LIGHT-weight high performance welded STRUCTures –

"LIGHTSTRUCT "

Welding of a frame in Arvika Plant

Project within Production Technology

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Content

FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which half is governmental funding. The background to the investment is that development within road transportation and Swedish automotive industry has big impact for growth. FFI will contribute to the following main goals: Reducing the environmental impact of transport, reducing the number killed and injured in traffic and Strengthening international competitiveness. Currently there are five collaboration programs: **Vehicle Development, Transport Efficiency, Vehicle and Traffic Safety, Energy & Environment and Sustainable Production Technology.**

For more information: www.vinnova.se/ffi

1. Executive summary

The development of new products requires a continuous increase in payload, speed, fuel efficiency, increased demands on life and more environmental friendly machineries. The way to meet these requirements is to introduce new and/or refine applied methods, optimize structures and introduce high strength material It is also necessary to upgrade the holistic view of resulting capability of the total manufacturing system that is a sum of welding process capabilities, intercommunication and toleransing. The aim of Lightstruct is to develop conditions to manufacture lightweight welded structures within construction machineries. In this project we have studied novel procedures which will contribute to this process thus keeping Swedish industry at the leading edge regarding performance, material utilization and energy conservation. The project contain following major tasks:

- Investigation of fatigue analysis methods based on weld defects.
- Analysis of plasma hybrid welding and measuring system analysis including mapping of the occurrence of weld gap.
- Measurement system analyses of different evaluation methods including mapping of the occurrence of weld gap.
- Implementation of control chart and weld quality strategies are started.
- A study to correlate the International Standard for cut edges (ISO 9013) to fatigue strength

Some of the project output will be direct used within the involved manufacturing industries. The introduction of novel welding procedures and higher quality levels, require increased operating competence within manufacturing units and that will promote a more scientific based co-operation between development and production engineers. It will also contribute to reduce lead-time in product development and thus a cost reduction of product development. The project has also reinforced the research and education within the participating universities. By SSAB, KTH, HV, CTH and The Swedish Welding Commission the project results will also reach a wide range of Swedish industry and consultancy firms. The main contributions to FFI targets are:

- Reduced weight increase productivity in terms of handled ton steel/hour
- Reduced weight mean less material and less influence on environment
- The new processes will reduce lead-time in production, thus a potential increased production capacity
- Products with better performance will improve competitiveness

2. Background

Load-carrying structures and components in construction machineries, cranes, forest machines, mining equipment, transport vehicles and agricultural equipment are often complex welded steel constructions. Normally 60-80 % of the vehicle weight consists of steel plates and steel castings in thickness 6 – 70 mm with welding as the primary joining technology. In ship structures, ship engines and in offshore structures, the main supporting structures are fabricated from steel plates with thickness between 10- 200 mm. There are also other structural details in trains, busses, were different welding technologies are used. In the energy sector there are several types of welded structures especially in the growing wind mill industry. Structural details and components in many types of products are continuously subjected to variable amplitude loading during operation. Typical significant load ranges in operation lie between 1000 - 20000 cycles per hour for many types of vehicles and machineries. That means that during an economic life of about 10000 - 25000 hours in operation structures and components will sustain 10 - 500 million significant load ranges. Fatigue damage is thus the most common failure mode for the mentioned equipment in operation.

Fatigue failures in many structures as bridges, off-shore structures, pipe lines, ship, construction machinery, train bogies, does often start in welds. Design and manufacturing of "normal" structures is already an important task and require accuracy especially in robotic welding in serial production. For lightweight welded structures stress levels increase and structure are more sensitive for deviation from the specification or error in fatigue design. The fatigue life of welded joints show a great scatter due to variation of weld profiles, size and location of defects, different residual stress distributions, relaxation of residual stress during operation and influence from blasting, before painting. There is also a large scatter between the intensity of the fatigue loading in a fleet of products, compare the loading condition for a retired person with a rally driver. The scatter of the fatigue life and fatigue loading thus complicate an optimum fatigue design for serial produced products.

Welding and other joining principles are key technologies for many Swedish industries and other organizations. Welding is by far the largest method, but other and new joining methods or combination of welding and other methods are increasing. One third of the Swedish BNP is estimated to be related to welding. There are 20 000 full time welders within Sweden and approximately 250 000 persons has welding related activities as a part of their work. One third of the 10 000 industrial robots are used in welding processes. Welding is a central and important factor for the continuous success of Swedish industry and it is of outmost importance to strengthen

research and education within welding and related activities to preserve and increase the competitiveness. The added value in production will increase when a higher weld quality is introduced in the Swedish production system thus improving the competitiveness in Swedish welding factories.

The Swedish Industry have partly failed to develop/introduce production methods to be able to use the high strength steel which has been available for more than 25 years in welded structures with high demand on fatigue resistance. Due to shortsighted cost reasons, high quality requirements on welded joints are seldom used which limit the introduction of more high strength steel and many welded components are 20 - 40 % heavier than what is possible. Furthermore there is lack of resources and competence within production units which further reduce the possibility to introduce improved welding processes. There is an urgent need to develop new welding or other joining processes for serial production of lightweight components for advanced machineries or structures.

3. Objective

Reduction of weight will require advanced design in more high strength materials and a radically new approach to production engineering. The potential weight reduction of welded structures is in the range of 15 - 40 % depending on today status of the structures and used production methods. In some cases an increased cost due to higher material prize will occur, but this will be compensated by a much higher payload for the owner. Within this project the aim is to develop design and manufacturing procedures for lightweight structures by process development, process optimisation, geometry optimisation and education. The project is based on results from a series of earlier projects and had the following objectives.

- Study and map the possibilities by employing hybrid welding processes in current serial production.
- Further development of existing weld quality systems for hybrid welding processes.
- Increased knowledge on the effects of local weld geometry, residual stresses and defects on the fatigue strength of high strength steel in conjunction with new welding processes.
- Design and development of l demonstrators manufactured with new hybrid welding processes.
- Further development of the technology platform LOST (Lightweight Optimised welded Structures) for continuing knowledge building and education within the Swedish industry and technical universities

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4. Project realization

The aim of Lightstruct is to develop conditions to manufacture lightweight welded structures within construction machineries. Manufacturing of lightweight structures means reduction of thicknesses and higher stresses which require a higher manufacturing quality. Following major research activities are performed within Lightstruct:

1. Investigation of fatigue analysis methods based on weld defects.

2. Volvo CE has worked to standardize evaluation methods, based on the defects described in the welding standard. Measurement system analyses (MSA) have been conducted for selected methods to ensure their effectiveness, with the objective to reduce the variation in evaluation among the different plants. This result is now in an implementation phase in the company.

3. Tests with plasma hybrid has been performed and analyzed with respect to the process' impact on quality evaluation. Changes in the welding processes makes different demands on the competencies, methods and equipment used at the company. The tests showed, for example, an increased occurrence of cold laps which cannot be detected non-destructively. Plasma hybrid also leads to an increase in the parameter flora which requires different ways of working at the company.

4. A mapping of the gap occurrence and its impact on resource efficiency has been performed. The study showed a large variation that had a major impact on resource efficiency. The varying gap is affecting the throat size and penetration. This leads to waste in the production processes e.g. a larger occurrence of manual root passes than expected was identified

5. Interview studies regarding the implementation of control charts, control plans and weld quality strategies in the welding business are started. .Analysis of plasma hybrid welding and measuring system analysis is performed including mapping of the occurrence of weld gap. Studies regarding the implementation of control chart, control schemes and weld quality strategy are started. Experiments with different types of weld wires and a study to correlate the International Standard for cut edges (ISO 9013) to fatigue design is performed.

Volvo CE and COREMA and CTH contributed with design of experiments. Several welding experiments were performed and the weld process performance was explored with predictive modeling from experiments and meta-modeling. Fatigue test of welded test bars is performed at KTH. Lightstruct is carried out with 3 Industrial Phd students from Volvo CE Arvika and Braås plant and Phd students from KTH and HV

5. Results and deliverables

5.1 Delivery to FFI-goals

The development of new generations of products requires a continuous increase in payload, speed, fuel efficiency, increased demands on life and more environmental friendly machineries. ´The only way to meet these requirements is to introduce new and/or refine applied methods, optimize structural geometry and introduce more high strength material. In this project we have studied novel procedures which will contribute to this process thus keeping Swedish industry at the leading edge regarding performance, material utilization and energy conservation. Some of the project output can be direct used within the involved manufacturing industries.

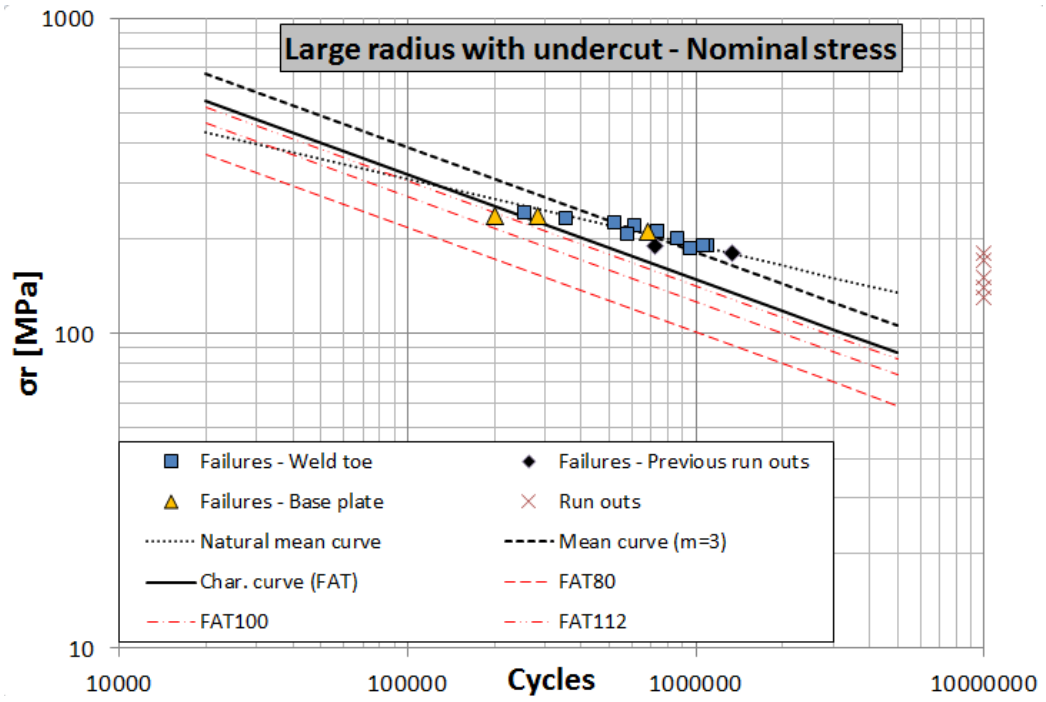

Figure 1: Excellent fatigue life result of an improved welding procedure.

The introduction of novel welding procedures and higher quality levels, require increased operating competence within manufacturing units and that will promote a more scientific based co-operation between development and production engineers. It will also contribute to reduce lead-time in product development and thus a cost reduction of product development. Figure 1 show results from improved welded procedures, the red curves are results from normal welded procedures. FAT 80 is the standard design curve for the actual joint. The result opens possibilities for cost effective introduction of high quality welds and increased usage of high strength steels.

The project has also reinforced the research and education within the participating universities. By SSAB, KTH, HV, CTH and The Swedish Welding Commission the project results will also reach a wide range of Swedish industry and consultancy firms. The main contributions to FFI targets can summarized as:

- Reduced weight increase productivity in terms of handled ton steel/hour
- Reduced weight mean less material and less influence on environment during material processing
- The new processes will reduce lead-time in production, thus a potential increased production capacity
- Products with better performance will improve competitiveness of Volvo and other Swedish industries.

6. Dissemination and publications

6.1 Knowledge and results dissemination

Within Ligthstruct there are manufacturer of construction machinery, welding equipment and steel mills within the project and the dissemination of project results will be a part of the natural contacts between numerous supplier and customers. Implementation of project result is already ongoing in some of the participating companies. Furthermore some of the early project results were presented in the 2nd Swedish Conference on Design and Fabrication of Welded Structures, 9-10 October 2013, Borlänge. Within the education at KTH, CTH and HV the project results will be part of education on different levels. The Welding Commission will use both results and participants from Lightstruct in education of Swedish industries and organizations related to welding of high performance structures. Some of project results will be presented and discussed during IIW-events (International Institute of Welding) during the coming year. The dissemination of the project results is planned to be organized together with the research project ONWELD later 2015 or spring 2016.

6.2 Publications

Bertil Jonsson, Industrial engineering systems for manufacturing of welded structures exposed to fatigue, Licentiate Thesis in Lightweight Structures, KTH Stockholm, Sweden 2012

Zuheir Barsoum (editor), Proceedings of 2nd Swedish Conference on Design and Fabrication of Welded Structures, 9-10 October 2013, Borlänge, Sweden, ISBN 978-91-7501-864-5.

Fatigue design of lightweight welded vehicle structures: influence of material and production procedures, Zuheir Barsoum, KTH, ibid.

The development of fatigue Loaded welded steel structures, Jack Samuelsson, KTH ibid.

A Different View of Quality Assurance for Fatigue Loaded Structures, Anna Ericson Öberg, Chalmers/Volvo CE, ibid

:Innovative welding procedures for efficient fabrication of fatigue loaded structures, Erik Åstrand Volvo CE, ibid.

Fast optical 3D scanning method using structured light for quality- control and reverse engineering, Stefan Rosén Toponova, ibid.

An algorithm for assessing weld surface geometry in welded joints, Thomas Holmstrand, KTH, ibid

Influence of oxides movement on cold lap formation, Peigang Li, University West, ibid

Influence of welding parameters on weld quality and productivity using metal cored wire, Kimon Drosos and Stavros Kotsakis, Dept of Material and Manufacturing Technology, CTH 2013.

Ericson Öberg, A. & Åstrand, E. The subjective judgement of weld quality and its effect on production cost. Design, Fabrication and Economy of Metal Structures, 24-26 April 2013 Miskolc, Hungary.

Åstrand, E., Öberg, A. E,. & jonsson, B, Cost Affecting Factors Related to Fillet Joints. Design, Fabrication and Economy of Metal Structures, 2013 Miskolc, Hungary. Springer, 431-435.

Ericson öberg, A., Hammersberg, P. & Svensson,L-E.. The right evaluation method - an enabler for process improvement. *International Conference on Joining Materials.* Helsingor, Denmark 2013.

Ericson - Öberg, A.. Improved Quality Assurance of Fatigue Loaded Structures. Licentiate of engineering, Chalmers 2013.

Åstrand, E. Welding of Heavy Structures Subjected to Fatigue Licentiate of engineering, Chalmers, 2013

Ericson Öberg, A., Wikstrand, S. & Mattsson,S. The influence of gaps on resource efficency. Swedish Production Symposium, Gothenburg, 2014 .

Erik Åstrand: Key changes in the welding of fatigue loaded structures. Swedish Production Symposium, Gothenburg, 2014.

Fatigue life assessment of improved joints welded with alternative welding techniques. T. Holmstrand, N. Mrdjanov, Z. Barsoum, E. Åstrand, Engineering Failure Analysis 42 2014

Peigang Li, Cold lap formation in Gas Metal Arc Welding of steel: An experimental study of micro-lack of fusion defects, ISBN: 978-91-977943-5-0.

7. Conclusions and future research

This project investigates new hybrid welding processes for highly fatigue loaded structures. The aim was to perform a more general study including the influence on fatigue design, manufacturing and quality. The project introduces also possibility of HVM (High Value Manufacturing) for a wider group of industries which will create conditions for a more sustainable society and a better position for Swedish industry. The project has provided the Swedish industry and universities with new knowledge to improve both education and production. The research continues with following activities:

- Cut edges will be investigated in large program during 2015-2016.
- Within fatigue design the analysis of residual stresses including relaxation will be further developed to increase the possibility to increase the accuracy of predictions and also include relaxation.
- Welding deformation of large welded structures will investigated.
- There are difficulties to use local methods at weld end and more research is needed.

8. Participating parties and contact persons

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