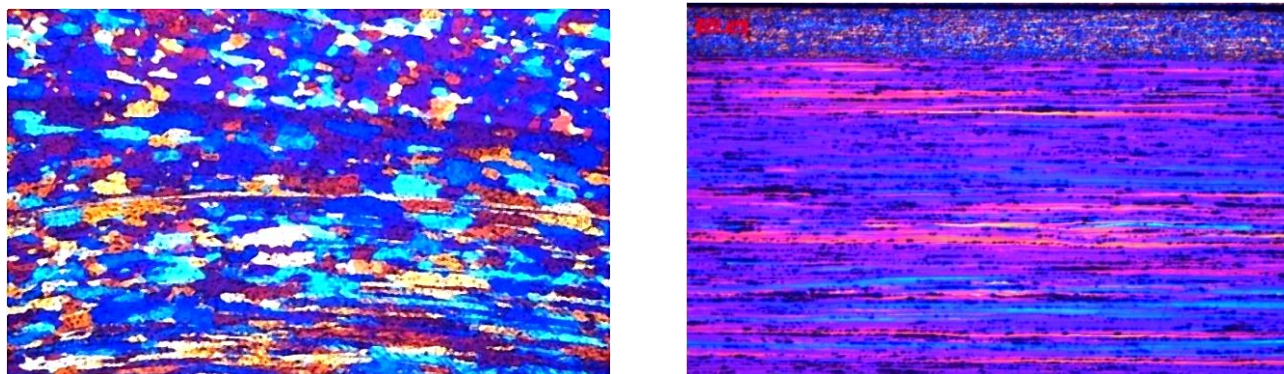


Figure 3 Characteristic metallographic bond patterns for sound interfaces

3.3 Peel tests and boundary diagram

Peel and T-peel type tests can be used for the evaluation of bond quality [9]. During the laboratory work, the T-peel test proved to be the faster and simpler solution, while it was suitable for the comparative evaluation of bond strength. The crosshead speed was set to 20 mm/min. The recorded force-displacement curves made it possible to determine the maximum peel force and, by using a correction factor, the peel stress referred to the bonded interface.

The tests were performed at cladding temperatures of 480, 500 and 520 °C and in the total reduction range of 40-80 %. At 40 % reduction the peel force was 0 N at all three temperatures, indicating the absence of bonding. Increasing reduction and temperature generally increased the peel stress, but the increase was not linear. This confirms that the formation of the bond is not controlled by temperature alone, but by the combined effect of temperature and deformation. Some characteristic peel stress values calculated from the T-peel tests are shown in Table 2.

Table 2 Some characteristic peel stress values calculated from the T-peel tests

Relative reduction (%)	Peel strength, 480 °C (N/mm ²)	Peel strength, 500 °C (N/mm ²)	Peel strength, 520 °C (N/mm ²)
50	4.98	12.02	18.07
60	27.00	29.99	60.18
70	41.99	78.01	86.98
80	120.05	150.05	174.08

Based on the results, three technological regions can be distinguished in the temperature-reduction space. In the first region, welding-type bonding does not occur. In the second, intermediate region, bonding is uncertain and therefore cannot be considered safe for practical rolling. In the third region, the bond is reliable enough for further deformation. The boundary diagram constructed from the laboratory data is therefore not only a descriptive result, but also a practical aid for selecting bonding-pass parameters.

The laboratory results show that the pass design has a dual function in the planning of cladding technology. On the one hand, it must create sufficient surface pressure and deformation to initiate bonding. On the other hand, it must avoid the deformation state in which the cover sheet and the core material move relative to each other to an extent that causes the bond to open. Consequently, the stability of the layer interface is a direct measure of whether the selected rolling schedule is suitable for the given composite structure.

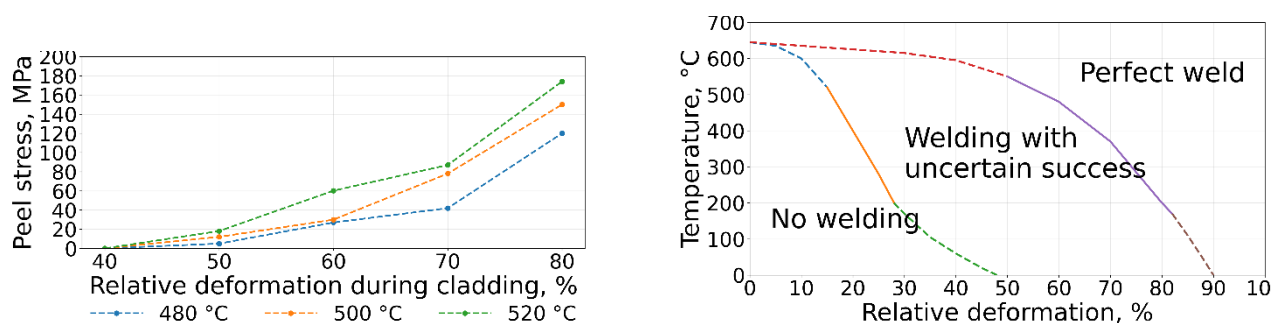


Figure 4 Results of the peel tests and the boundary diagram for the expected formation of bonding

4. CONCLUSIONS

Based on the laboratory experiments, the stability of the interface in metallic sheet composite structures produced by rolling cannot be reduced to a single parameter. Bond formation is controlled by temperature,

deformation, the condition of the contacting surfaces, and the deformation resistance and elongation behaviour of the individual layers. The first bonding passes are therefore not simple thickness-reduction steps, but decisive technological operations in which the later rollability of the package is largely determined.

The Ford-tool basic test proved to be a suitable preliminary qualification method because the bonding tendency became comparable and the specimens could be evaluated by both mechanical and metallographic methods. The rolling experiments confirmed that at too small reductions the compressive stress is not sufficient, while at too large reductions the different elongation of the layers may cause the opening of the interface. Consequently, the rolling schedule has to be designed so that bonding starts under controlled conditions and the relative displacement of the layers remains limited.

A proper bond is expected to develop at a total reduction of 60 % or higher and at a starting temperature of around 500 °C, but metallographic inspection cannot be omitted because of surface defects and air entrapment. The T-peel test is suitable for quantitative evaluation, and the use of the $\beta = 0.33$ correction factor made it possible to calculate peel stress values. The results clearly showed that increasing temperature and reduction improve bond strength, but the process remains sensitive to the actual deformation state.

On the basis of the results, a technological window can be defined in which the bonding passes support not only the closing of the layers, but also the bond reliability required for subsequent rolling. The presented approach is suitable for the preliminary laboratory assessment of different metallic sheet composites and for the later development of industrial pass-design logic. The work also shows that stable layer co-deformation and interface integrity must be evaluated together when the rollability of multilayer metallic sheets is assessed.

ACKNOWLEDGEMENTS

Supported by the university research scholarship program of the ministry for culture and innovation from the source of the national research, development and innovation fund.

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