Laser welding of dissimilar alloys – case study

Background

Fuel efficiency and other criteria challenge many manufacturing sectors to design composite structures comprising various materials with different properties. This poses a great task for joining technology to provide adequate solutions to facilitate such designs. In the automotive industry for instance, there is a big drive to apply dissimilar materials to save weight and this is likely to expand in future with the new fuel efficiency regulations.

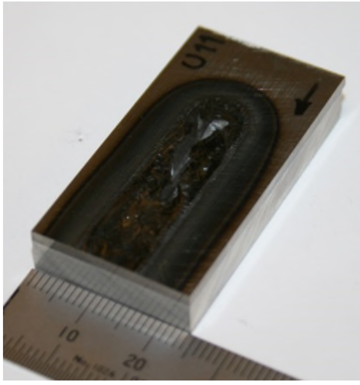


Fig.1: *Steel to aluminium lap joint using laser welding*

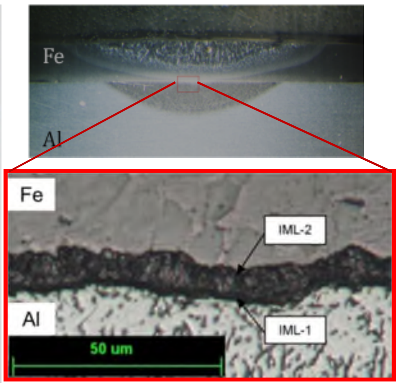


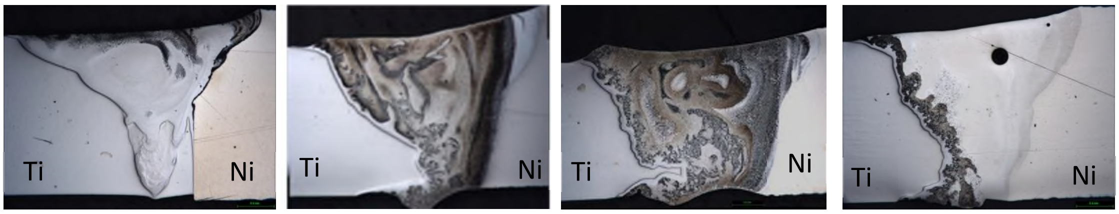
Fig.2: *Macrograph and SEM picture of Fe-Al inter-layer*

Laser welding enables precise control of applied energy and, unlike any arc-based welding process, allows for independent control of energy distribution and total energy input. For example laser energy can be focused to a small spot size of the order of a few tens of microns or the same energy can be spread over a larger area, i.e. the energy goes where and how it is needed.

The key challenge in joining of dissimilar materials is accurate control of the fusion behaviour and the mixing of interfacing materials. Often in metals, the limited solid solubility of one metal within another generates intermetallic phases at the interface resulting in undesirable mechanical properties. An example of intermetallic layer in aluminium-steel joint is shown in Fig.2. Thus the main strategy is to provide enough localised energy necessary to form a joint, but the fusion zone should be small in volume to decrease the likelihood of the intermetallic compounds. Also control of the thermal cycle has to be considered to minimise diffusion. Lasers are one of the most suitable tools for such a demanding application.

Project scope

In this project different strategies of joining titanium alloy to nickel and stainless steel were investigated to determine the relationship between joint type, welding conditions and joint strength. It was found that the volume fraction of each alloy and mixing during welding is one of the most significant factors determining the strength of the joint. As shown in Fig.3, a laser beam can be precisely positioned in order to achieve a suitable offset position of the heat source relatively to the interface of welded materials. The phase constituents of the fusion zone are modified by changing the laser offset, resulting in different mixing ratios of the materials. This control would not be possible with arc-based welding processes, where the arc column would tend to a material with preferable electrical properties.



Melting ratio: 90%Ti & 10%Ni | Melting ratio: 63%Ti & 37%Ni | Melting ratio: 43%Ti & 57%Ni | Melting ratio: 37%Ti & 63%Ni

Fig.3: *Effect of laser offset on mixing ratio of Ti-Ni joint*

The mixing ratio has a direct impact on the phase constituents and formation of hard intermetallics. As shown in Fig.4, the hardness of the joints changes with changing the mixing ratio. The likelihood of formation of intermetallic phases reaches a maximum at a mixing ratio of 50%. One solution to this issue would be to find an optimum point where the volume fraction of one material is minimised, but there is enough melting to ensure sufficient integrity of the joint.

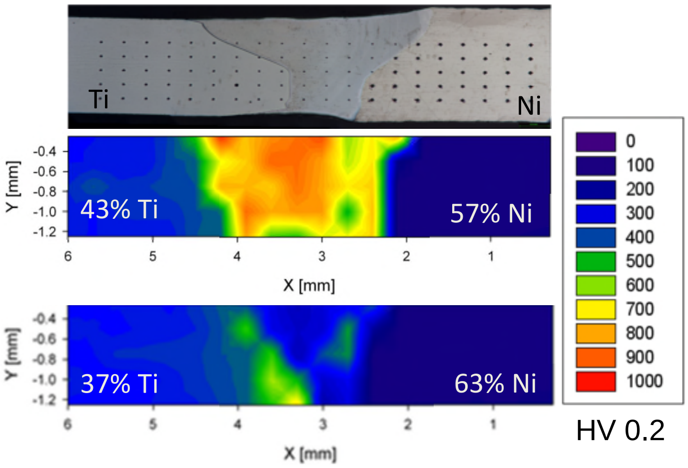


Fig.4: *Effect of mixing ratio of Ti-Ni on hardness of joint*

Another way of preventing phases from excessive mixing and forming hard phases, but still enabling melting of sufficient amount of materials required to form a joint, is the use of interlayers. In the example in Fig.5 a direct joint between stainless steel and titanium is shown and has very poor properties. The brittle nature of this joint can be mitigated by using an interlayer material. In this case the stainless steel was welded to a nickel interlayer, which then was welded to the titanium alloy, as shown in Fig.6. Combining the precise control of a laser with the selection of suitable material combinations allows a high integrity joint to be produced.

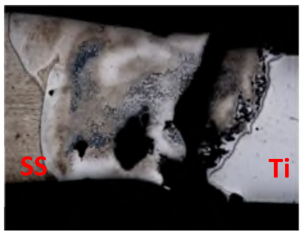


Fig.5: *Stainless steel-Ti joint*

Summary

Joining of dissimilar and highly dissimilar materials is a very challenging task due to formation of brittle phases. With laser welding this can be minimised by a careful control of the mixing ratio of each material or by using interlayers of compatible pairs of materials.

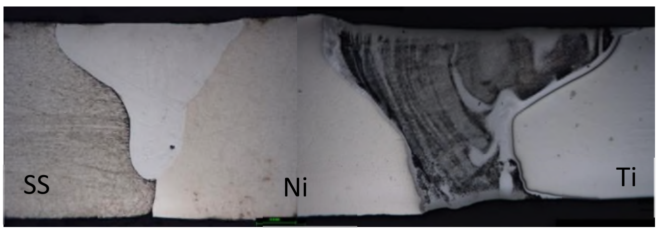


Fig.6: *SS-Ti joint using Ni-interlayer*

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