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APPLYING FRICTION STIR WELDING TO THE ARIANE 5 MAIN MOTOR THRUST FRAME

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ABSTRACT

Fokker Space developed and is responsible for delivery of the motor thrust frame on the cryogenic main stage of the Ariane 5 launcher. It is essentially an unpressurised conical structure consisting of many integrally machined Aluminium 7075 alloy parts interconnected by the extensive use of manually installed Hi-lok™ fasteners. For ease of manufacture and assembly, the majority of parts interconnect by lap joints.

The increasing international competition in the commercial launcher market is directly linked to the demand from Arianespace that the European Space industry delivers future Ariane 5 launchers at substantially reduced cost. This in turn has led Fokker Space to pursue a vigorous programme to bring cost cutting production processes to full maturity. This programme includes friction stir welding (FSW).

INTRODUCTION

Up to now the primary interest and major developments in FSW have been as an alternative to other butt welding techniques. Modifying the motor frame design for butt welding is not acceptable due to programme impact and risk. This was the motivation for Fokker Space to set up a research programme with TWI specifically aimed at applying FSW to lap joints. Lap joints offer significant advantages but present particular problems that must be overcome to achieve acceptable weld quality. This paper describes the progress to date and the plans for the future.

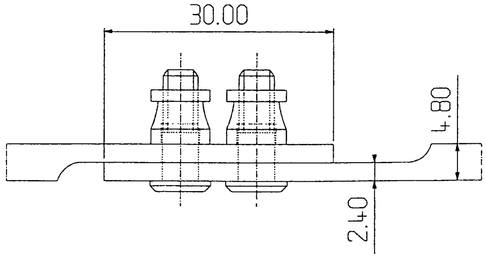

Figure 1: Overlap Connection

The connection in question is the overlap shown above. The material is 7075-T7351 with an original plate thickness of 50mm (see figure 10).

ASSEMBLY

The thrust frame main cone is constructed from 12 integrally machined, blade stiffened, flat panels that are shot peened to the required form. The panels are then positioned, drilled and fastened together in the main assembly jig. Another feature of the thrust frame are the three "ring frames" fastened to the smooth outer surface of the cone. The blade stiffeners are on the inside of the structure.

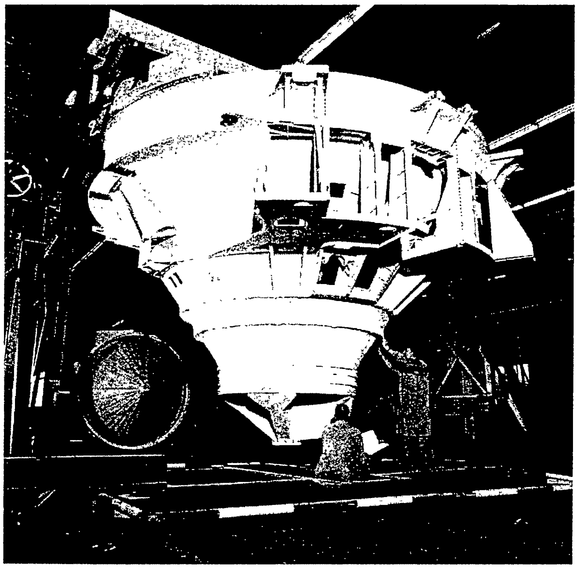

Figure 2: Ariane 5 Main Motor Thrust Frame

The aim is to create a main cone sub-assembly in a new jig with FSW for the interconnection of the conical panels. Initially the ring frames and other secondary structures can be riveted to the cone in the same jig. The main cone sub-assembly can then be directly placed into the main assembly jig saving both cost and time spent in the main jig. The final ambition is to FSW the ring frames to the cone which will mean lap welding Aluminium 2024 to the 7075 of the main cone.

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TOOL DESIGN

In the FSW of aluminium it is essential that the stirring motion breaks up the oxide layer on the mating surfaces[1]. This fact makes overlap welds fundamentally different from butt welds. For butt welds the primary stirring motion required is in-plane, while overlap welds need out-of-plane mixing across the interface of the two sheets.

Based on their core research programme (CRP), TWI suggested a number of tools which were variations on a common theme. The principle difference in a FSW tool for lap welds is the application of a second "shoulder" located at the interface region between the two plates. The lower part of the pin is reduced in diameter and has a flattened profile to stir up the oxides and to improve the material flow[2]. An advantage of lap welding is that the pin does not have to penetrate close to the bottom surface as is the case with single pass butt welding.

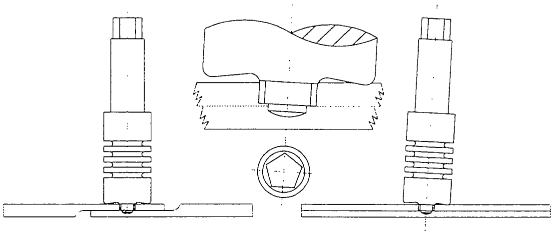


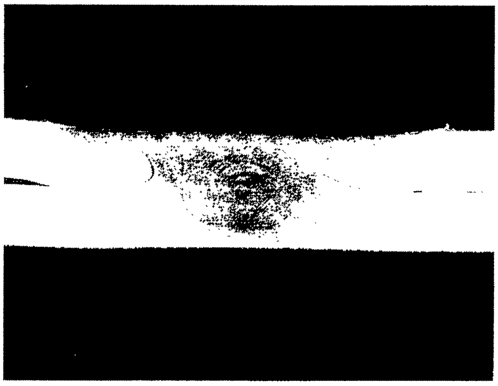
Figure 3: Tool Design

Figure 4: Friction Stir Welding Facility

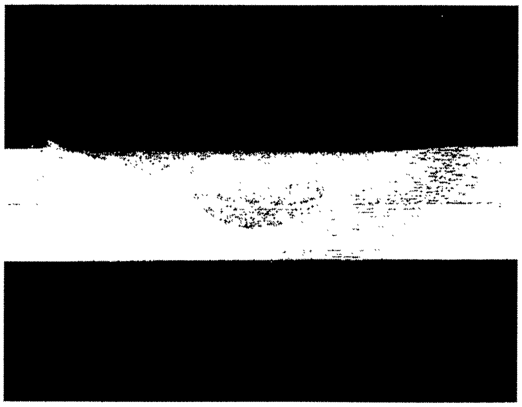
WELDING TRIALS AT TWI

The first trials were conducted with 250mm square, 2.5mm thick 7075-T73 clad sheet. The 7072 cladding unexpectedly contaminated the weld nugget and there was lifting of the free edge of the top sheet.

Trials continued with the cladding removed from the mating surfaces. The metallurgical sections looked better but significant upper sheet thinning occurred in the top sheet as can be seen in the cross-section below.



The tool design was modified so that less metal moved in the direction of the top-sheet. Trials then continued with flat 250mm square sheets of 2.4mm thickness machined from 10mm thick 7075-T7351. The results were very satisfactory as can be seen below.



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Having demonstrated the feasibility of a high strength lap weld it was necessary to move to a more representative configuration. To that end a new series of trials was conducted with 1m long 4.8mm thick flat plates with a 2.4mm thick lip including a radius (see figure on page 1), machined from 10mm thick 7075-T7351. A micro-section of the first 1m weld (Weld A) can be seen below and is very similar to that at the bottom of the previous page. The hand drawn line indicates the failure location.

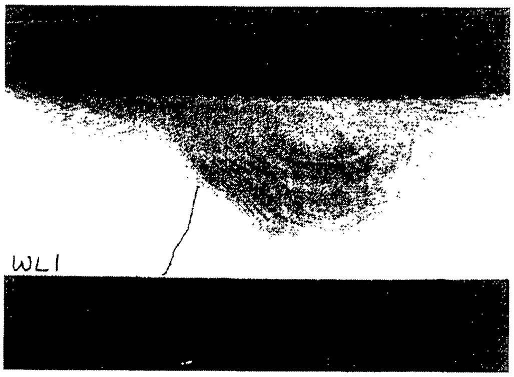

Figure 5: Weld Micro-sections

MECHANICAL PROPERTIES

After completion of each 1m long weld, five 25mm wide strips were cut from the plate to determine the tensile strength at positions along the complete weld length. During some of the trials thermocouples were placed close to the weld centre line (adjacent to the locations where the tensile specimens would be taken) to determine if and when a steady state condition is reached during welding.

When tested in tension, the stress state in a lap joint is a combination of direct, bending, shear and peel stresses. Therefore the results cannot be directly compared with a pure tension test on parent material or seen as pure shear strength if failure occurs in the weld. It should also not be forgotten that some local "thinning" of the top sheet near the weld increases the local stress and reduces the apparent tensile strength.

The Weld A failure locations were all in the bottom sheet in the heat affected zone (HAZ). The performance of Weld B is clearly inferior and failure occurred once in the top sheet, twice in the weld nugget and twice in the bottom sheet. The cause was identified as sheet thickness variations extending outside the ±0.1mm tolerance band.

Before performing Weld C the available plates were inspected and the most dimensionally accurate chosen rather than a random selection. This resulted in a restoration of the earlier strength values but for this weld the failure locations were all in the upper sheet.

The measured tensile stress at failure for these three welds are shown in figure 6. Also shown is the 200 MPa ultimate allowable design stress for the bolted connection. The design ultimate tensile stress for 7075 T7351 is 450 MPa.

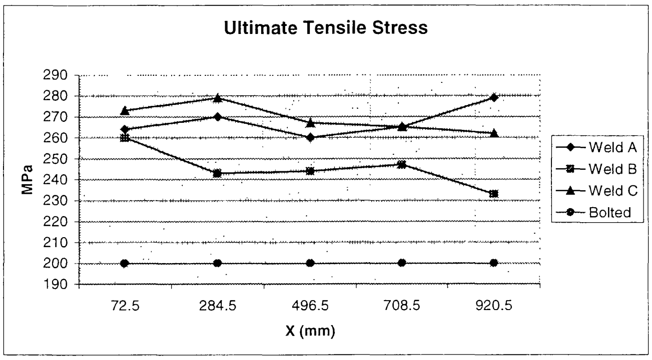

Figure 6: Ultimate Tensile Stress

TEMPERATURE MEASUREMENTS

Degradation of mechanical properties in aluminium alloys occurs during welding as a consequence of the heat-input normally in the HAZ. A typical graph of the temperatures measured during FSW is given below.

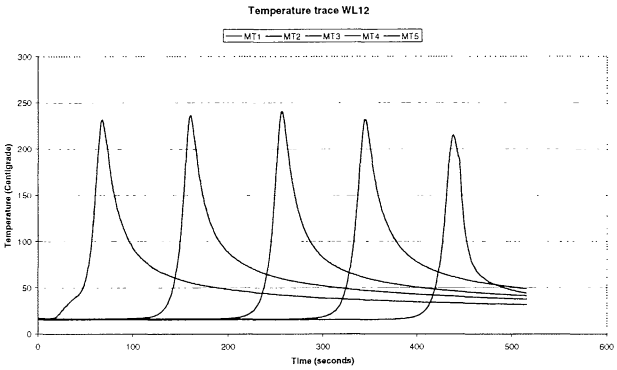

Figure 7: Temperatures during welding

As can be seen in figure 7, even at the start of the welding operation, which includes plunging near the plate edge, the temperature does not rise above that of the rest of the weld. As the tool moves away from the starting point, the peak temperature only varies within a limited range indicating that a steady state condition is reached at or very close to the start of the welding operation.

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HARDNESS VALUES

In order to determine the actual ultimate strength of the weld, hardness measurements have been performed on a weld cross section. The measurements start in the parent material, pass through the HAZ, into the weld nugget and out the other side. The location of the hardness measurements can be seen in figure 8.

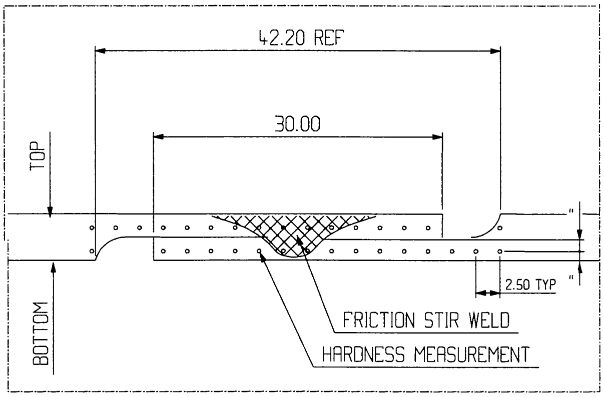

Figure 8: Location of Hardness Measurements

The results of the hardness measurements are given in figure 9. It is clear that the harness degradation and hence the actual degradation of the material strength is considerably less than indicated by the tensile tests.

It can be concluded that measured degradation in tensile strength compared to the parent material is partially due to the lap configuration where an applied tension results in a complex combination of direct, bending, shear and peel stresses in the joint.

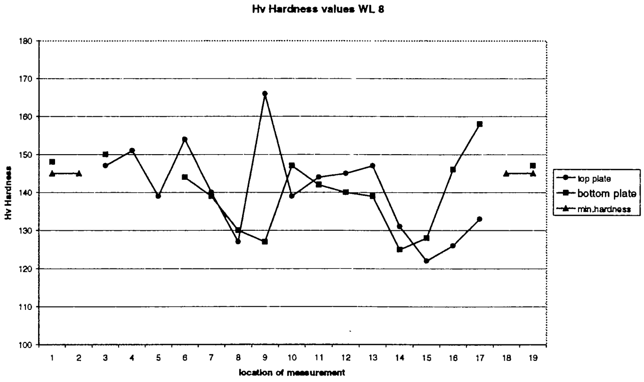

Figure 9: Hardness Values

CURRENT AND FUTURE RESEARCH

Having achieved a satisfactory tool design and optimum weld parameters it was necessary to produce more welds in order to gain some statistically meaningful strength data.

Therefore FS and TWI established a programme to manufacture two more tools of the same design and perform ten more lap welds on 1m long panels with a tolerance of ±0.05mm on the 2.4mm thick lip. This programme has just been completed and although it is too early to report the results the first indications are very promising. The temperature measurements in figure 7 come from this latest series of trials.

The next step, planned for early 2001, is to perform five welds using 0.5m long panels with representative blade stiffeners. In addition five bolted connections will be produced using identical 0.5m long blade stiffened panels (see figure 10). Fokker Space will then conduct an extensive test programme to compare the performance of the welded and mechanically fastened connections.

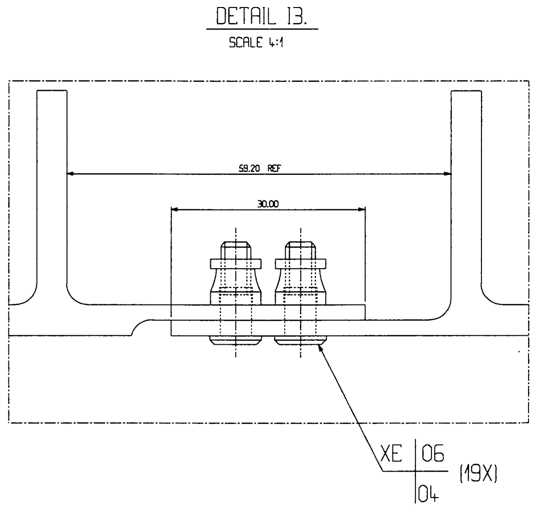

Figure 10: Lap Connection with Blade Stiffeners

A further step in the qualification of the process for the Ariane 5 motor frame will be the welding of full scale (peened) conical panels requiring a 2.5m weld length. There is also a need to determine the tool wear rate and its effect on weld performance.

The friction stir welding of the ring frames to the cone will require a separate research programme into the lap welding of aluminium 2024 to 7075.

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MOTOR FRAME WELDING JIG

The intention is to make the new cone sub-assembly jig multifunctional, i.e. for both riveting and FSW. In the first instance the cone, including the ring frames, will be assembled using the conventional Hi-lok™ fasteners. This offers the very lowest technical and programme risk. The jig can be easily modified to allow FSW of the cone connections and eventually the ring frames to the cone. FSW promises to deliver not just cost savings but also some increased stiffness and reduced mass.

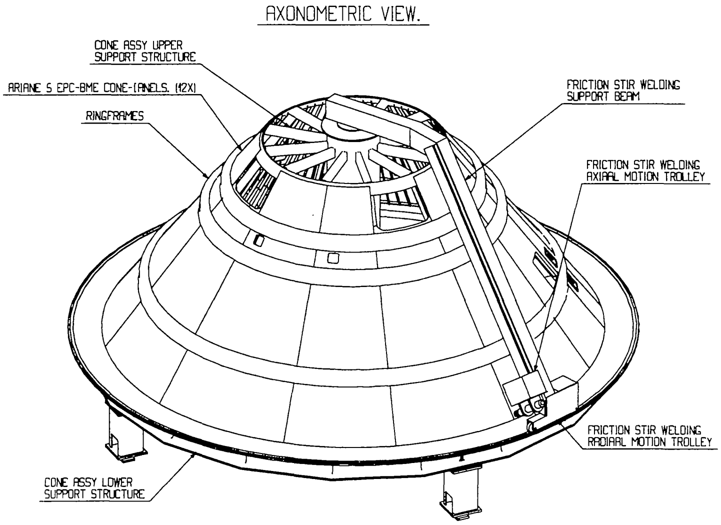

Figure 11: Sketch of Motor Frame Welding Jig

CONCLUSIONS

FSW can readily be applied to lap joints in Aluminium 7075-T7351. Although the tensile strengths measured in this investigation are lower than those that can be obtained with butt joints, they are at an acceptable level to replace bolted lap joints.

For unpressurised structures lap joints offer the significant advantages of generous tolerances at interfaces between components and ease of assembly. The fact that FSW can now be applied to such connections adds the advantages of a simple; low energy; automatic; high strength; high stiffness; minimum mass and low cost welding process.

ACKNOWLEDGEMENTS

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REFERENCES

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