PROJECT FINAL REPORT

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HQ-TUBES

High-Quality Tube and Pipe Production by Hybrid Laser-Arc Welding

Theme FP7-SME-2007-1, 222289

Project duration: 24 months
Project website: www.hq-tubes.eu

1 Overview of the project

Hybrid laser-arc welding offers many advantages compared with conventional arc or laser welding. The process does, however, require a high level of control if high-quality welds are to be produced. This project tackles the issues of weld quality and productivity improvement for manufacturing tubes and pipes through development of advanced sensors for the hybrid laser-arc welding process. Hybrid process development must be performed for each material to be welded, with the main focus in this project being on austenitic stainless steels and C-Mn steels. By developing and integrating sensors that monitor weld quality and allow process modification, the project will increase the quality and productivity of European tube and pipe manufacture beyond the state of the art, enabling it to overcome foreign competition.

There is a large industry in Europe for pipe and tube manufacture with many users of the finished product around the world. Competition in manufacture from outside Europe is high, and increasing, particularly from Far East countries. In current manufacture, conventional arc welding processes, such as MIG/MAG and submerged arc welding, are mainly used to produce finished pipe and tube over a range of materials, diameters and wall thicknesses. Some of the problems facing tube manufacturers include production of too much scrap product due to process inconsistencies, lack of on-line quality control, inconsistent equipment operation, inconsistent joint preparation and presentation, low productivity and reliance on the skill of operators to change process parameters to maintain weld quality, particularly during changeovers, i.e., when tube material, diameter and/or wall thickness is changed. The European tube and pipe manufacturing industry needs to increase both the productivity and the quality of its products, to become more competitive and to safeguard employment in a fast-changing market.

The time taken to weld a tube contributes significantly to the cost of the finished product; indeed for some tube types the welding time is 50% of the total manufacturing cycle time. For this reason, the welding task becomes a critical path in the whole production process, not only for economic reasons, but also because this can influence delivery time. This in particular, is becoming more and more important as users require "just-in-time" sourcing of product and components. Furthermore, customers are now demanding better weld quality, as the need for a "fit-for-purpose" product is better recognised and costs of failure escalate. Mechanical failures, the third most frequent cause of spills for oil lines, are often the result of weld imperfections that can be traced back to the welding during manufacture. In operation, many pipes and tubes contain hazardous substances and the consequences of a weld failure is therefore very significant, not only in economic terms, but also in terms of the environment, and for human and other life forms.

Figure 1 Hybrid Laser-Arc welding

The SME Partners in this project include end users in the pipe manufacturing sector, manufacturers of sensor equipment, and software system integrators. Some of these already have involvement with the tube and pipe manufacturing sector, whereas others wish to increase their involvement with this sector. They have a common need to generate new markets with the introduction of new and competitive products. The approaches to the concepts of monitoring and hybrid laser-arc welding of pipes and tubes resulting from this project are therefore equipment-independent, maximising the scope for industrial use of the technology.

2 Summary of project objectives

The concept of the HQ-TUBES project has been to develop an equipment-independent approach that allows the manufacturing quality and productivity of C-Mn steel pipes and tubes to be improved, resulting in a reduction in scrap rate from 3 to 1%. This is achieved by the following key objectives:

- Demonstration of the suitability of the hybrid laser-MIG/MAG process for the manufacture of C-Mn steel tubes and pipes, in wall thicknesses ranging from 4 to 10 mm, and capable of a productivity improvement of between 6 and 8 times that currently achieved for submerged arc welding.
- Development of a universal Open Diagnostics System (ODS) capable of capturing on-line weld quality information in combination with positional data to allow operators to control the pipeline welding operation through a visual, user-friendly interface. Weld quality information are provided by means of coaxial, in-process camera-based analysis and on-line (camera) inspection of the weld root, which has been developed in the project.
- Development of articulated-arm controlled seam tracking and adaptive control algorithms capable of extending the welding process tolerance to joint fit-up to at least 25% of the material thickness welded.
- Development of the HQ-TUBES system capable of reducing current scrap rates from 3 to 1% using hybrid laser-MIG/MAG welding, adaptive control and the ODS developed in the project.

3 Work performed and results achieved

The HQ-Tubes workplan is divided into 7 work packages. Work packages 1–4 deal with the development of the individual key components and process know-how on which the proposed HQ-TUBES system is based on. Work package 5 deals with the integration of the key components into a demonstrator and evaluates the performance. Work package 6 covers the dissemination activities and exploitation actions and work package 7 covers consortium management and assessment of progress and results related tasks.

3.1 Work package 1: Specification and requirements

The main objective was the establishment of the general project development frame through the synthesis of specifications and requirements for the different tasks. These tasks contain definitions for workpiece, hybrid laser-arc welding application, quality and the implemented hard- and software for the HQ-TUBES prototype, determination of the SMEs' requirements and of the international state of the art for hybrid laser-arc welding as well as definition of a pilot case for validating the hybrid laser-arc welding process in tube and pipe manufacturing.

3.2 Work package 2: Hybrid laser-MIG/MAG process development

The main objective was the development of hybrid laser-MIG/MAG welding procedures for agreed applications, focusing on filler material and gas mixture specification, weld profile optimisation and heat input minimisation, to achieve the required quality for welded tube and pipe.

Welding conditions were developed for the material grades of steel and austenitic stainless steel in thickness ranging from 4 to 10 mm. Process development has been carried out with two laser sources: CO_2- and Disk lasers as well as with Yb-fibre lasers of beam powers up to 10 kW.

A complete literature survey has been carried out before the start of experiments concerning the hybrid laser-arc welding process of steel with reviewing of applicable literature to focus on parameters, material, laser source etc.

3.3 Work package 3: Process monitoring

The main objectives were the development, evaluation and provision of systems for process monitoring. The monitoring system includes an Open Diagnostics System (ODS) that supervises and documents parameters of the hybrid laser-arc welding process. A seam tracker has been applied to assure the correct position of the processing head. A root monitor inspects the seam from below. A coaxial process monitor records images of the hybrid welding process using a high-speed camera. These systems have been set up, tested and fitted out with suitable interfaces to assure an easy integration into the HQ-Tubes prototype system.

The concept of the Open Diagnostics System (ODS) has been designed (see Figure 2). The ODS is set up to collate data simultaneously from different interfaces and make them available for a real time evaluation of the welding process quality. The ODS is designed as an operator-supporting system for process set-up, processing, documentation and analysis.

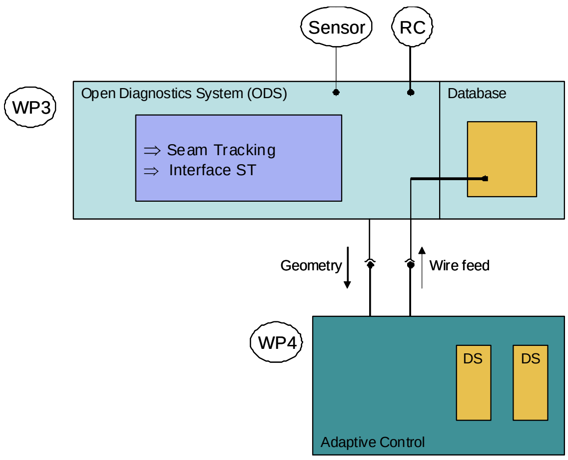
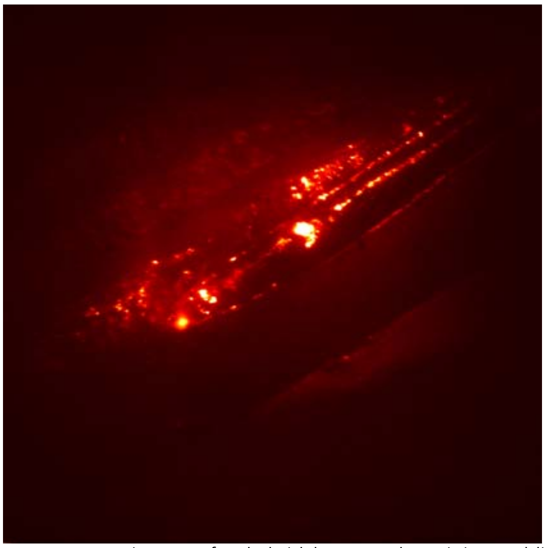


Figure 2 Concept of the ODS-system

The ODS enables the operator to operate a range of different sensor devices, to visualise, record and control the process conditions relevant for the resulting welding process quality. The ODS is set up as a modular open framework which links monitoring and inspection systems from different vendors into a multisensory network for process supervision and recording. The main objective of the ODS is to link the distributed stand alone systems to enable synchronised recording of all data identified to be relevant for the traceability of quality characteristics.

The development of joint geometry and position measuring system has also been finalized: The communication between Seam Tracking Control PC (STC-PC) and Reis Robot System (RRS) via Ethernet has been established. A XML-interface was introduced as a proprietary software protocol for receiving and sending axis position values in a robot related tool coordinate system. User variables were implemented into the RRS control for bidirectional communication. The robot position is submitted in six values for X-, Y- and Z-coordinates as well as for A-, B- and C-angle positions and additional the actual speed of linear axis is transmitted. The STC-PC calculates the desired position of the processing head and transfers the set point values to the RRS control. For the demonstrator II at ILT the seam tracking was adapted to the seam conditions of the spiral tube specimen.



Root camera image of a hybrid laser-arc butt joint welding of 8 mm mild steel S355J2G3 (parameters: P_L = 6.8 kW, feed rate of 1.5 m/min, image size of 1024 x 1024 pixel, exposure time of 50 µs and frame rate of 100 fps)

Figure 3 Seam root monitor

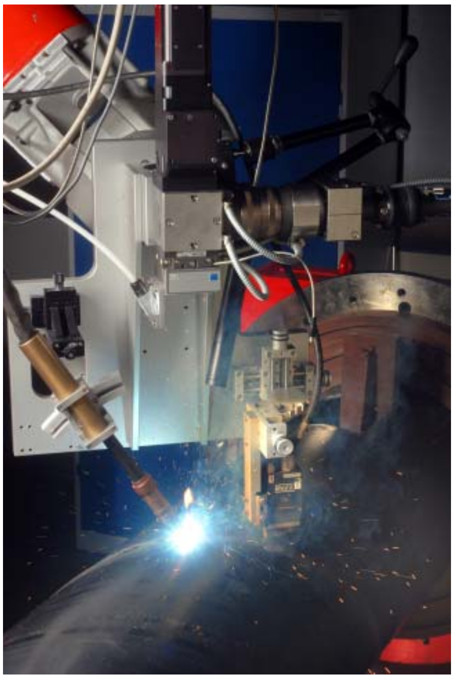
The Root Monitor and Inspection System (RMIS) which serves as an element of the open diagnostics system (ODS) is designed, assembled, installed and set into operation (see Figure 3). The RIMS consist of both a root monitor and a seam geometry inspection sensor.

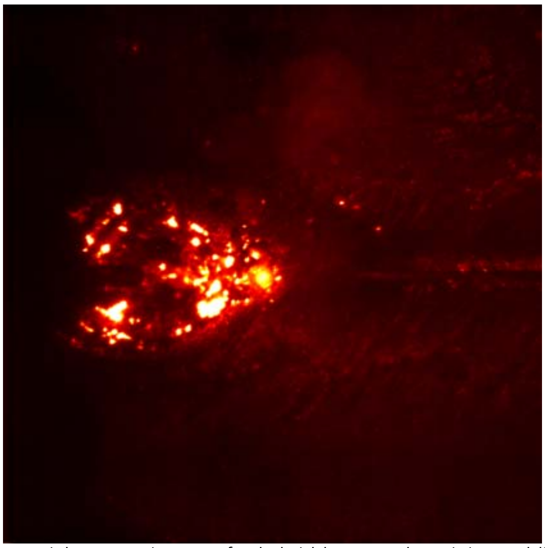
The functionality and reliability of RMIS is tested within a robot system and with a disc laser on flat steel probe sheets of different thicknesses and with varied beam power and welding velocities. Both, the robot system and the disc laser are elements of the pre-production demonstrator which is setup for HQ-TUBES at Fraunhofer ILT.

Welding tests were performed with beat on plate welds as well as with welds of square butt joints both in down hand position. The root monitor enables the observation of the melt pool during welding. With the help of the root monitor welding imperfections due to misalignment of the laser beam with respect to the joint gap as well as spatter, sagging and drop through of molten material can be detected.

The post process seam geometry inspection sensor (SGM from PRECITEC) is attached in line with the root monitor. The SGM uses the triangulation principle to measure the geometry of surface of the root seam perpendicular to the welding direction. The SGM enables the detection of imperfections like sagging, undercut, high low mismatch and notches.

The coaxial monitoring system for the hybrid CO_2-laser-arc welding process is designed and brought into operation. For hybrid laser-arc welding with a CO_2-laser a first test series was carried out to start-up the hybrid laser-arc welding equipment and to determine the requirements of the CPC-system and the imaging optic. After the requirements were determined the monitoring system was optimised regarding to the capability of the optical system. Test series have been carried out to investigate the performance of the monitoring system.





Coaxial camera image of a hybrid laser-arc butt joint welding of 8 mm mild steel S355J2G3 (parameters: P_L = 6.8 kW, feed rate of 1.5 m/min, image size of 1024 x 1024 pixel, exposure time of 50 µs and frame rate of 100 fps)

Figure 4 Coaxial process monitor

After the design of the 1 µm processing head and the integration of the coaxial monitoring system the entire monitoring system is integrated into the HQ-TUBES demonstrator I (see Figure 4).

The coaxial process monitor, the root monitor as well as a seam tracking system are integrated into the demonstrator in a pre production environment and linked to the open diagnostic system (ODS) which collates data from all these different sources into an object relational data base. Finally the image analysis algorithm are tested and refined. The model based background subtraction algorithm Min Max Deviation is found to be most suitable to identify joint gap, key hole and melt pool under pre-production conditions.

3.4 Work package 4: Adaptive control

The main objective was the development of algorithms for adapting welding conditions, e.g., welding or wire feed speed, to fit a given measured joint geometry, to ensure the output meets weld quality requirements.

Within the HQ-Tubes project, methods for adaptive control were developed successfully in WP4. Hybrid laser-arc welding trials were carried out, using a high brightness (6mm.mrad) 5 kW Yb fibre laser. Different sets of fixed conditions were used, along joints between 8 mm thickness S355 steel plates, with different amounts of joint gap and/or hi/lo mismatch. These trials identified suitable changes in parameters which might increase tolerance to joint fit-up.

Following appropriately accurate calibration, a laser-camera was used for both seam tracking and real-time adaptive control of robotic manipulation and welding equipment. Adaptive changes, in those welding parameters identified in the fixed condition trials, were used successfully to extend the tolerance of the hybrid process beyond that which would be achieved using fixed conditions (Figure 5).

Close fitting joints (with a 6 mm broad root face joint preparation) were welded to ISO 13919-1:1997 Class B at 1.6 m/min. The same welding conditions were also suitable for making Class B welds along joints with up to ~0.6 mm hi/lo mismatch, or along joints with ~0.3 mm joint gap.

Figure 5 Adaptive controlled welding

With an adaptive reduction in welding speed to 1.2 m/min, the tolerance to mismatch could be increased from ~0.6 to ~1 mm. Similarly, with an adaptive increase in wire feed rate of ~60% (by volume), Class B welds could made along joints with gaps up to 0.6 mm in width. Joints with a combination of both mismatch and gap could also be welded with adaptive control, although the tolerance to joint gap in these cases appeared to reduce slightly.

Without adaptive control, re-entrant weld toes, or excessively deep weld top bead underfill, resulted along joints with values of mismatch >0.6 mm in height, or gaps >0.3 mm in width, respectively.

From this work, an outline system specification has been compiled, with set-up guidelines given, and the tolerances that can be achieved have been documented.

3.5 Work package 5: Implementation and evaluation of the HQ-Tubes system in pre-production environment

In this work package, the systems developed in work packages WP3 and WP4 for the hybrid laser-MIG/MAG welding of tube and pipe material are assembled to form the HQ-TUBES system. This includes the ODS, the joint geometry and position system, the root monitoring and the coaxial process monitoring systems, as well as the adaptive control algorithms.

As pilot case the seam guided hybrid welding of spiral pipe probes has been demonstrated with the 10 kW disc laser on the robot plant at ILT. The required pipe probes were prepared and pre-tagged by the SME partner CSEPEL. The setup of the robot handling system, which could be used right in the same way in the production facility of the tube manufacturers CSEPEL or others, is shown in Figure 6.

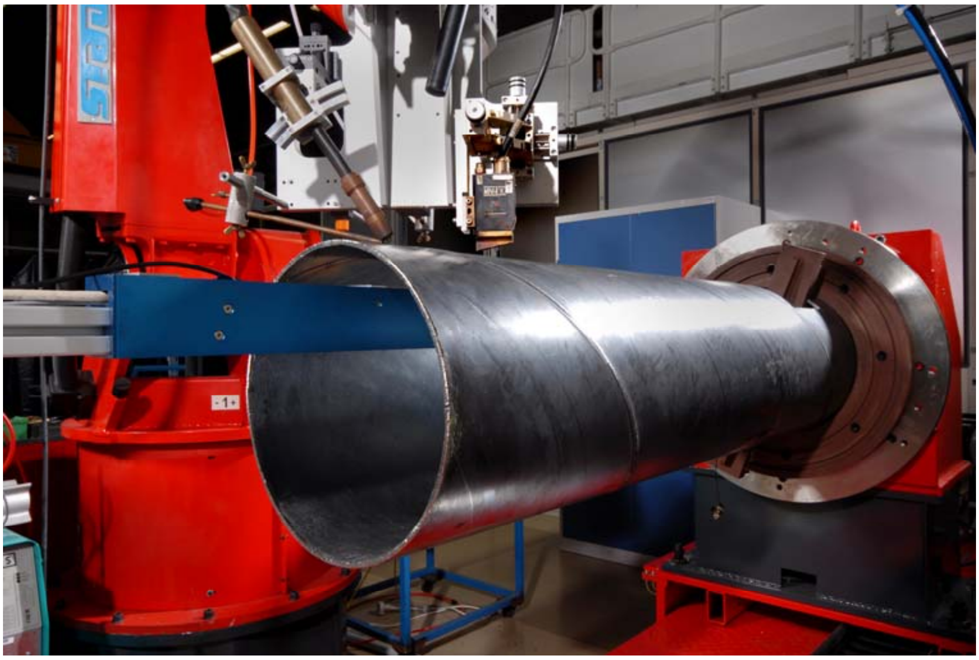


Figure 6 HQ-TUBES demonstrator with spiral tube specimen

3.6 Work package 6: Dissemination and exploitation

The main objective is to carry out dissemination activities and exploitation actions in order to promote the results of the project to the European industrial & scientific community and exploit these results so as to be beneficial for the participating SMEs, as well as other EU SMEs not part of the current Consortium.

The dissemination activities represent a very important part of the HQ Tubes project work programme. For this, the R & D performers play an important role. Among the most important such activities envisaged in the project, the following key dissemination actions have been taken: Project Web site; Appearance on trade fairs; Newsletters and scientific papers; Conference presentation.

It was agreed among the consortium, that two complementary directions will be gone to exploit the HQ TUBES project results. First, the project partners will pursue the exploitation of the system as a whole, integrated system to be installed tube and pipe manufacturing companies in the partners' countries and abroad. The HQ TUBES system will be exploited as a whole product to be sold (the hybrid welding process, the sensor systems for guiding and monitoring, the software including the "open diagnostic system"). Exploitation will also come from the usage of specialized personnel to install and maintain the system (which means physical system installation on machines on side). Secondly, the consortium will exploit individual HQ TUBES components, to be included in other systems finding applications in similar or different domain problems. As an example, the ODS Software (open diagnostics systems software) module could be used independently of the other laser welding applications. The developed version of ODS software system could be distributed to potential customers in order to collect all important welding data and so be able to let minor qualified personnel run the welding system just by selecting the complete parameter setup for a specific application.

The project partners themselves will perform further market analysis for each potential market where the various components of HQ TUBES might find demand, and in those markets that will be deemed fruitful, the partners will actively promote the components. For this end, the dissemination activities of the consortium will prove invaluable, since they will make known to the potential customers the availability and quality of the systems.

4 Expected impact

The welding results of the HQ-Tubes hybrid welding system have indicated clear advantages in welding (i.e. production) speed and at the same time improved seam quality. The continuous supervision and analysis of the weld seams (top and lower bead) allow for immediate corrective actions in the case of weld failures or defects. This is owed to the integrated monitoring and control through the ODS system.

Six to eight times higher production rates are expected through the application of hybrid laser-MIG/MAG welding instead of currently used MIG/MAG or submerged arc welding. Faster welding speeds also mean lower distortion, meaning that specifications in terms of pipe or tube concentricity can more easily be achieved. Though hybrid welding needs more sophisticated quality control, the application of more consistent and reliable monitoring (and adaptive control) will also reduce the time and effort for off-line quality checks significantly.

5 Partners involved

Fraunhofer ILT	Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V., Institut für Lasertechnik	D
	Bay Zoltan Institute (BAYATI)	HU
TWI	TWI Ltd – World Centre for Materials Joining Technology	UK
	S&F NC-Systemtechnik GmbH	D
CSEPEL Coil Pipe Ltd.	CSEPEL Coil Pipe Ltd.	HU
PRECITEC	Precitec Optronik GmbH	D
photon focus	Photonfocus AG	CH
META Welding with Vision for 25 years	MetaVision Systems Ltd.	UK
SCHOELLER	Schoeller Werk GmbH & Co. KG	D
OCAS we catalyse your growth	OCAS NV	B

HQ-TUBES

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