JOINING OF TITANIUM-ALUMINIUM SEAT TRACKS FOR AIRCRAFT APPLICATIONS – SYSTEM TECHNOLOGY AND JOINT PROPERTIES

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ABSTRACT

The current state of the art in light-weight construction for aircraft structures such as seat tracks, is the use of either aluminium or titanium materials. Whereas aluminium seat tracks are light-weight and less expensive, titanium seat tracks offer superior corrosion properties at higher cost. In order to combine the advantages of both materials, a hybrid Ti-Al structure is proposed. To produce such a structure, an appropriate thermal, laser-based brazing process was developed in a joint project of BIAS and their partners from industry. In this paper, the results from this research work will be reported and discussed. On the basis of the development of an appropriate system technology, the process development will be described, focusing on the main influencing parameters of the process on joint properties, which were characterized by metallurgical analyses, hardness testing and static tensile tests. It will be shown that laser beam joining is suitable to produce load-bearing aluminium-titanium-structures.

IIW-Thesaurus keywords: Aircraft; Aluminium; Brazing; Lasers; Titanium.

1 Introduction

To reduce the weight and costs in conventional wide-bodied aircrafts, aluminium is used for seat tracks. To avoid defects from the presence of liquids in the passenger cabin, it is desirable to utilize titanium instead of aluminium in the imperiled area of the seat track, the so-called crown, to which seats and other elements of the cabin are mounted. Since the remaining seat track part should still be made of aluminium (especially for cost reasons), a joining technology for aluminium-titanium butt joints needs to be developed.

Currently, the connection of structural elements from dissimilar materials like aluminium (e.g. EN AW-6056) and titanium (e.g. TiAl6V4) can be realized e.g. by mechanical joining processes such as riveting [1]. These are still the most widely used techniques in the aircraft industries. An alternative for joining titanium and aluminium is the use of laser-based processes. However, the key aspect during joining of aluminium to titanium is the formation of intermetallic phases [2, 3], which depends on process-related temperature-time cycles [4]. As a result of excessive phase formation, embrittlement of the joining zone is observed [5, 6]. Thus, if joints with high toughness and strength are required, the intermetallic phase layer has to be limited to a minimum thickness [7].

Aside from such welding processes as diffusion welding, which are certainly not appropriate for joining seat tracks in a length of 6 m or more, some research concerning local joining processes for titanium to aluminium has been published. Nippon Aluminium suggested taking titanium clad with copper in combination with a zinc aluminium soldering metal; the joint should be made by ultrasonic welding [8]. Other techniques have been presented by Suoda [9] and Fuji [10, 11]. Suoda reported on aluminium-titanium joining using an electron beam. Fuji used a friction welding process for this kind of dissimilar joint. Furthermore, the use of explosive welding to realize aluminium-titanium joints for lightweight applications [12] was reported.

Considering local, laser-based processes, some research was also done at the institute of the authors [13-15]. In Figure 1 a suitable process for aluminium titanium process is shown.

For the overlap configuration the laser spot was unfocussed and directed onto the titanium sheet. Heating up the titanium, the aluminium alloy was molten by the heat transferred from the titanium sheet. After this, the unmolten titanium sheet was pressed onto the aluminium using a pressure roller head to realize a metallic joint by the effect of diffusion.

For the aluminium titanium butt joint configuration, the focus spot of the laser beam was on the surface of the specimens. The exact positioning of the spot was necessary to realize a reproducible joining result. In this process,

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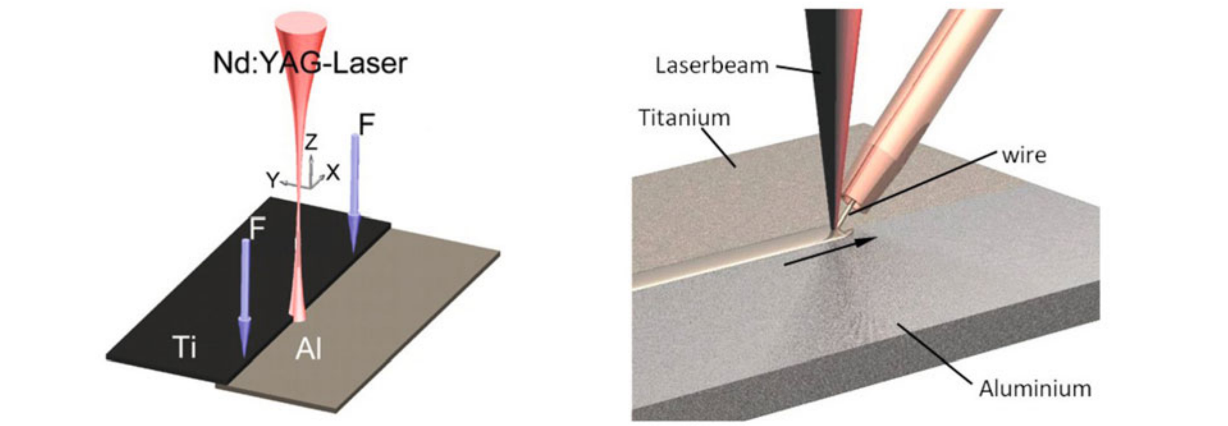


a) for overlap geometry b) for butt joint geometry

Figure 1 – Principle of laser joining of aluminium and titanium [14]

the focus was displaced on the titanium. To minimize the formation of a gap between both joining partners, the specimens were fixed in a special clamping device. The failure of this joint in tensile testing was on the aluminium side.

In summary, a laser beam process can be used for local joining of aluminium titanium hybrid structures. To transfer laser-based process for this task to industry, the joining equipment has to be enhanced. Therefore, sensors have to be adapted to guarantee a constant and exact positioning of the laser spot and specimens to achieve reproducible joint appearances and properties.

2 Aim and scope

The task was to develop a suitable process to produce load-bearing aluminium-titanium-structures. Therefore, it was necessary to enhance the existing joining system to guarantee reproducible joint properties.

In this paper, the development of the joining system will be explained first. The presentation of the influences of the spot position on the joint properties follows subsequently. Furthermore, the development of the process and the main influences on the tensile strength of the joint will be reported and discussed. Afterwards, taking into account the high sensitivity of the process on the position of the working heads in vertical direction, the enhancement of the joining system by appropriate sensors is presented. Finally, prototype aluminium-titanium seat tracks with a constant joint quality on a length of 1 m will be demonstrated.

3 Experimental

3.1 Principle of the proposed joining process and experimental set-up

Figure 2 shows the principle of the simultaneous double sided joining process. Prior to the experiments, the aluminium side of the joint area is machined by milling into the shape of a material reservoir, which replaces, respectively, acts as a filler material. The sheets are arranged in vertical position with aluminium on top to achieve a good wetting of the titanium sheet under the effect of gravitation.

As sketched in Figure 2, the laser beams are not working in focus and irradiate both aluminium and titanium. Thus, no vapour capillary is formed, and a heat conduction joint is produced. Thus, the aluminium is molten and the titanium is heated up to ensure the wetting by the aluminium melt. The titanium remains in a solid state during joining; the joint is achieved by the formation of intermetallic phases between both materials, which need to be kept small due to their high brittleness.

For the transfer of the process principle into an experimental facility, a gantry system was developed. The defocused Trumpf HL 4006D lamp pumped Nd:YAG laser has a maximum power of 4 kW. The joint was shielded by argon to reduce effects from environmental air, resulting

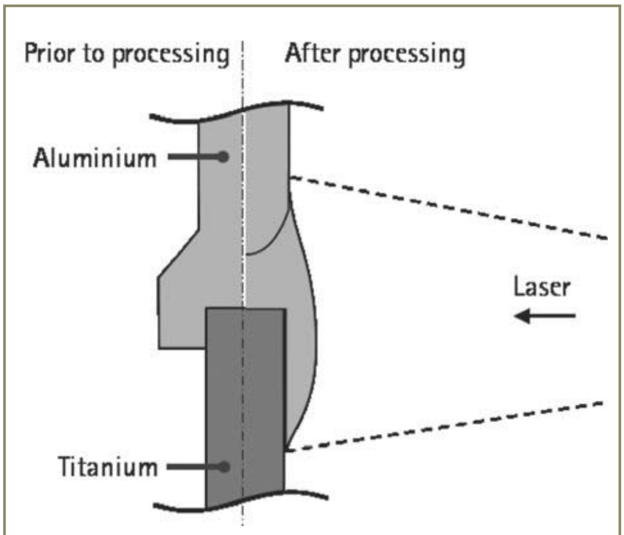


Figure 2 – Process principle of the aluminium-titanium joining process

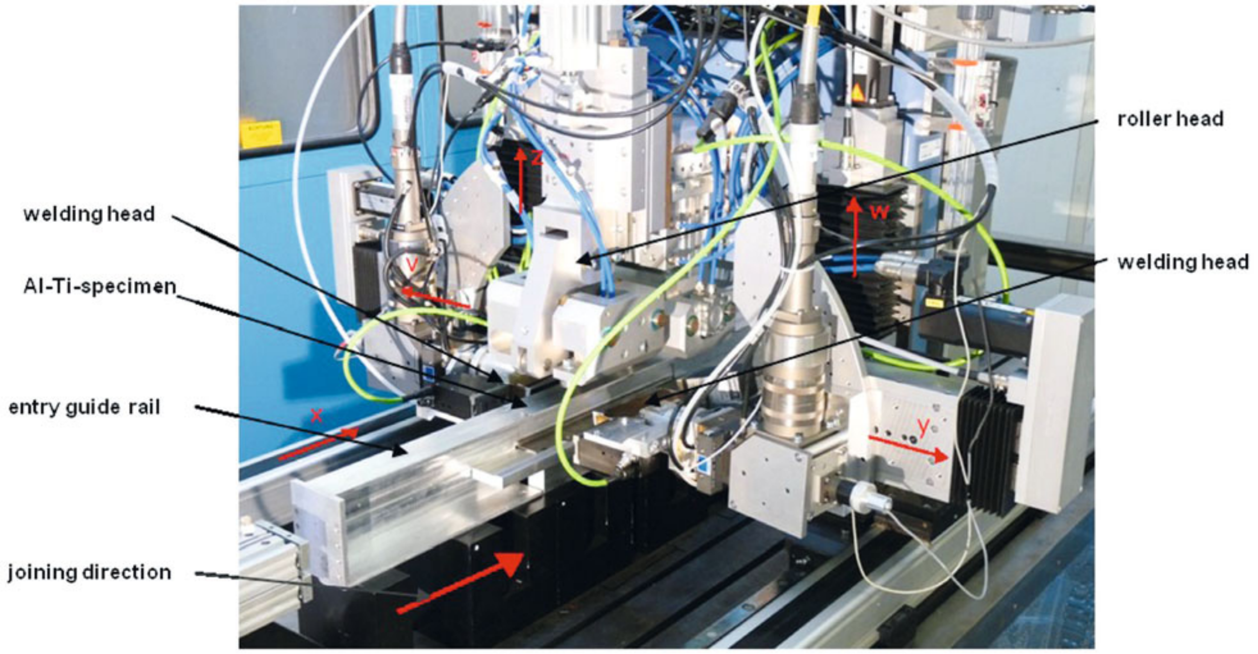


Figure 3 – Joining system

in the potential formation of oxides and nitrides on the materials. The gantry system with the main components is shown in Figure 3.

For clamping, a roller head is attached to the gantry system and is moved along the seat track during the joining process. The part of the roller head in front of the joining process consists of a pair of guide rollers and a pressure roller. The part succeeding the joining process consists of two lateral pairs of guide rollers and two pressure rollers, each with a lower clamping force than the leading ones. To provide a steady transfer of the guide rollers and the pressure rollers, an entry and a run-out guide rail are integrated.

3.2 Materials

The basic investigations were performed on the material combination EN AW-6056 T6/ TiAl6V4. Instead of seat track profiles, sheet materials were clamped in clamping devices and used for the experiments. The length of the test sample was 330 mm; the thickness of the material was 1.8 mm on the titanium side and 2.0 mm on the aluminium side. Both materials were pickled to guarantee a reproducible surface appearance.

3.3 Methods

All brazed sheets were analysed by metallographic and mechanical testing. For metallographic testing, cross-sections were taken from the specimens. After polishing, the specimens were etched by VAW from Dasa AG to visualize and analyse the intermetallic phase seam. To evaluate the quality of the seam, the surface and geometry were analysed and cross-sections were taken from the sheets. Figure 4 illustrates the joint parameters measured to characterize the cross-section.

For testing the tensile strength, three specimens were taken from each specimen. Furthermore, the hardness of the joint was tested by applying the industrial standards.

3.4 Experimental procedure and program

Before joining, the specimens were cleaned with alcohol to prevent joint defects from impurities. After that, the specimens were fixed onto the clamping device. Furthermore, the shielding gas chambers were positioned on the surfaces. Then, the laser was switched on and heated up the aluminium until it started to melt. The joining process started after establishing a basic parameter setting, the investigations were focused on a variation of the heat input per length. This was done by varying the laser power at a constant velocity of the working heads. Furthermore, the position of the working heads in vertical direction with respect to the lowest aluminium edge was varied (so-called offset).

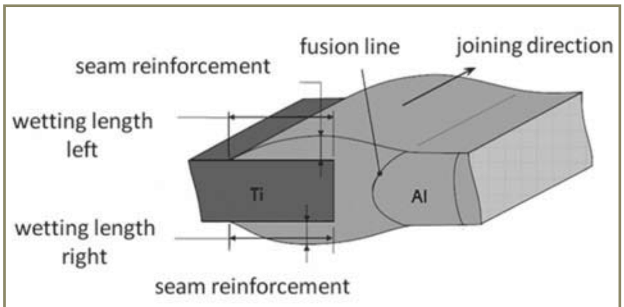


Figure 4 – Measurement principle for the cross-section of the seat track

4 Results and discussion

4.1 General observations

The joint appearance follows the typical characteristics of hybrid material joints. The aluminium was molten and wetted the titanium. In Figure 5, a typical joint appearance and a cross-section are given. By the simultaneous joining process, a reproducible, constant wetting length of 3.6 mm and a seam reinforcement of 0.6 mm can be achieved.

The surface of the aluminium joint shows fine weld ripples which are quite normal for aluminium joining. Moreover, there are no joint defects like pores or hot cracks detectable. The cross-section shows a symmetric joint appearance. The wetting lengths on both sides are at the same value, which indicates a stable process. Because of the symmetric wetting the specimens show reproducible joint properties and potentially less distortion than for non-symmetric wetting.

The joint was realized by the formation of a phase seam, which was about 1.75 µm thick. Figure 6 presents typical phase seam thicknesses versus nominal heat input per length.

Generally, with increasing heat input, phase seam thickness is increased. This is more obvious for a heat input up to approximately 750 kJ/m, where phase seam thickness increases from approximately 1.2 µm to approximately 1.75 µm. For a higher heat input, only a very moderate increase in average phase seam thickness is observed. However, phase seam thickness remains below 2 µm on the average, which is uncritical for the strength of the weldments. With respect to optimum process stability, the further experiments were done at 750 to 800 kJ/m.

In addition to the phase seam thickness, the hardness of the joint was also measured. In Figure 7 a typical graph of aluminium and titanium hardness, one day after joining and after natural ageing for up to 49 days, is shown.

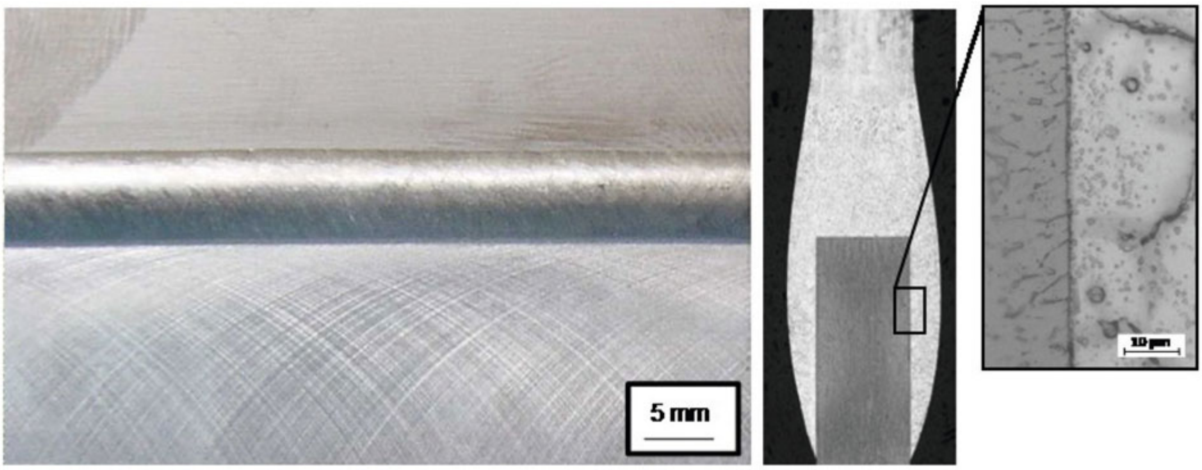


Figure 5 – Joint appearance and cross-section

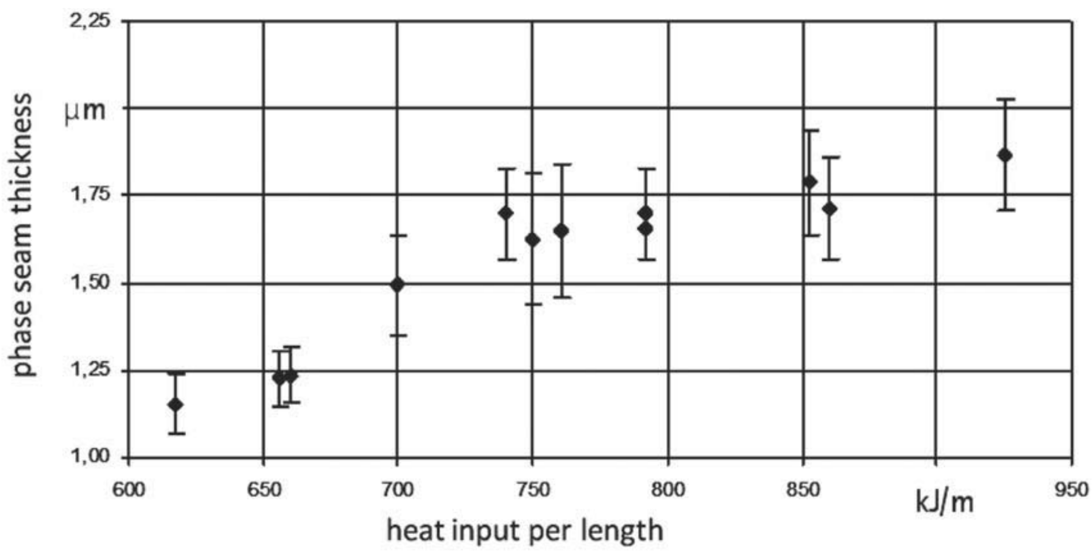
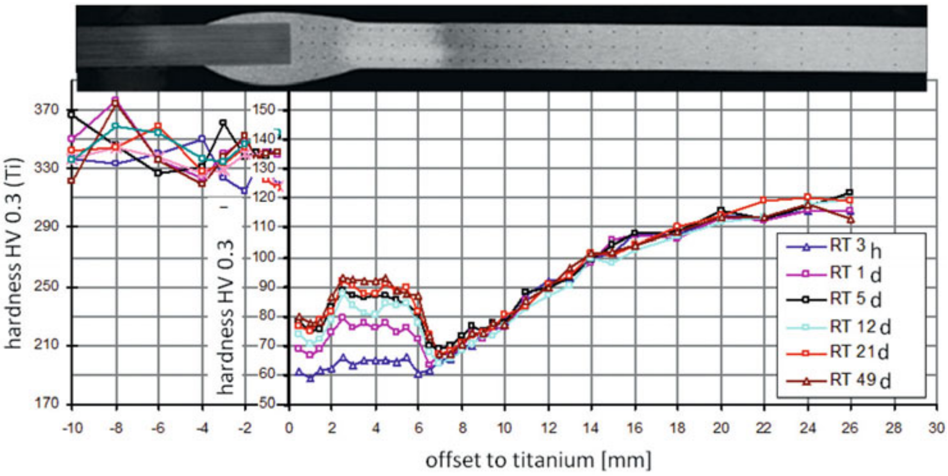


Figure 6 – Phase seam thickness versus heat input per length



(RT X d indicates natural ageing for X days).

Figure 7 – Hardness measurements

On the aluminium side a first minimum of hardness can be identified directly at the contact zone to titanium. Furthermore, a second minimum is at the end of the heat-affected zone. This graph is typical for brazing of such aluminium alloys and results in tensile testing in a failure of the joint at the end of the heat-affected zone of aluminium. Although natural ageing will increase hardness to a certain extent, the basic failure location is not affected.

Furthermore, different wetting lengths were identified in the investigations which could be traced back to different spot positions of the laser relative to the lowest edge of aluminium. Such variations can happen through fabrication tolerances of the specimens or deviations in the positioning of the working heads. The different wetting length resulted in variations of the tensile strength of the joint. To prevent and identify such phenomena, sensors were adapted to the working system and different positions of the working heads in vertical direction were investigated.

4.2 Effect of different positions in the vertical direction on joint properties

In the investigations, a deviation of the wetting length was identified. By varying the laser power or the position of the working heads in the vertical direction (relative to the lowest edge of the aluminium profile), the so-called offset, the wetting length can deviate from the optimal parameters. Whereas laser power can be kept constant, specimen geometry can vary due to fabrication tolerances. As an example, there may be height differences in the profiles, resulting e.g. in a variation of the lowest edge of the aluminium profiles relative to the laser spot.

Simulating such fabrication tolerances by a de-positioning of the working heads in the vertical direction relative to the standard position, the wetting length of the titanium-aluminium joint was found to vary on the right side from 2.88 mm to 4.47 mm and on the left side from 2.54 mm to 4.09 mm for an offset range of 1 mm. Both wetting lengths were increasing with a de-positioning of the laser spot onto the titanium until a full penetration of the joint at an offset of –0.4 mm. The disparity between the left and right side wetting lengths was measured to be –0.25 up to +0.45 mm. The seam reinforcements and the wetting length versus offset are shown in Figure 8 with, on the right side, cross-sections for the parameters of 0.2 mm offset to titanium. No offset and offset of 0.4 mm to aluminium are shown.

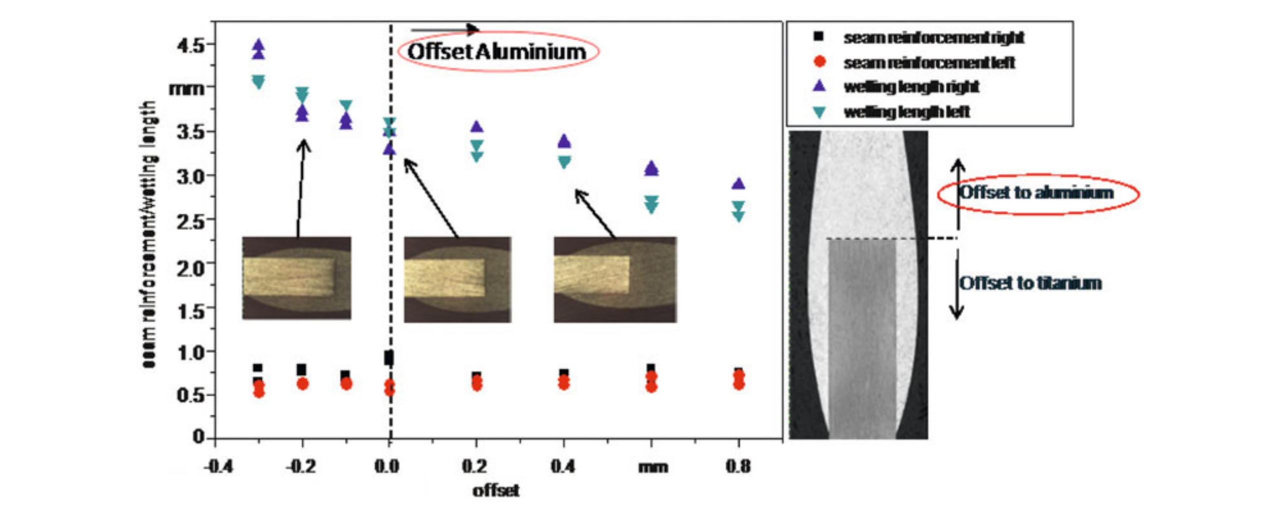
The increasing of the wetting length when de-positioning on the titanium can be traced back to different absorption rates of aluminium (5 %) and titanium (13 %) for a wavelength of 1 064 nm (Nd:YAG laser). The larger the area of the laser spot on titanium, the more laser power is absorbed, resulting in a temperature increase especially in titanium. Thus, by heat conduction in titanium, the temperature field in titanium is widened. This in turn means that the spreading of the aluminium melt on titanium is promoted, as it is supposed that, for our processing conditions, wetting will stop if the isothermal line having the melting temperature of aluminium on titanium. Consequently, as the total amount of aluminium melt is not significantly affected by the offset to titanium in the ranges investigated, wetting length will be increased.

The relevance of wetting length is due to its link to the tensile strength of the specimens. By varying the offset of the laser spot, the effect of the different positions of the laser spot on tensile strength was investigated (Figure 9).

As it is presented the maximum tensile strength can be identified at a wetting length of 3.6 mm. This value can be reached at the optimal parameter settings.

4.3 Triangulation sensor system for edge detection and positioning

In view of the effects explained above, it is necessary to guarantee a reproducible positioning of the working heads with respect to the aluminium edge in order to ensure a regular wetting and a tensile strength within



(Negative values indicate a position on titanium).

Figure 8 – Seam reinforcements and wetting length versus offset of the laser spot

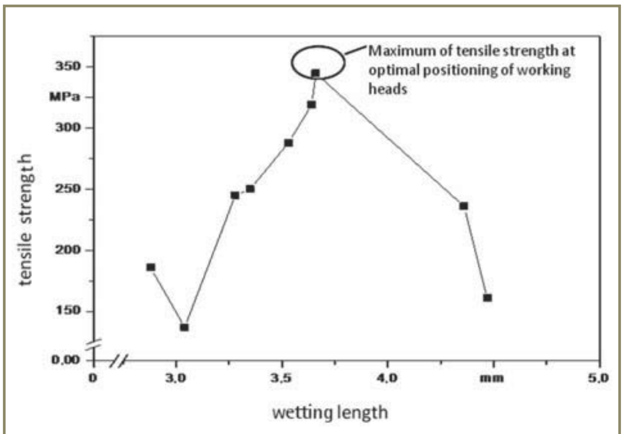


Figure 9 – Tensile strength versus wetting length

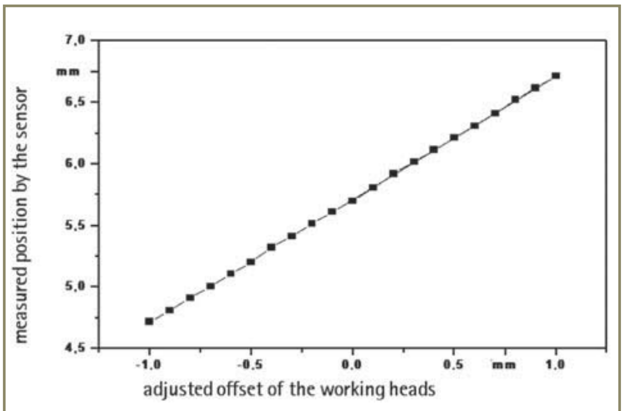


Figure 10 – Measured position versus adjusted offset of the working heads

specifications. Therefore, triangulation sensors by Falldorf GmbH were mounted directly on the working heads. These sensors can detect the vertical position of the lowest aluminium edge. Thus, it is possible to recalibrate the working heads in case of deviations in vertical directions of the specimens (e.g. by tolerances) or de-positioning of the working heads.

In Figure 10 the investigation of the discrepancy between the measured value of the sensor and the adjusted offset of the working heads to optimal position is shown.

In Figure 10 it can be seen that a linear correlation between the offset and the measured position was obtained. This means that the sensor is able to identify the position of the laser spot with respect to the lowest edge of aluminium. Thus, if the profile is measured in the clamped condition, the relative position of the working heads can be adjusted accordingly, allowing to perform a reproducible joining process with regular wetting and adequate tensile strength.

4.4 Demonstrator of seat-track profile

On the basis of the above studies, it was possible to fabricate a titanium-aluminium seat track for aircraft applications with acceptable joint properties with respect to the requirements of the industry. In Figure 11 the demonstrator with 1 m in length is presented.

5 Conclusions

Within this paper, it was demonstrated that the heat-conduction laser joining process is a suitable joining process for a dissimilar material combination of aluminium and titanium.

Figure 11 – Demonstrator of titanium-aluminium aircraft seat tracks

By a systematic variation of process parameters, it was shown that titanium-aluminium joints with optimized properties with respect to seam appearance, seam geometry, microstructural integrity and static strength can be produced within a comparatively wide parameter envelope. In particular, it was established that an increase in heat input will lead to an increase in thickness of the intermetallic layer, which however still remains at an uncritical level of less than 2 µm.

With respect to geometrical parameters, it was shown that the position of the lowest edge of the aluminium profiles relative to the laser has a significant effect on wetting length and the resulting tensile strength. By integrating an appropriate set of laser triangulation sensors into the production system, it was demonstrated that such variations due to geometrical tolerances in parts can be compensated by adapting the brazing path to the measured geometrical position in order to produce reproducible joints.

Finally it was demonstrated that it is possible to transfer the developed process to an aircraft demonstrator (seat track element) with a constant joint quality on a length of 1 m.

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