COOP-CT-2006-032240

OLIWAM

Development and Validation of On-Line Monitoring and NDT Inspection of Laser-Welded Thin-Sheet Automotive Components

Horizontal Research Activities Involving SME's

Co-operative Research (CRAFT)

Publishable Activity Report

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Contents

1 Background

The automotive industry sector is a vital part of the European economy. The EU is the largest automotive production region in the world with 34% of global manufacture and the industry comprises 7.5% of all manufacturing sectors within the Union. The increasing demand for improved fuel efficiency and reduced emissions at lower and competitive costs has prompted the industry to seek new ways of reducing the weight of cars by using lightweight materials, as well as new joining processes and manufacturing concepts.

The automotive industry was one of the first to introduce lasers, in the late 1970s, for welding small parts. In today's automotive industry, laser welding is increasingly used, not only for producing Tailor-Welded Blanks (TWBs), a light-weighting concept introduced in the mid-nineties, but also as an alternative to resistance spot welding in Body-In-White (BIW) assembly, as this continuous welding process provides structures with increased rigidity, allows thickness reductions and therefore greater potential for lightweight car body designs. Notwithstanding the success of laser welding for automotive structures, the geometries and advanced materials used in modern cars still cause problems for laser welding. For instance, porosity and blowholes when lap welding two Zn-coated steel sheets that form the roof-to-side pillar, or, weld imperfections, such as cracking and excessive HAZ softening, in materials such as ultra-high-strength steels (>1000Mpa) and aluminium alloys.

Therefore quality monitoring and inspection of the produced parts is essential to ensure good performance in service. Currently, three different techniques can be used for quality control of laser welds: *process monitoring*, *optical weld bead inspection* and *non-destructive (NDT) inspection*. Whereas the first monitors the laser process and/or the molten pool before it solidifies, the last two inspect the seam after solidification. In their current forms, process monitoring is carried out, by definition, on-line or in real-time, i.e. as the welding is carried out, whereas most of the optical weld bead inspection and all of the NDT inspection is done off-line. This means that the inspection is conducted with the welded part removed from the production line, i.e. inspection constitutes an additional operation and adds cost to the product. Moreover, current NDT inspection and *tear-down*, in which a fully assembled car is put through a controlled crash, is only a sampling test. This means that not all produced parts or products can be inspected individually.

Because of the implications on the human and economic costs of the currently applied procedures, major vehicle manufacturers prefer to have an NDT record for each weld, with the intention of performing testing in a fully-automatic way and on-line, which is the focus of the OLIWAM project. This pre-competitive project is aimed at developing a new, fast, monitoring and NDT inspection system, the OLIWAM system, to be used on-line, providing a 100% inspection rate for thin-sheet laser welded automotive components. The system's software will allow for on-line evaluation of the results, with remedial actions, if any, taken immediately, significantly reducing repair costs and scrap rates. Generic concepts for up to a further four NDT inspection systems will also be developed to further facilitate fast, reliable on-line detection of weld imperfections.

Implementation of the OLIWAM system, which provides 100% weld inspection, will reduce human casualties as a result of unexpected failure of safety critical structures. 100% on-line weld inspection will also contribute to reduced manufacturing costs, by allowing repair to take place at the most appropriate point in the production line or prevent defective parts continuing along the production line.

2 Project execution

2.1 Objectives

Nowadays, laser welding is commonly used in the automotive sector, for instance, for the production of Tailor-Welded Blanks and Body-In-White assemblies. Producing high-quality welds is of the utmost importance to ensure acceptable in-service performance. For this, on-line monitoring and non-destructive testing (NDT) of all welds is preferred, but currently not viable.

This project will develop the OLIWAM system, i.e., automated equipment capable of on-line detection of the types of weld imperfections that are typically found in TWB and BIW assemblies. The OLIWAM system will employ a series of NDT and process monitoring techniques, adapted to the materials and joint geometries of a selected TWB and BIW application, and the imperfections typically found for these welded parts. It will analyse the received data at high speed and provide go/no go status for the welds produced.

2.2 Consortium

The following partners participated in the OLIWAM project

- Advanced Technology Group (ATG), Prague, Czech Republic - SME
- Aimen (AIM), Pontevedra, Spain - RTD
- Computerised Information Technology (CIT), Milton Keynes, UK – SME
- Microtest (MIT), Madrid, Spain - SME
- Micon (MON), Varna, Bulgaria - SME
- Precitec Optronik (PRE), Rodgau, Germany - SME
- Tecnitest Ingenieros (TEC), Madrid, Spain - SME
- Solblank (SOL), Barcelona, Spain - end-user
- Volkswagen (VW), Wolfsburg, Germany - end-ser
- NDT Consultants (NDC), Coventry, UK - RTD
- TWI, Cambridge, UK - RTD
- Zenon, Athens, Greece - RTD

The project coordinator was TWI.

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2.3 Summary of results

At the onset of the project, the OLIWAM partners agreed on two automotive applications, representative of today's automotive production, to be used as benchmarks for assessing the performance of the OLIWAM prototype system. The first is a Tailor Welded Blank (TWB) that is part of the SEAT 3-door frame, comprising a butt joint between two zinc-coated steel sheets, 0.9mm and 1.65mm in thickness. The second is a Body-in-White (BiW) triple lap joint that is part of a VW door inner. The joint comprises two zinc-coated steel sheets, 0.7mm and 1.5mm in thickness, with a 2mm thickness uncoated steel sheet in between.

For both applications, weld imperfections typically encountered in production were identified and ranked in order of their impact on the joint's integrity. The five most critical imperfections and their acceptance levels were selected for each of the applications, which would serve as the performance specification of the OLIWAM prototype system.

Both end-users, i.e. Solblank and VW, supplied a range of welded samples which had been rejected in production, because of the imperfections they contained. In addition, a range of welds with engineered imperfections that simulated the specified critical imperfections were also produced. These imperfection samples were used by the Partners to assess one or more of the NDT inspection techniques under investigation, including Magnetic Flux Leakage (MFL), Electro-Magnetic Acoustic Transducer (EMAT), Eddy Current (EC) and Digital Radiography (DR).

The *on-line* feature of the NDT inspection was discussed at length with both end-users, and, for the purpose of the project, was defined as *within the time constraints of the production cycle*. For both applications, laser process monitoring is done in *real-time*, i.e. as the process takes place, but NDT inspection has to be done once the weld has solidified.

Both Solblank and VW consider NDT inspection of a welded part as *on-line*, if this is carried out (after welding) prior to the next part being completed and ready for inspection. It was assumed that this interpretation would also be accepted across the industry, as the two applications investigated, i.e. TWB and BiW, represent the majority of today's automotive (laser) welding applications.

Based on the initial results of the monitoring and NDT inspection trials carried out at the various partners, the consortium agreed at the project mid-point, that the OLIWAM system prototype would include the plasma and temperature photodiode sensors, a coaxial CMOS camera, an MFL sensor array and an EC inspection probe. The latter was only to be used for the TWB butt joint, and not to be included for the BiW triple lap joint configuration. Although the DR results were found to be favourable for both applications, the Consortium had reservations about the ease of use of the technique in a production environment and in particular the safety aspects of X-ray radiation. For that reason, the technique was not included in the OLIWAM prototype design. However, by the end of the project, partner CIT designed and tested radiation shielding that was suitable for use by both end-users and capable of reducing the X-ray emission rates to levels acceptable to the Regulations (SI 1999.3232 Regulation 16(1)) and Approved Code of Practice (IRR99 AcoP Para 248-9) for X-ray radiation. The results in terms of finding an alternative approach to the EMAT technology, which at the time the project started was already in use in industry (including at end-user Solblank) in the form of the Temate® system (supplied by Innerspec Technologies), proved inconclusive.

In addition to the technologies to be included in the OLIWAM prototype, a generic design approach was also agreed at the project midpoint for both the system hardware and software. A modular principle was adopted for the hardware, to allow for the differences between the two selected applications, in terms of geometry and (NDT) inspection, and, for retrofitting additional sensors at a later stage, if required. This modular assembly basically comprised an application-dependant interface onto which the generic inspection modules for the MFL and/or EC inspection technique would be attached, and which was designed to be mounted onto the actuators currently in use at both end-users. A CompacRio platform with LabView software was chosen, as it offered the flexibility required for the prototype work. The laser process monitoring signals were recorded during welding and the NDT inspection signals during the subsequent inspection cycle. For the TWB butt joint, the data acquisition of the monitoring signals (photodiodes and CMOS) was through Precitec's LMW (Laser Weld Monitoring) interface, and for the EC and MFL sensors through the CompactRio platform. All signals were recorded (and synchronised) with the carthesian coordinates of the robotic arm TCP, to uniquely identify the position and length of each weld and imperfection(s), if present. The same approach was adopted for the BiW triple lap joint, but without the EC signals for this joint configuration.

For the TWB butt joint application, it was demonstrated that the MFL, EC and DR techniques, as well as the plasma and temperature sensors and the CMOS camera, were all capable of detecting lack of fusion. This imperfection can currently not be detected using the Temate® system in use at end-user Solblank. Moreover, the DR technique offers an improvement in the minimum size of lack of penetration, misalignment and internal porosity that can currently be detected. Lack of penetration and misalignment can also be detected using the MFL and/or EC technique, but not at the precision of the Temate® system. Nevertheless, the capability of detecting an imperfection with more than one technique reduces the risk of a "false friend" passing the inspection and possibly resulting in in-service failure. Moreover, based on the results achieved, the partners are confident that, subject to further development, both techniques could be refined further to match (or even surpass) the performance of the Temate® system.

The most critical of imperfections for the BiW triple lap joint configuration, according to end-user VW, is the lack of connection at the second interface, i.e. between the middle and bottom sheet. This imperfection can occur even though, visually, the top and bottom side of the weld appear to be acceptable. The only way of checking whether this imperfection has occurred, is using feeler gauges. This is done in practice, but is very labour-intensive (and expensive). The OLIWAM work has demonstrated that both the DR technique and both the plasma and temperature sensor signals can be used to ascertain the presence of a weld (connection) at the second interface. There is also indication that the MFL technique is capable of detecting this type of imperfection, but further work is required to demonstrate the reliability and consistency of this technique. It is noteworthy, however, that none of these techniques can be used to determine the size the weld width at the second interface. However, this should be possible by (optical) visual inspection of the weld width at both the top and bottom side, and interpolating between measured values.

3 Plan for Exploitation and Disseminating the Knowledge

Although the concept of *on-line* detection of structure-critical imperfections in laser welded TWB butt joints and BiW triple lap joints was demonstrated in this project, further development of both the hardware and software are required to turn the developed OLIWAM prototype into a commercial system.

- In terms of hardware, further work is required in particular for the BiW triple lap joint configuration, where the 3D aspect of the joint and the accessibility of the joint for the various car models to be welded pose serious design challenges.

- In terms of the software, all elements to make up the software have been completed within the project duration. However, further work is needed on the data analysis and the user-interface. The latter will comprise a graphical representation of the part inspected and its constituent welds, together with an indication of those areas of the welds where one (or more) of the sensors detected an imperfection. The user can then ‘interrogate’ the software and call up the underlying signal traces for each of the imperfections identified. Each of the imperfections will also be given a ‘confidence value’ derived from the number of sensors that detected the imperfection in question.

The OLIWAM partners recognise the commercial value of the results achieved to date, and wish to further exploit these. The Consortium therefore agreed at the final project meeting (in March 2009) that the commercialisation of the OLIWAM prototype will be the subject of a proposal to be submitted to the Competitiveness and Innovation framework Programme (CIP). The approach may constitute two projects running in parallel, i.e. one focussing on the TWB butt joint application and the other on the BiW triple lap joint application. It is anticipated that the skills, experience and resources necessary for the commercialisation of the OLIWAM system are available from the existing Partners.