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Rigid-Die Clinching of Sandwich Composite Sheets

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ABSTRACT

This paper condenses an experimental study of rigid-die clinching for Litecor steel/polymer/steel sandwich sheets joined with galvanized steels. The investigated 0.7 mm steel combinations did not form acceptable joints, while selected 1.5 mm combinations created joints with cracking or weak interlocking. The method was therefore unsuitable for the tested material systems.

KEYWORDS: *sandwich composites; Litecor; clinching; galvanized steel; tensile-shear test; mechanical interlock*

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I. INTRODUCTION

Steel/polymer/steel sandwich materials are attractive for lightweight structures because they combine metallic stiffness with the low mass and damping ability of a polymer core. Such composites are useful where weight reduction must be achieved without losing resistance to bending, vibration or thermal loading [1]. In this group, Litecor represents a layered material with thin outer steel sheets and a polymer-based intermediate layer, and previous studies have examined its forming and joining behaviour [2-4].

Joining remains a critical limitation for sandwich structures. Fusion welding can damage the polymer layer, mechanical fastening introduces holes and stress concentrations, and adhesive bonding increases production time and may be sensitive to environmental effects [5,6]. Clinching offers a different route: the sheets are locally plastically deformed by a punch and die to create a mechanical interlock without additional elements or heat input [7].

The present shortened article reformulates the original experimental work and focuses on whether a rigid-die clinching process can join Litecor with high-strength and micro-alloyed hot-dip galvanized steel sheets. The main evaluation criteria are joint formation, tensile-shear load capacity, failure mode and metallographic evidence of cracking.

II. Methodology of Research

The experimental programme used Litecor sandwich material with a total thickness of 1.3 mm. Its outer layers were HX220YD steel sheets with a thickness of 0.3 mm, bonded to a 0.7 mm polymer core. The counter materials were galvanized steels HCT600X+Z, HX420LAD+Z and HX340LAD+Z, tested in two sheet thicknesses: 0.7 mm and 1.5 mm.

Round clinched joints were produced by mechanical clinching with a rigid die. Both possible sheet orientations were considered because the position of the material on the punch side or die side can strongly influence the flow of material and the final interlock. For the 0.7 mm steel sheets, a 3.6 mm punch and 5 mm die were used; for the 1.5 mm steels, a 5 mm punch and 8 mm die were applied. The dimensions of testing samples are shown in Fig. 1. These dimensions of the samples are defined by STN 05 1122 standard.

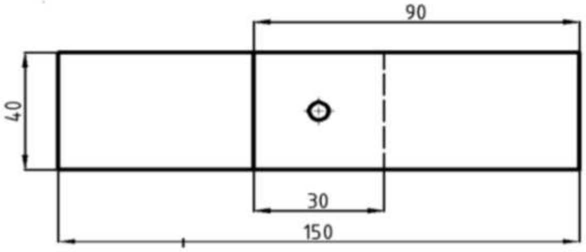


Fig. 1 The dimensions of testing samples

The joints were assessed by tensile-shear testing, and metallographic observation. The aim was not only to record maximum force but also to determine whether the joint could be considered structurally acceptable. The tensile test was performed on a TIRAtest 2300 metal tensile testing machine (Fig, 2).

Fig. 2 The tensile test machine TIRAtest 2300

The mechanical response was evaluated by a tensile-shear test, i.e. tensile loading of single-lap clinched specimens. For each successful material combination, three specimens were compared by the maximum force Fmax and by the shape of the load-displacement curve. The curve was important because it indicated whether the joint failed suddenly after crack initiation or whether the interlock carried the load until pull-out. Metallographic samples were prepared through the joint centre to verify the actual geometry of the neck, the die-side bulge and any cracks in the interlocking area. The metallographic observation of the samples was performed on a KEYENCE VHX-5000 light optical microscope - see. Fig. 3.

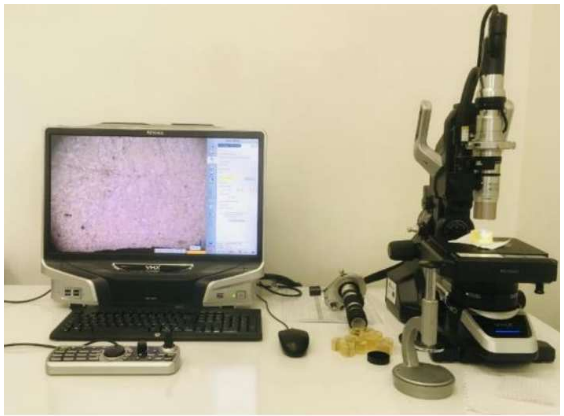


Fig. 3 The digital microscope Keyence VHX-5000

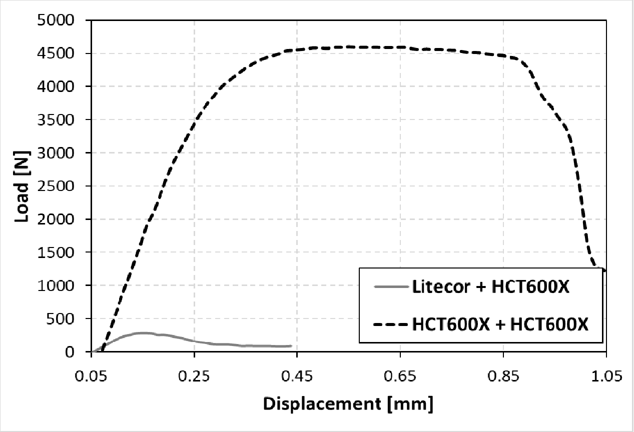
III. Results and Discussion

No acceptable clinched joints were produced for Litecor combined with 0.7 mm HCT600X+Z, HX420LAD+Z or HX340LAD+Z, regardless of whether Litecor was placed on the punch side or the die side. The thin steel sheets and the limited formability of the Litecor outer skin did not provide enough favourable material flow to create a reliable undercut.

For 1.5 mm galvanized steels, joint formation was possible only in selected orientations. Litecor joined with HCT600X+Z formed a visible joint, but cracking appeared in the interlocking area. The measured maximum force was very low, with an average of approximately 279 N from three specimens. The crack changed the failure behaviour to neck fracture and made the joint unacceptable.

The HX420LAD+Z and HX340LAD+Z combinations with Litecor reached much higher tensile-shear capacities. Their average maximum forces were about 2.66 kN and 2.71 kN, respectively. These specimens mainly failed by pull-out, which indicates a stronger interlock than in the HCT600X+Z combination. The load–displacement curves for observed material combinations are shown in Fig. 3. However, metallography still revealed cracks at the bottom of the Litecor sheet, and this damage can initiate separation of the lower part of the joint (Fig. 4).

The tensile-shear test separated apparently formed joints from joints that could be considered functional. In the 0.7 mm steel variants, the process result was already negative before tensile loading, because the sheets did not create a continuous mechanical lock. Therefore, these variants were excluded from mechanical comparison and were treated as technological failures. This observation is important because reducing the thickness of the counter steel sheet did not compensate for the limited ductility and small thickness of the Litecor outer layer.



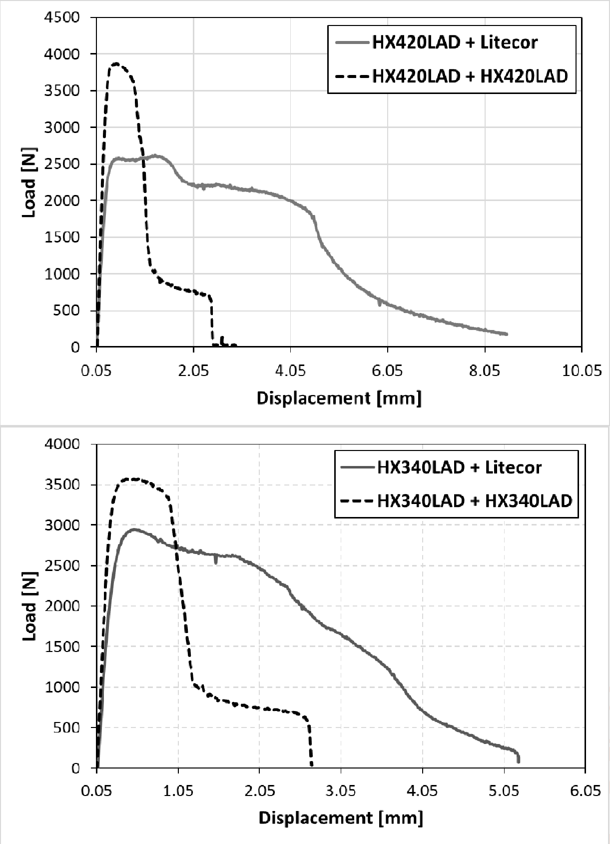


Fig. 3 The load–displacement curves of: a) Litecor and HCT600X+Z, b) HX420LAD+Z and Litecor, c) HX340LAD+Z and Litecor

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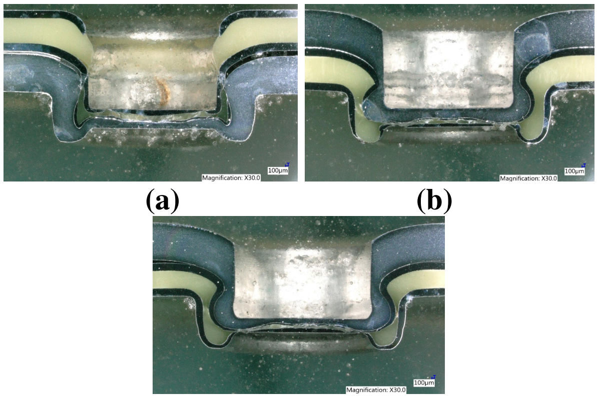
(a) (b)

(c)

Fig. 4 The metallographic observation of the clinched joints: a) Litecor and HCT600X+Z, b) HX420LAD+Z and Litecor, c) HX340LAD+Z and Litecor

The HCT600X+Z/Litecor combination is the clearest example of why joint appearance alone is insufficient. Although a joint shape was obtained when Litecor and the 1.5 mm HCT600X+Z sheet were combined in one orientation, the tensile-shear test gave only 275-286 N. Such low values are not comparable with the other successful-looking variants and correspond to premature neck fracture. The mechanical record is consistent with the metallographic section, where a crack was found directly in the interlocking area. The crack reduced the remaining load-bearing cross-section and prevented the interlock from developing the full resistance expected during pull-out.

By contrast, HX420LAD+Z/Litecor and HX340LAD+Z/Litecor showed a more stable tensile-shear response. Their measured maximum forces were in the kilonewton range, and the dominant failure mode was pull-out. The higher forces indicate that the interlock was better formed and that the sheets were able to transfer load for a longer time. However, the metallographic inspection does not allow these joints to be classified as fully acceptable. Cracks occurred at the bottom of the Litecor side, especially near the highly deformed zone. This damage may not immediately reduce the maximum force as strongly as the interlock crack in the HCT600X+Z sample, but it can act as an initiation site for further separation during service.

Considering both tests together, the tensile-shear test quantified the external load-bearing capacity, whereas metallography explained the internal reasons for failure. The best mechanical values were therefore not sufficient as a single acceptance criterion. A joint with a high Fmax but visible cracking in the sandwich layer remains risky because the polymer core and the thin steel skins do not provide the same reserve of plastic deformation as a monolithic steel sheet. For this reason, the results support a combined evaluation procedure in which process feasibility, force-displacement behaviour, failure mode, and cross-sectional integrity are assessed simultaneously.

The results confirm that clinching is highly dependent on the local deformation capacity of all layers. The clinching stages of offsetting, upsetting and flow pressing require enough material flow into the die groove [12]. In the tested Litecor material, the 0.3-mm outer HX220YD layer and the polymer core limited the flow. Although clinching is generally suitable for joining thin sheets [9-11], the rigid-die variant did not provide a safe process window for the sandwich/steel combinations investigated.

IV. Conclusion

Rigid-die clinching was not suitable for joining Litecor steel/polymer/steel sandwich sheets with the examined galvanized steels. The 0.7 mm steel combinations did not form acceptable joints, and the successful 1.5 mm combinations were limited by cracking or insufficient joint quality. The tensile-shear test showed that the HCT600X+Z combination had very low load-bearing capacity, while the HX420LAD+Z and HX340LAD+Z combinations reached higher forces but still failed mainly by pull-out. Metallography confirmed that the limiting factor was not only the value of maximum force but also the integrity of the interlocking and bottom regions of the Litecor sheet. The decisive factor was the small thickness and deformation capacity of the Litecor outer steel layers. Further work should therefore consider modified die geometry, locally supported forming or alternative mechanical joining methods before this material combination can be applied in load-bearing structures.

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