SIXTH FRAMEWORK PROGRAMME
PRIORITY 4
Aeronautics and Space

Specifically Targeted Research Project

COINS

Cost effective Integral metallic Structure

Publishable Summary Report

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Contents

Overview

The top-level objective of COINS (COst effective INtegral metallic Structure) was to extend the application of integral metallic structures utilising Friction Stir Welding (FSW) by "*advancing the state of the art of FSW technology, developing new geometries for FSW, and through innovations in structural design*". Fifteen partners, including end-users, research organisations, universities and materials suppliers were involved in the project, which completed in 2010.

The project consisted of six inter-dependent Work Packages (WP). Summaries of these, together with their main achievements are presented below.

WP1 Friction Stir Welding Standards and Testing

It is essential in highly collaborative projects such as COINS to have consistency of data, both process and test. To achieve this, process and test documents were produced early in the project that provided guidance to all partners on data that needs to be recorded, and the test standards to be used; to this end, a Welding Procedure Specification (WPS) was developed as a consistent means for exchange of data between project partners.

Accounting for the effects of weld residual stress in testing was identified as a specific knowledge gap. Fatigue crack growth rate testing has demonstrated residual stress can have a significant effect on the test data that is produced; importantly, judicious selection of the test sample size is important to capture the effects of residual stress. Although models to predict the effects of residual stress on fatigue crack growth rates are beginning to mature, they are still not sufficiently accurate to be used as for design in welded structures. In the meantime, alternative approaches that are conservative must be employed. Unfortunately, this will entail tests of samples of a recommended minimum size that contain full size residual stress fields. For components and structural elements, which are of a size smaller that that required to create a full-scale residual stress field, the test size and sample geometry should be matched to the application geometry and scale.

WP1 Outputs

1. D1 Revised FSW Process Standard [REPORT]
   Information to be recorded when conducting FSW in the COINS project, includes Welding Procedure Specification (WPS)

2. D2 Revised FSW Test Standard [REPORT]
   Recommendations and guidelines for testing welds produced in the COINS project, including the effects of residual stress.

WP2 Design of Cost Effective Integrated Metallic Structure

Prior to COINS, utilisation of FSW for the fabrication of cost-effective integrated metallic structures took a rather simple approach. Conventional fastened joints were often directly substituted for FSW equivalents and local thickening was used for strength matching to the parent material. In this work package, more sophisticated design solutions were investigated.

The activity splits into two types of research; development of design data for welded structures and novel designs of components, structural elements and structures incorporating FSW. The design concepts take advantage of the potential cost and weight savings afforded by FSW whilst locating the weld within the structure so that the modified weld mechanical performance could be best exploited.

Specific investigation was made into aspects of mechanical performance of welded structures under fatigue loading such as damage tolerance and crack deviation.

Development of design related properties and numerical models to predict performance used residual stress measurements and formed a significant part of this work. The measurements assessed the influence of sample thickness, geometry and dimensions on residual stress field, which coupled with the subsequent measurement mechanical performance allowed the validation of quantitative models for fatigue crack growth in residual stress fields.

Improvements in damage tolerance (fatigue growth resistance) of FSW samples were achieved using two techniques. The first involved the used of crenulations (local periodic changes in the plate cross section) to change the fatigue crack growth rates of cracks propagating in this geometry of sample. In the second technique, strips of aluminium were bonded to the substrate and were observed to reduce greatly the fatigue crack growths rate as they encountered the strap.

WP2 Outputs

1. D3.1 Design of Damage Tolerant Welded Structures - Design [REPORT]
   Design evaluation of component and structural elements. Innovative design and consideration of the location of welds within the component have been shown damage tolerant solutions can be achieved.

2. D3.2 Design of Damage Tolerant Welded Structures – Measurement & Test [REPORT]
   Manufacture, measurement and testing of damage tolerant designs including residual stress measurements and modelling.

3. D15 Design Considerations for Integral Structure Including the Effects of Residual Stress and Cracks [REPORT]
   Summary of design optimisation activities.

WP3 Development of New Applications

The extent FSW has been applied in manufacturing has been rather limited. For airframes, common examples have included longitudinal joints for fuselage panels, rib-feet and fabrication of panels by joining extruded stiffeners. These applications use simple joint configurations with similar materials and are considered relatively mature. Potentially many more applications could exploit the advantages afforded by FSW processes.

Work package 3 evaluated a range of new applications for FSW, including dissimilar alloy joints, new joint geometries, welding extrusions followed by forming operations and fabrication of enclosed structures. The techniques developed were exhibited through the production of several demonstration components that included:

- Closed aircraft beam structure
- Semi-closed land vehicle hull
- Aircraft bulkhead and shear web

WP3 Outputs

1. D4.1 Process Data on New Similar and Dissimilar Alloys [REPORT]

Welding process development for similar and dissimilar alloy combinations. These included conventional 2000 and 7000 series aluminium alloys together with new aluminium-lithium alloys in thicknesses up to 15mm.

2. D4.2 Test Data on New Similar and Dissimilar Alloys [REPORT]
   Metallographic and mechanical test data for similar and dissimilar alloy combinations.

3. D5 Friction Stir Welding of New Joint Geometries [REPORT]
   Record of new joint geometries investigated and tool designs. These include joining extruded sections to plate material, overlap joints, joining to laminated structures, offset welds, tailored blanks, fillet joints and interlocking joints.

4. D12 Hardware Comprising Realised Applications [DEMONSTRATOR COMPONENTS]
   Demonstrator components incorporating new and novel joint configurations and dissimilar materials.

5. D19 Realisation, Testing and Evaluation of New Applications [REPORT]
   Evaluation of new applications and demonstrator components.

WP4 Repair Applications

Repair of a structure containing FSW is essential for all applications. This concerns both repair during the production process and in-service repair. The possibilities for using FSW as a repair tool have previously only been superficially investigated and have largely been restricted to analysing the effect on the microstructure of re-welds. Within COINS, repair applications using FSW encompassed three specific areas; in-production repair including dissimilar alloy combinations, in-service repair of FSW in integrated structures and development of the technology and processes for using FSW as a repair tool on general structures.

Repair strategies were developed for recovering from tool (pin) breakages. One solution, following removal of the broken pin, was to machine-out and insert a plug to backfill the hole. The repair was completed by over-welding the damaged area and incorporating the plug material in to the weld. An alternative was to use friction spot welding to secure the pin. Non-penetrating surface repairs were also investigated. These included repairs in thin section material using foil inserts and in thick-section using laminations. The latter was implemented to overcome issues with repair of closed structures where rear-face support was not practical. This also led to the rules being established for practical repair in structures without the provision of rear-face weld support. Concept designs for portable systems were included in this study.

WP4 Outputs

1. D13 In-Production Repair of FSW [REPORT]
   Repair strategies for tool (pin) breakages and in-production surface damage and thinning using foil inserts.

2. D16 In-Service Repair of FSW [REPORT]
   Repair of in-service components including an aircraft door assembly and combinations with riveted joints.

3. D17 FSW as a Repair Tool [REPORT]

Repair of failed weld joints and laminate repairs in thick-structure. Concept design for portable repair system.

WP5 Combination of FSW with Other Manufacturing Processes

The FSW process will normally be combined with other production processes, which may include bonding, mechanical fastening, pocketing (milling, chemical etch) and various forming methods. Therefore, FSW cannot be considered in isolation. The activities within the work package considered the effects of processes preceding FSW operations and subsequent processes such as forming.

The combinations investigated included the effect of time delay and pre-welding operations such as cleaning and paint removal on the resultant mechanical performance. A focus for this work package has been the combination of FSW with forming operations, both stretch and creep-age forming. This has involved validation experiments such as bi-axial tensile tests to support model development and testing on representative articles. Corrosion resistance of FSW joints was also assessed.

WP5 Outputs

1. D6 Combining FSW with Prefabricated Parts [REPORT]
   Report on the an investigation of laser cleaning procedures to remove paint, the role of pre-welding operations and external finishing on weld quality, the effect of time delay and pre-welding operations, an investigation of deformation from other processes and the feasibility of manufacturing redundant joint concepts.

2. D11 Hardware Evaluation Panels of FSW Combined with Forming [REPORT + HARDWARE]
   Summary of parts manufactured for stretch and creep-age forming evaluations.

3. D18.1 Combining FSW with Stretch-Forming [REPORT]
   Characterisation of stretch formed articles including FSW

4. D18.2 Combining FSW with Creep-Age Forming [REPORT]
   Characterisation of creep-age formed articles including FSW.

WP6 Improvements to FSW Processes

Whilst the FSW process is considered to be robust and mature for some applications, there remains significant scope for further improvements and refinements. The work package sought to develop process models and fundamental understanding, primary process improvements, post-weld treatments and process monitoring and control of FSW.

A number of process improvements were investigated such as the influence of FSW tool coatings and their effect on weld quality. The coatings modify the friction coefficient, and were shown to have an effect on the quality in the weld nugget and the tool temperatures during processing. Two alternative tool concepts were developed. Bobbin tools using the new Diabolo pin design demonstrated weld thicknesses up to 23mm are now achievable, and the DeltaN fixed shoulder tool was raised to a higher maturity level. The tool design was greatly simplified and made more robust. The DeltaN tool allows a reduction in the down force of up to 50% and can significantly reduce component distortion.

WP6 Output

1. D7 Process Modelling and Data for FSW [REPORT]
   Numerical model development and simulation of FSW processes for prediction of temperature, residual stress and distortion.

2. D8 Primary Process Improvements [REPORT]
   Report on the influence of FSW tool coatings on weld quality, bobbin and DeltaN tool concept development and an investigation of edge preparations for mitigating lack-of-penetration defects.

3. D9 Surface Treatments [REPORT]
   Report on laser surface melting and friction buttering processes for corrosion protection of FSW joints, and an evaluation of peening (shot and laser shock) treatments to improve mechanical properties,

4. D10 Process Control [REPORT]
   Investigation and development of process monitoring methods and control strategies for improving the quality of FSW components.

5. D14 Heat Treatments [REPORT]
   Assessment and characterisation of the effects of post-weld heat treatments on the weld properties, specifically dissimilar alloy combinations.