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USE OF FRICTION STIR WELDING ON PRIMARY STRUCTURES OF AIRCRAFTS INSTEAD OF RIVETED JUNCTION

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Abstract

AIRBUS ATLANTIC is aerostructures leader and major worldwide player for design and production of primary structure of aircrafts. AIRBUS ATLANTIC designs and builds complex composite, metallic and hybrid aerostructures parts and sub-assemblies, such as fuselage sections, for both civil and military programs. For several years, AIRBUS ATLANTIC leads research programs dedicated to FSW technology.

Friction Stir Welding is a solid phase joining process commonly used in aluminum industry. Contrary to fusion welding process, FSW allows welding of 7xxx and 2xxx alloys, frequently used in aeronautic industries. Repeatability and low cost are the main qualities which make FSW a good candidate to replace riveted assemblies on aircraft structures. Fastening assembly removal should enable substantial weight and cost saving.

Typical junction area of fuselage is riveted for common commercial aircraft. These junctions are sized by fatigue and damage tolerance criterion, due to pressurization loading, with single-shear or double-shear geometries, and potential overlap.

The use of FSW could be a solution to solve criticality of fuselage junctions due to the proof of its high mechanical properties. Two welding configurations are possible: butt joint welding and lap joint welding. Due to corrosion criteria, butt joint welding is the best configuration.

The main challenge is to prove the viability of FSW to develop an industrial process which takes account of certification and cost aspects. This one includes no defect in welded area, capability of maintenance and no destructive testing to detect possible crack.

Keywords: FSW, Riveted junction, Fuselage, Primary structure

1. Introduction

2. Context in primary fuselage structure

2.1 State of the art

In current aeronautical environment, the assembly of structure is mainly done by riveting. To joint primary structure, thousands of rivets or fasteners are used. This way to assemble is robust and well known. But each drilled hole weakens the resistance of the structure, in particular in fatigue and damage tolerance. All the efforts in the structure are transmitted by the fasteners. So overstress appears around each hole, and they could the cause of damage during the life of the aircraft.

The solution is to assemble by a means to permit a continuous joint between parts. And the welding responses at this need because it joints by a solid phase without break. Friction Stir Welding allows to joint high performance aluminum alloys in aeronautic structures.

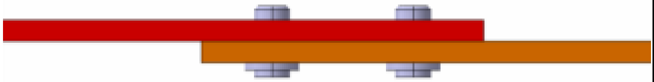	
Classical riveting junction (2 rows of fasteners)	New welding junction

Figure 1 – Comparison riveting and welding junctions.

But it is necessary to design structures which are compatible to use Friction Stir Welding. And a complete well-known mechanical characterization of the welded joint is necessary to permit a full sizing of primary structure assembly by FSW.

2.2 Key challenge

The main drivers of the use of friction stir welding on Fuselage primary structure are to known the mechanical characteristics of the structure in static, fatigue and damage tolerance in the welded area. It is necessary to known the down factors compared native material following several mechanical behaviors of solicitation: traction, compression and shear in the joint area. By definition of the process FSW, different areas have to be known: the central area which is called ’nugget’ and in the areas which are thermic affected or thermomechanical-affected by the FSW process.

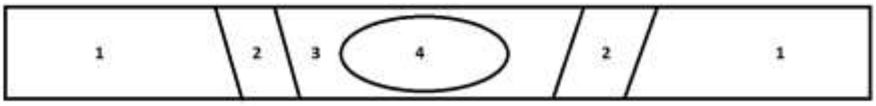

Figure 2 – Welding zone of FSW: (4) nugget zone, (3) thermomechanical-affected zone, (2) heat-affected zone and (1) base material.

And the main rule of this fuselage primary structure keeps being a pressure barrier with a good resistance to the corrosion, especially in the lower arear of fuselage. And finally, keep in mind the usual objectives of all aircraft structures: to optimize the recurrent cost and the weight of the aircraft structure.

3. Key Parameters of welding

3.1 Configuration

In this present study, the considered configuration is a butt joint of a thin plate (orange are a on the figure 3) with a machined thick plate (red area on the figure 3). From a geometrical point of view, the thickness of the welded area is 3mm in the studied configuration.

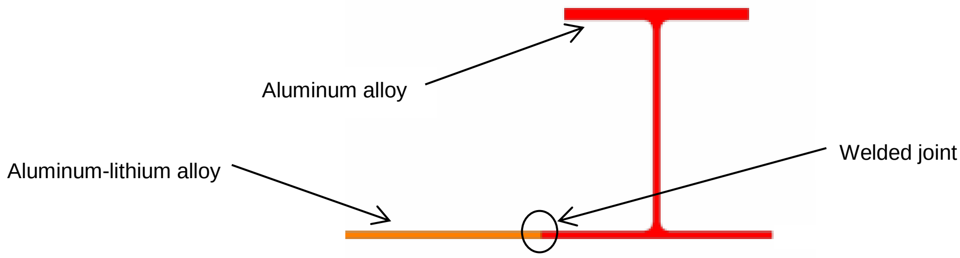

Figure 3 – Design configuration.

The aim is to define the key parameter values to obtain a high-quality welded butt joint with two thin plates of dissimilar aluminum alloys. In this specific case, the material of the configuration is one 7040 aluminum alloy thin plate and one 2198 aluminum-lithium alloy thin plate 2198.

3.2 Key parameters definition

To valid the welding process, tests are performed on specimens to define the best parameters set. The three main parameters are the rotation speed of the rotating tool, the advance speed of this one and the forge tool force.

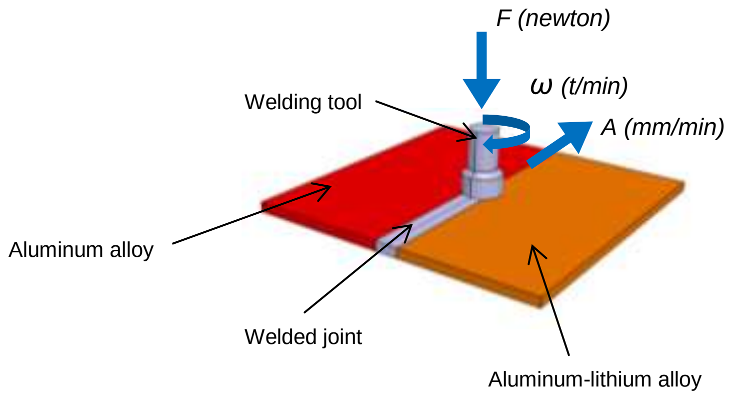

Figure 4 – Welding configuration.

From a frozen forge force, different values of advance speed and rotation speed of the welding tool have been tested.

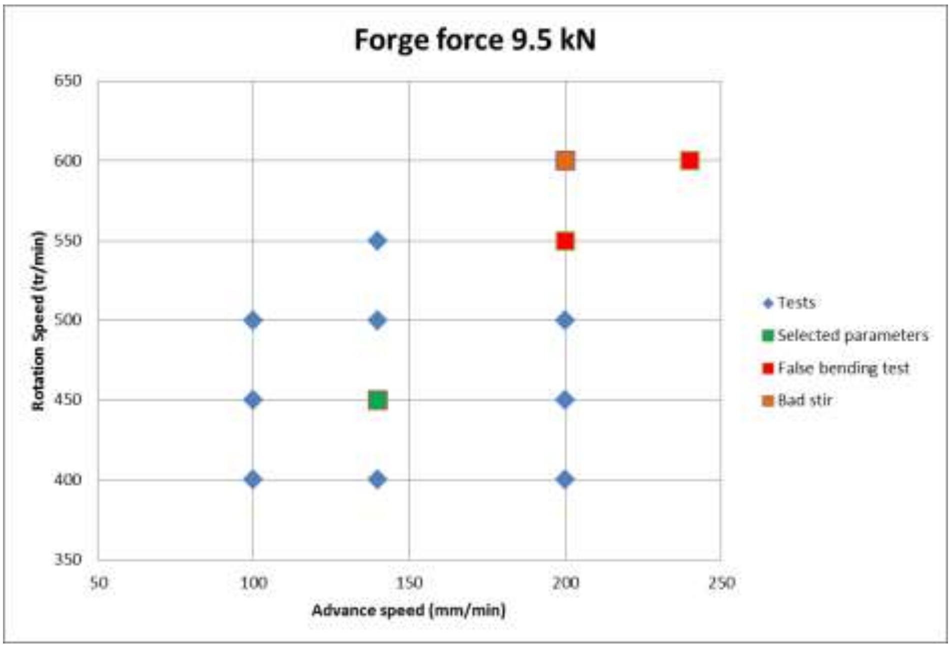

Figure 5 – Welding parameters.

The best parameters have been found after testing of different parameter sets.

3.3 Validation of welded joint

Each set of parameters have been tested, in three different ways:

A visual inspection of the weld is done to see the appearance of the welded area and the presence of flash. The criterion of acceptance is only if there are few flashes and negligible surface default in the welded joint.

Figure 6 – Example of welded specimen.

Following reference [1], a bending test is performed to identify the possible lack of penetration.

Figure 7 – Bending test.

A micro-graph of the joint section permits to validate the quality of the nugget and of the thermal affected area.

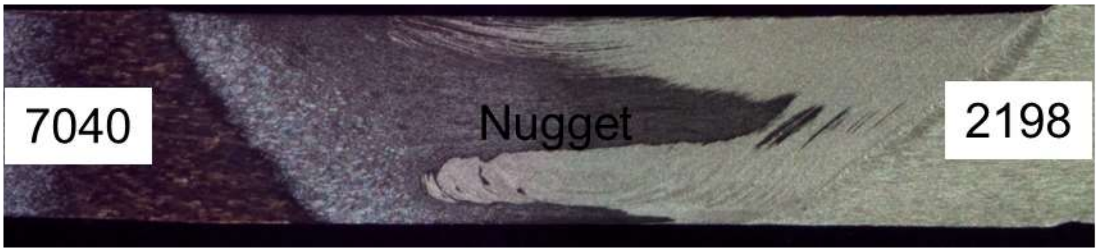

Figure 8 – Macro-graph of valid joint.

4. Mechanical characteristics

4.1 Approach

With optimized parameters set, a complete campaign of mechanical testing has been done on dissimilar butt joint. The aim is to compare the weld metal with both parent metals in a dissimilar welded joint.

To allow comparison with native materials, the same manufacturing process, including heat treatment and post processing, and the same test conditions are applied to non-welded materials.

And possible reduction factors are evaluated by a direct calculation between the results of non-welded materials and the welded test specimens.

4.2 Static mechanical characteristics

Static characterization tests with tension and shear solicitation have been done.

Tension static testing is done following reference [2]. Shear static testing is done following reference [3]. Welded specimen results are compared to both parent material specimen results.

There is a decrease of 25% of tensile strength (Rm) between the welded material and the parent material with the lowest mechanical properties, i.e. 7040 aluminum alloy. And the shear strength decreases of 10% between the welded material and the parent material with the lowest mechanical properties, i.e. 2198 lithium-aluminum alloy. Globally we found acceptable reduction factors compared to the mechanical properties of the non-welded material.

Nevertheless, the elongation is divided by two between weld metal and parent metal.

4.3 Fatigue and damage tolerance characteristics

Fatigue characterization test with the similar solicitation (tension) has been done. Tension fatigue testing is done following reference [4]. Welded specimen results are compared to both parent material specimen results. The behavior of the weld is similar to the material with the lowest mechanical properties, i.e. 7040 aluminum alloy.

Propagation crack and R-curve tests have been done following references [5] and [6].

There is a decrease of the resistance capability in damage tolerance, but for the current design of welded junction, it is acceptable, because the junction in classic fuselage primary structure remains sized by the fatigue criteria.

4.4 Corrosion behavior

One of the main requirements remains the corrosion resistance.

The corrosion behavior of the welded joint has been studied in two steps.

4.4.1 Welded joint without post heat treatment

To evaluate the corrosion behavior of welded joint, some tests have been realized on welded junction between 7040-T7451 and 2198-T851 materials, directly after welding. Several tests were done on welded specimens: salt spray and filiform following references [8] and [9].

Inter-granular corrosion is founded on the 7040 side. The corrosion is localized along the heat affected area, which could due to galvanic corrosion. To solve this problematic, the requirements of reference [10] have been applied. We have applied a heat treatment on full assembled structure after welding operation.

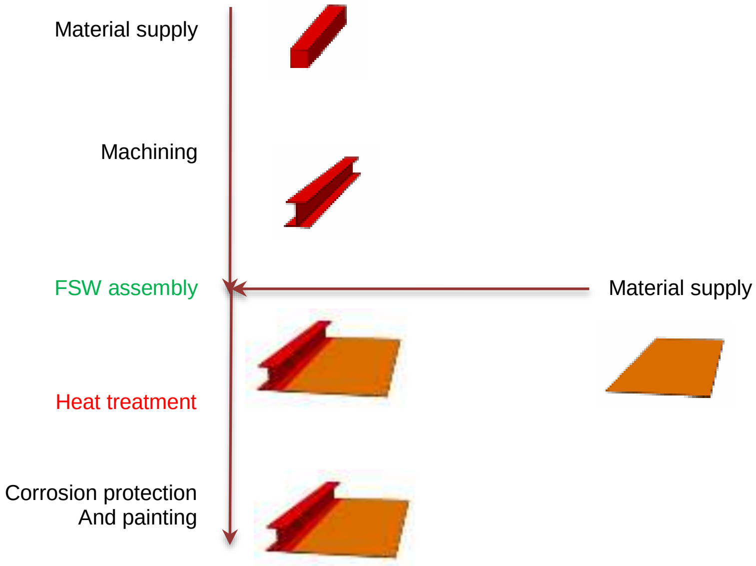

Figure 9 – Manufacturing process.

4.4.2 Welded joint with post heat treatment

With this new process which includes heat treatment after the welding operation, same corrosion tests have been performed in similar conditions.

For Neutral Slat spray test, after 3000 hours in the test chamber with a neutral atmosphere, there is no defect on the specimens.

For Salt spray filiform test, after 960 hours in the test chamber with a hydrochloric acid atmosphere, all the defects close to the welded area are acceptable, because their length are less than 2 millimeters.

These test results validate the complete process including the operations after welding.

5. Demonstrator definition and production

With all the knowledge of this new technology, a proof of concept has designed. The aim is to manufacture a demonstrator to valid the capability of the friction stir welding applied on dissimilar aluminum alloys to produce large integral component without fasteners. The different materials remain 7040 aluminum alloy for machining large parts and 2198 aluminum-lithium alloy for thin plates.

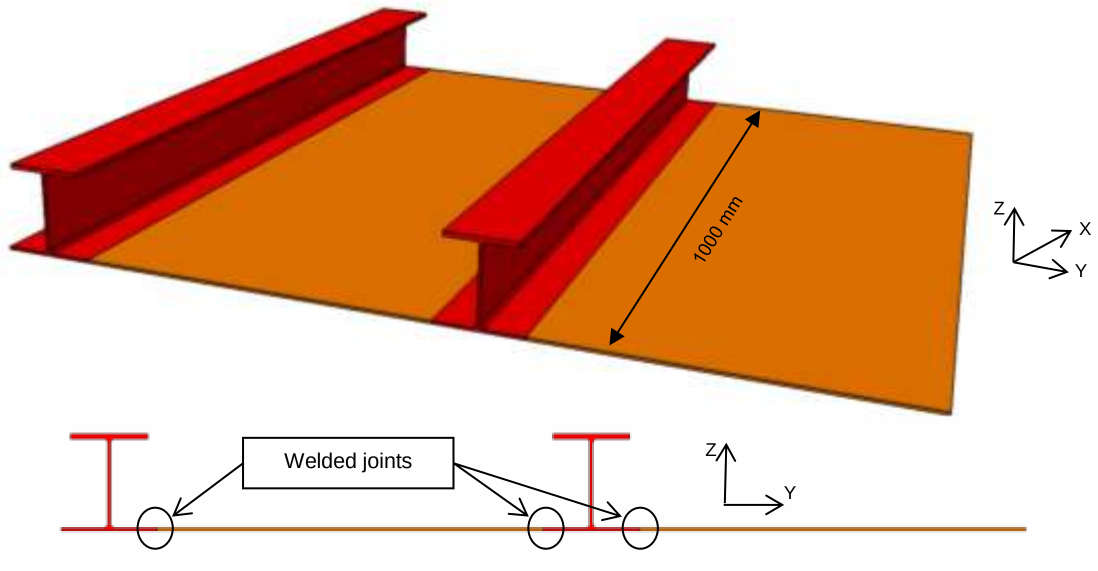

Figure 10 – Demonstrator design.

On this demonstrator, there are three linear welded joints.

We have built two demonstrators. Each demonstrator was welded at the three locations. A non-destructive testing of all the welded areas is done, to prove the good quality of the junction. After welding operations, the complete process including heat treatment, corrosion protection and painting, has been applied on the two demonstrators.

To control the geometrical dimensions of these demonstrators, we have done a complete scan. The main possible deviation is on the Y-axis. And the difference between theoretical dimension and the measure on demonstrator are lower than 0.5 mm on the both demonstrators. It is equivalent to the current riveting solution, so this requirement is validated.

6. Conclusion

The friction stir welding, specifically applicate to fuselage primary structure could be a solution to reduce the use of riveting junction.

The main previous identified limitation was the corrosion, but with the good heat treatment after the welding operation, the corrosion behavior is acceptable.

From a fatigue and damage tolerance point of view, this technology stays very interesting. The mechanical characteristics of welded joint are similar than ones of the parent material. And the deletion of fastener still is the main benefit of the use of welding.

Currently, a special attention on the riveted junctions is necessary during all the maintenance phases of aircraft inspection. So FSW technology could be the solution.

The production of demonstrators permits to validate definitively the capability of manufacturing.

Nevertheless the main challenge is to prove the viability of FSW to develop an industrial process which takes account of several other aspects: the certification of dissimilar welded junction, the capability of maintenance and reparation, and the capability to weld a complex junction and to perform efficient no destructive testing on welded area.

7. Contact Author Email Address

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8. Copyright Statement

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