The Interface between Aluminium and Steel Joined by Hybrid Metal Extrusion and Bonding and by Cold Roll Bonding

Bergh, T.[1], Arbo, S.M.[2], Westermann, I.[2], Holmestad, R.[1] and Vullum, P.E.[1]

[1] Department of Physics, Norwegian University of Science and Technology, Norway, [2] Department of Materials Science and Engineering, Norwegian University of Science and Technology, Norway

Joints of aluminium and steel offer the low weight of aluminium and the high strength of steel, and find applications e.g. in vehicle bodies. There are challenges in creating successful joints by conventional joining methods, due to the large differences in thermo-physical properties, e.g. melting points, and the limited solid solubility between aluminium and steel. The interface in aluminium-steel joints generally consists of an intermetallic compound (IMC) layer that differs in thickness, morphology and type, depending on the joining process, corresponding parameters and the parent alloys used. The IMC layer can be detrimental to the mechanical properties of the joint, and therefore, complete characterisation of the interface region is necessary to understand the performance of the joint. In this work, transmission electron microscopy (TEM) studies of the interface characteristics of aluminium (AA6082) joined to steel (SN355) by the newly developed and patented Hybrid metal extrusion and Bonding (HyB) technique is presented for the first time [1]. TEM characterisation of joints consisting of steel and aluminium sheets joined by cold roll bonding (CRB) is also presented.

Several candidate IMCs have similar compositions, but differ in crystal structures. Thus, both spectroscopy and electron diffraction are employed in this work, with a focus on the latter. To determine the crystal structure and orientation of the grains in the IMC layer, scanning precession electron diffraction (SPED) is used. In SPED, the beam is scanned across the area of interest, and a precession electron diffraction pattern is recorded at each pixel, with a resolution down to ~1 nm [2]. Emphasis is put on developing a general programming-based routine for phase determination from SPED data using PyXem [3]. The results from SPED will be compared to other techniques. Electron energy loss spectroscopy and energy dispersive X-ray spectroscopy data are analysed with the toolbox HyperSpy [4], in order to quantify the phases in the IMC layer.

For one CRB joint, the IMC layer is discontinuous, up to 3 μm thick and consists of the three distinct phases; cubic α-AlFeSi, Fe_4Al_{13} (θ) and Fe_2Al_5 (η). Figure 1(a) displays a virtual bright field image, created from SPED data, where the three phases can be seen. Preliminary results for the HyB joint indicate a narrow IMC layer 20-40 nm in thickness that contains silicon, in addition to iron and aluminium. A bright field TEM image of this interface is shown in Figure 1(b). The combination of results from several electron microscopy techniques gives a complete description of the microstructure of the IMC layer in aluminium-steel joints and aids in explaining the mechanical properties of such joints.

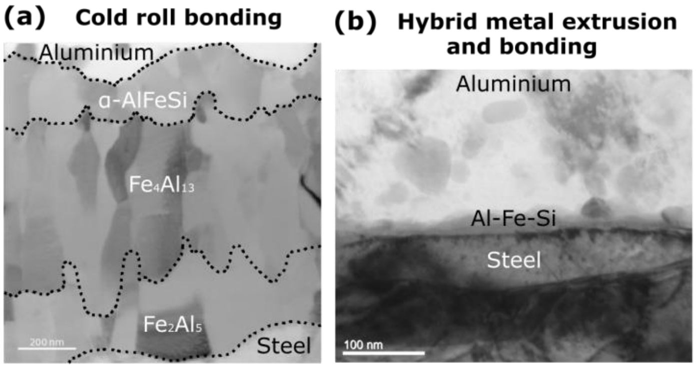

Figure 1: (a) Virtual bright field image created from SPED data, that shows the three phases (cubic α-AlFeSi, Fe_4Al_{13} (θ) and Fe_2Al_5 (η)) found at the interface of an aluminium-steel joint made by CRB. The black dashed lines indicate the boarders between the different phases. **(b)** Bright field TEM image of a narrow IMC layer containing aluminium, iron and silicon, found at the interface of an aluminium-steel joint made by HyB.

References

[1] Ø. Grong, Welding Journal 91 (2012) 26-33.

[2] E.R. Rauch, M. Veron, Materials Characterization 98 (2014) 1-9.

[3] PyXem (2018), www.github.com/pyxem/pyXem

[4] F. de la Pena et. al, Hyperspy (2017), DOI: 10.5281/zenodo.592838

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