

WELDING

AEROSPACE CASE STUDIES: LASER WELDING TITANIUM

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Welding of primary structural parts is by no means a new process to the aircraft industry; three quarters of a century ago it was extensively used in the construction of tubular frames that were the skeleton of fuselages. Vestiges of this remain as welded tubular engine bearers for smaller aircraft, for example. As designs matured towards stressed skin aluminium alloy monocoque construction, mechanical fasteners - primarily rivets - became the almost universal method of joining. There were good reasons for this; welding limited the choice of alloys, to some extent eliminating the strongest, also welding was an art as much as a science so that the strength of riveted joints was more predictable.

Corrosion protection was another major factor, aluminium alloy parts being particularly susceptible to corrosion in crevices. With riveted lap joints, protective finishes could be applied to the aluminium alloy parts before and during assembly, something that is not generally compatible with welding. Another reason is that Alclad was, and to some extent still is, a widely used material for skins. It consists of a strong aluminium alloy core with thin surface layers of pure aluminium to provide protection against corrosion. Welding compromises this in the weld region, because the surface and core materials are mixed into the weld reducing both the strength of the core and destroying the corrosion protection.

Increasing welding efficiency in the aircraft industry

Pressures to improve efficiency in the aircraft industry, in addition to reducing costs and the environmental footprint, have accelerated the introduction of new materials and processes that favour the wider use of welding on all types of aircraft. In particular, growth in the use of carbon-based composites has resulted in an increase in the use of titanium, in order to avoid the galvanic corrosion associated with aluminium alloy/carbon interfaces.

In 2016, titanium alloys made up around 11% (by weight) of total aircraft raw material demand, with this figure predicted to increase at a compound annual growth rate of 3.4% over the next 5 years. This outstrips the growth of all other aerospace raw materials except composites.

Currently, most titanium structural components are produced by machining (from billet, ingots,

and forgings) and/or by mechanical fastening techniques (bolts or rivets). Welding has been largely avoided due to concerns with reduction in mechanical properties such as fatigue strength. The production of parts by machining typically leads to inefficient buy-to-fly ratios (as high as 20:1), which is increasingly uneconomical, involving high material labour cost. Building composite aircraft such as the Boeing 787 is reported to require around 130 tonnes of titanium alloy materials to be processed of which less than 20 tonnes of titanium will actually fly. The cost of titanium being in the region of \$3 million, with machining costing at least as much again, leads to high repeat costs and long lead times for items based on forgings.

A further concern with the predicted increased use of titanium components is the availability of sufficient machining capacity. Compared with aluminium alloy components, titanium is more difficult and slower to machine, so a direct change-over does not apply.

The OLIVER project

OLIVER is an Innovate UK-supported project that aims to further develop knowledge of laser welding titanium, and its application to structural aerospace assemblies. The project aims to exploit this knowledge by developing a UK manufacturing capability both within the UK supply chain and OEMs. The project includes case studies from Leonardo, TISICS and CAV Advanced Technologies, each representing a first-to-market opportunity for the application of laser welding technology. This work is supported by technical input from IPG Photonics (UK), the Manufacturing Technology Centre, the Northern Ireland Technology Centre at Queen's University Belfast and TWI.

Case Study: Leonardo

The Leonardo case study involves laser welding of relatively thin titanium sheet material as a replacement for riveting and interface sealant through various thicknesses arising from varying number of layers of titanium sheet. Fatigue life and joint sealing are particularly important considerations from this application and the nature of the structure presents challenges of beam access and gas shielding due to the variety of corner and other features. Examples are shown in Figure 1.

The case study explores the potential to use laser seam stepper welding, or stitch welding, instead of riveting for a cabin roof assembly,

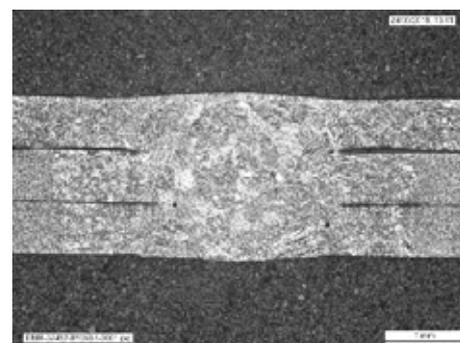
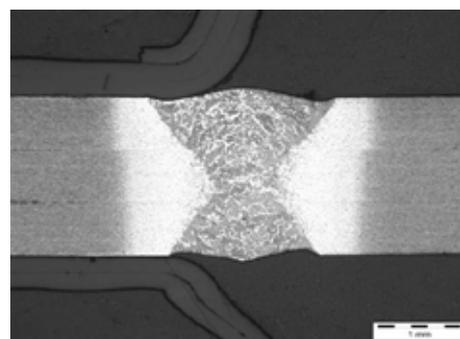


Figure 1: Laser welded 3 ply titanium skin lap joint (Images courtesy of TWI and IPG Photonics) - laser seam stepper welding.

which incorporates titanium firewalls. Current lead time incorporating the firewalls is 16 weeks of which approximately 12 weeks relates to the firewalls. Laser welding is expected to achieve a 30% reduction in assembly time. This relates to a lead time saving of 4 weeks per aircraft and 20% cost savings. This cost saving also makes UK manufacturing attractive against current off-shore manufacture.

Various joint configurations are being tested, see Figure 2, to quantify static and dynamic mechanical properties. Coupled with this activity MTC are developing in-process inspection using laser ultrasound (LU) techniques and have demonstrated the capability to detect defects smaller than required by the relevant welding standards. LU capability to detect standard required defects and sizes has been validated

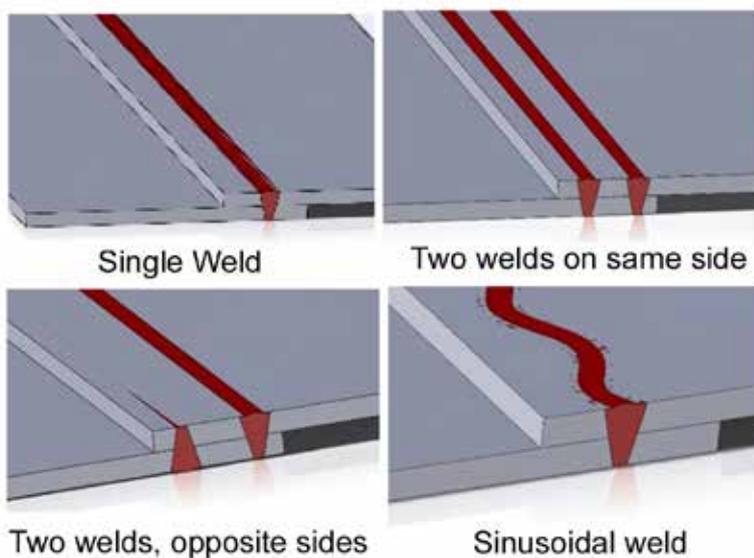


Figure 2. Possible weld configurations for titanium skin lap joints.

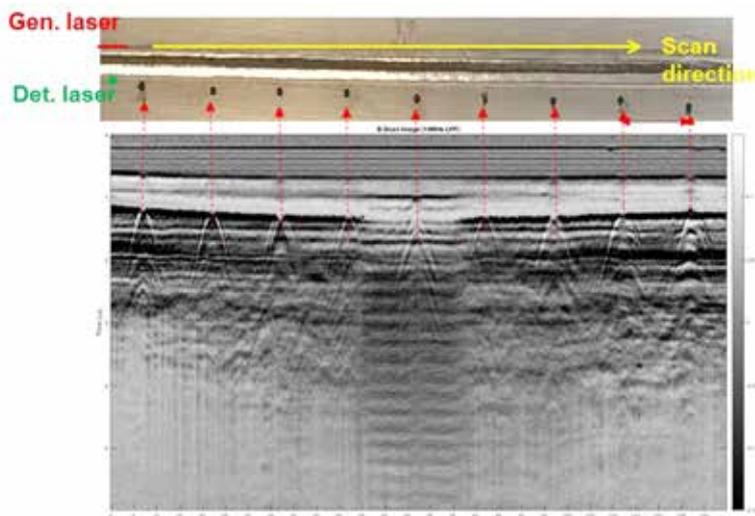


Figure 3: Laser ultrasound defect detection validation, where top shows the actual weld with calibration notches and scan details, below is the corresponding B-Scan which shows successful detection of all defects (image courtesy MTC).

using representative samples. As an example, Figure 3 illustrates a weld with calibration defects superimposed on the corresponding B-Scan, showing clear indications of all nine notch defects, all of which were consistent with their locations (the notch locations are marked with black dots). The separation of each peak is approximately 15 mm, which is consistent with the notches. There is also an artefact in the middle of the scan consisting of planar waves—this is thought to originate from contact with plates below the test article which is absorbing some of the ultrasonic energy. This indicates that the the LU system has the capability to detect subsurface defects.

Due to the high cost of re-certification it is unlikely that the change would be applied to the existing case study structure but the new capability will allow Leonardo to establish design rules for the application of laser welding technology to future titanium structures,

creating further savings and increasing the competitiveness of the UK manufacturing base.

Case Study: TISICS

The TISICS case study aims to develop the capability for laser welding within end fittings attached to Titanium Matrix Composite (TMC) struts. The struts consist of TMC tubes with monolithic titanium end fittings that are attached using hot isostatic pressing (HIP), a process that requires specific and expensive tooling for different types of end fitting. These struts are widely used, for example as load transfer members within undercarriages, side stays,

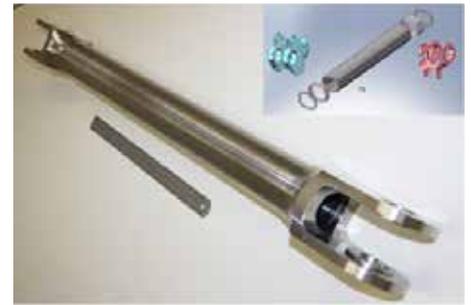


Figure 4: TMC Struts showing typical end fittings. (Image courtesy TISICS Ltd).

actuator linkages and brake reaction rods and light surface actuator rods.

There is a degree of commonality in the TMC tube parts of various components. This offers the possibility for increased manufacturing flexibility and cost reduction if the current monolithic end fittings are split into two parts, together with specific end features welded on at a later stage, as shown in Figure 4. However, to realise the full potential of this opportunity the size of the standardised end fitting must be minimised by placing the weld as close as possible to the HIP joint commensurate with avoiding heat damage to the TMC. Laser welding is an attractive solution as it offers the possibility to make the relatively deep weld required with minimum heat input and the process is being developed and optimised as part of the OLIVER activity.

CAV Advanced Technologies

CAV has been using robotic laser welding for lap joining and sealing titanium leading edge assemblies of its ice protection systems for some time, but has a future requirement that could be satisfied by laser butt welding.

The maximum available width of titanium sheet is currently 1.25 m and without a very significant demand for wider material, which would need to be far beyond that of the foreseen applications, material manufacturers cannot justify the very high investment that would be required to produce it.

The solution being explored within OLIVER is to join narrower material using laser butt welding. The challenges are to produce a 5 metre long distortion-free weld in thin material (up to 1 mm thickness) that has to be structurally sound as well as virtually invisible for aerodynamic and aesthetic reasons but coupon tests made so far at TWI have yielded promising results.

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