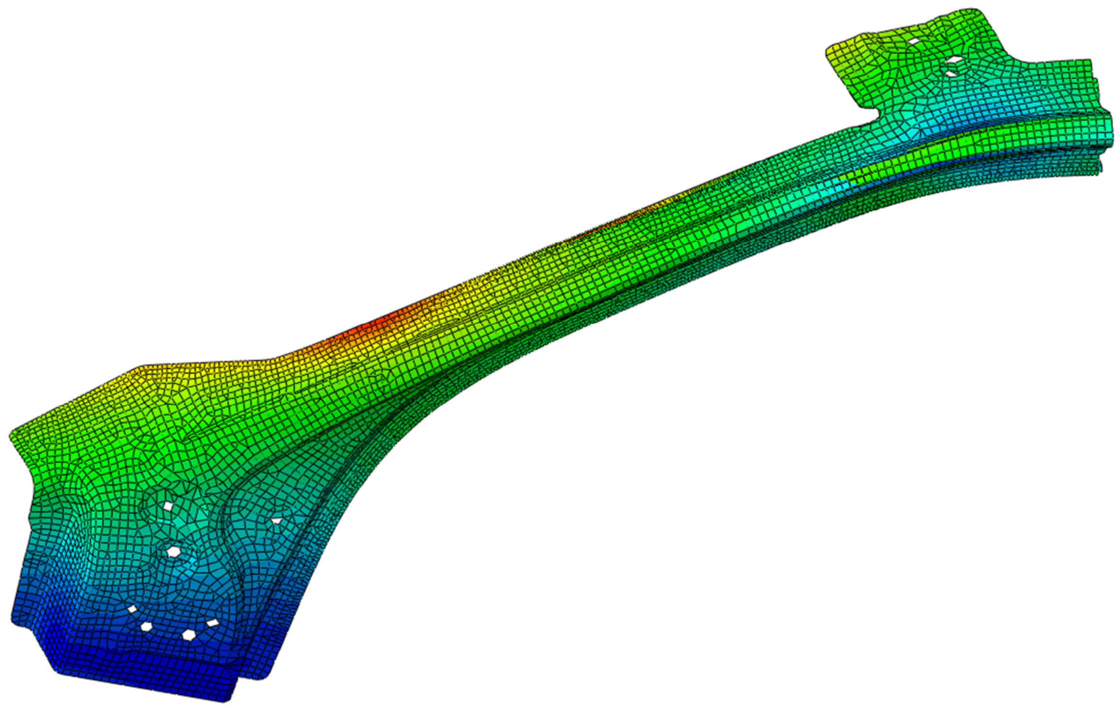
Styrning av distorsioner vid lasersvetsning av ultrahöghållfasta stål (LaserLight) Dnr 2012-03656



Project within VINNOVA FFI Sustainable Production

Authors: Arne Melander, Oscar Andersson, Karl Fahlström

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FFI

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.**

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1. Executive summary

Cost efficient production of light weight bodies of passenger cars and truck cabins is of central importance to Swedish vehicle industry. One main route to low weight is to use very high strength steels, so called ultra high strength steels, UHSS. Volvo Cars is the worldwide leader in the application of boron steels in car bodies and has today reached a proportion UHSS of some 40% in bodies. These steels have to be joined to one another and to other steel types. Spot welding is the dominating technology but laser beam welding has several advantages if the strength of boron steels shall be fully exploited. So laser beam welding is often used in critical applications.

Laser beam welding adds energy to the substrates in between the amount in spot welding and in MAG welding. The temperature rise during welding and associated expansion of the metals is one main cause of distortions during welding. In the case of the UHSS it is not possible to compensate for the distortions after welding by slight plastic deformation in straightening. The reason is that the strength is so high that firstly significant elastic deformation occurs and secondly that very high straightening forces are required to carry out straightening. This means that the dimensional accuracy after laser beam welding of UHSS must be very high. It must thus be possible to compensate for distortions before the welding process or the distortions must be minimized. This can be done by trial and error but this will be very time consuming so simulations become of primary importance.

In this project simulation tools were developed for laser beam welding. Three different levels of complexity of the tools were selected for different purposes. The simple methods give quick answers but they are less accurate. The more advanced tool should be used when high accuracy is required. The methods require different amounts of input data for the process and the material response. New such data were generated within the project for UHSS.

The new simulation methods were verified with experimental trials on idealized beams of two shapes. Laser beam welding was carried out on three different steel types: mild steel, DP800 and boron steel of 1500MPa tensile strength. The degree of agreement between the simulations and experiments was determined.

The trials on idealized beams were also used to find ways to minimize distortions. One efficient way is to minimize energy per unit length of weld by increasing welding speed at constant beam power or by using stitched welds with weld interruptions between the stitches.

The methods developed for idealized beam geometries were finally applied to an A-pillar of a passenger car. The simulation methods were used to predict experimental trials of distortions. Trials were made with different laser process parameters and the results were also compared to spot welding.

The project has generated new simulation tools for laser beam welding adopted for different purposes in the design and process planning of car bodies and truck cabins. The methods show good accuracy and can are useful tools to control and minimize distortions.

2. Background

Cost efficient production of light weight bodies of passenger cars and truck cabins is of central importance to Swedish vehicle industry. One main route to low weight is to use very high strength steels, so called ultra high strength steels, UHSS. These steels are primarily used in the load carrying structural parts of the bodies. Volvo Cars is the worldwide leader in the application of boron steels in car bodies and has today reached a proportion UHSS of some 40% in the most recent bodies. These steels have to be joined to one another and to other steel types. Spot welding is the dominating technology but laser beam welding has several advantages if the strength of boron steels shall be fully exploited. The reason for this is that the continuous laser beam welds can carry higher load the isolated spots of spot welding. So laser beam welding is often used in critical applications.

Geometrical accuracy is of critical importance in automotive production to achieve manufacturing robustness. If distortions are too large in magnitude or in variation or cannot be predicted, final product quality will be compromised. Especially in body-in-white production, which is early in the production process, geometrical robustness is of high importance as early distortions may propagate into later phases in the assembly line and cause even more difficulties.

Laser beam welding adds energy to the substrates in between the amount in spot welding and in MAG welding. The temperature rise during welding and associated expansion of the metals is one main course of distortions during welding. Heating leads to expansion which can cause permanent distortion which is not removed during cooling. In the case of the UHSS it is not possible to compensate for the distortions after welding by slight plastic deformation in straightening. The reason is that the strength is so high that firstly significant elastic deformation occurs and secondly that very high straightening forces are required to carry out straightening. This means that straightening is in practice not possible. Thus the dimensional accuracy after laser beam welding of UHSS must be very high. It must be possible to compensate for distortions before the welding process by adjusting the component geometries or fixturing and the distortions must be controlled and minimized. This can be done by trial and error or legacy methods but this will be very time consuming and expensive during a new car design process so simulations become of primary importance.

3. Objective

The general objective is to develop and verify tools for simulation of distortion during laser beam welding of car bodies and truck cabins. The tools shall be possible to use in the design and manufacturing process planning of new cars and trucks. The utilization of the tools shall make it possible to reduce the lead time for development of new products.

The specific objectives are:

- To develop FE simulation tools for distortion in laser beam welding on three different levels of complexity.
- To verify the simulation tools on two types of beam geometries on different steel types from mild steel to UHSS.
- To suggest ways to minimize distortion during laser beam welding
- To demonstrate the new tools on an A-pillar of a car body.
- To disseminate the new knowledge to the participating companies.

4. Project realization

The project uses different types of test objects to verify and demonstrate the simulation tools developed in the project. The first part of the project was to define the test objects.

Two geometries were used for the idealized beams. The beams were based on hat profiles of 700 mm length. Two hats could be welded together to create a double hat profile, **Fel! Hittar inte referenskälla.**,or one hat profile could be welded to a flat sheet to generate a single hat geometry, see **Fel! Hittar inte referenskälla.**a. These beams could act as idealised forms of A-, B- or C-pillars in a car structure or of side or crash beams, components which are a common application for laser beam welding as they require high structural strength and integrity.

One demonstrator was selected. It was taken from a Volvo XC90 passenger car and was an A-pillar. It is composed of three boron steel components which are welded together with spot welds and laser beam welds.

The idealised beams were used for systematic trials with several steel grades (mild steel, DP800 and boron steel) to find out the effect of steel grade and laser beam welding process parameters on distortions. Process parameters such as welding speed, focus depth, stitching and weld order was varied. The major modes of distortion were identified for the single and double hat profiles and several measurement techniques were developed and applied for triangulation purposes.

Three levels of FE models were developed. One simple level based on displacement of the material around the welds and an advanced model based on full coupled thermal-mechanical simulation. One level was also developed in between these models. The simple model requires limited input data for room temperature data. The most advanced model requires extensive thermal and mechanical input data at several temperatures and metallurgical data. The simple models need execution times in the order of minutes for the idealised beams but the advanced models several days on a multi core work station. The simulation methods were verified with the experimental trials.

The simulation tools were then applied to laser beam welding and spot welding trials on the A-pillar.

The results and tools were finally disseminated to the participating companies in a road show/work shop event as well as concise guidelines aimed at engineers in industry

5. Results and deliverables

As a first step in the project two idealized beam geometries were specified. They are manufactured from hat shaped beams of 700 mm length and 1.0 mm thickness. The hat shaped beams are hot formed in the case of boron steels and cold bent in the case of mild and DP800 steels. The hat beams are combined so that a double beam was created based on two hat beams and a single beam based on a hat beam and a flat sheet. The geometries are illustrated in **Fel! Hittar inte referenskälla.**a and 1b.

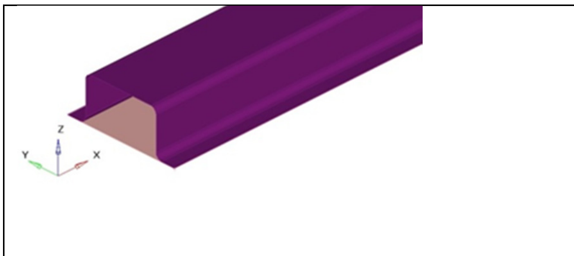	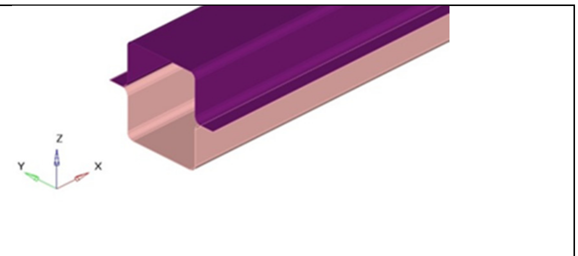
Fig 1a Single hat beam	Fig 1b Double hat beam

A fixture was developed for laser beam welding of the beams. The fixture applied pneumatic fixturing on six different locations on each side of the beam. The fixturing action can be applied and released individually on each fixturing location, Fig 2.

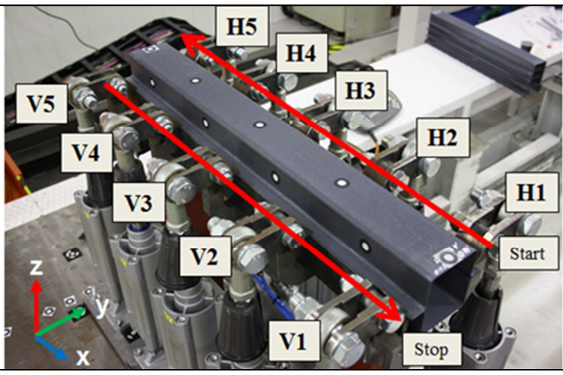

Fig 2. Fixture for laser beam welding of U-beams.

A Nd-YAG laser with peak power of 4kW was used for the trials. All trials were made at peak power but different welding speeds to alter heat input per unit length, welding patterns and continuous and stitch welding was applied. Different modes of releasing the fixturing points was also investigated.

Two modes of distortion were observed to be dominating, one for each beam type. In the case of the single hat beam it bent out from the original plane of the sheet, see u_z in Fig.3. The bending distance at one end of the beam was used as measure of distortion. The double hat beam which is symmetrical showed another type of distortion where the most significant one was widening of the profile, see Fig. 3. This widening was different along the beam length, forming an hourglass shape, and the widening at beam ends was used as measure of distortion, b1 and b3 in Fig. 3. All measurements were taken before and after for each welded specimen. The experiments showed some geometrical variations in the delivered profiles before welding, which were taken into account.

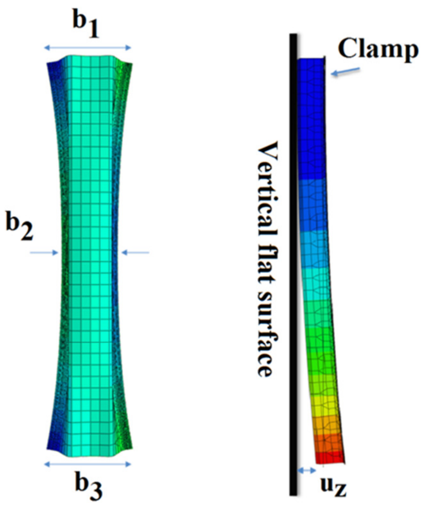

Fig 3. Distortion modes of double and single beams.

The experimental trials showed that the most important factors on distortion was steel type and laser energy applied to the beams. This is illustrated in Fig4. It means that low applied energy by means of high welding speed or laser stitching are the most efficient ways to reduce distortions. Laser beam welding order, release scheme of fixturing points did not show large effects. The boron steels usually showed larger distortions than the mild steel and the DP800 steels.

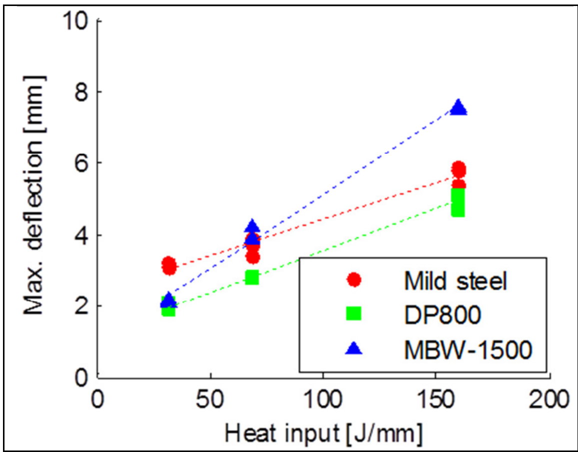

Fig 4a. Distortions for single hat beam

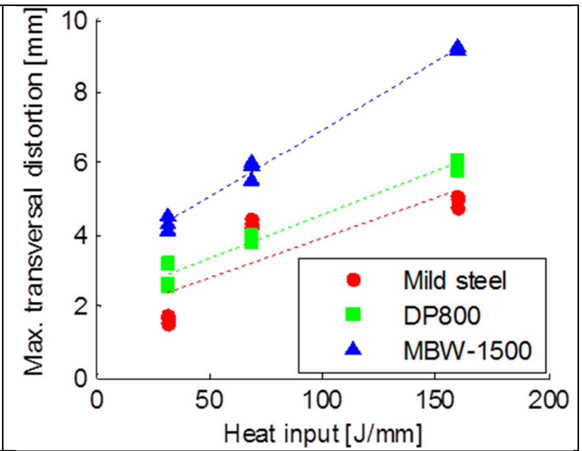

Fig 4b. Distortions for double hat beam

Three different levels of finite element (FE) models were developed to simulate the distortions. They were based on the following simplifications of the process:

- Displacement model assumes that the weld is expanded during welding and this expansion is used as starting position in the simulation. Shrinkage is then simulated with room temperature data in the simulation.
- Andersson model takes both weld expansion and shrinkage into account. It also considers different mechanical properties at different temperatures.
- Full couped simulation makes a very detailed model of the heat source and the thermal and mechanical response during the successive welding and cooling.

The first two models have execution times for a standard multi core work station less than an hour but the most advanced model type requires several days for the present beam types. The first to model types are considered realistic for simulation of real body components.

The models show better agreement with experimental trials the more advanced the models are. This is illustrated in Figs 5 where the correlation between experimental distortions and predicted ones are presented. The displacement model shows less satisfactory results. This is significantly improved in the Andersson model and the final fully coupled model shows a very accurate distortion prediction.

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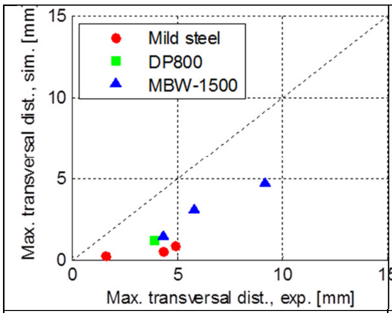

Fig 5a. Displacement model

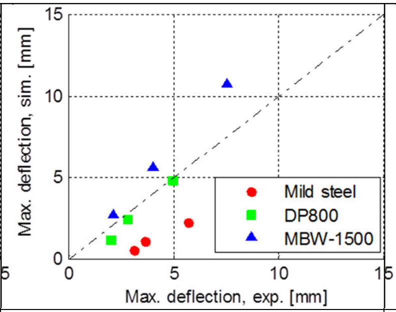

Fig 5b Andersson model

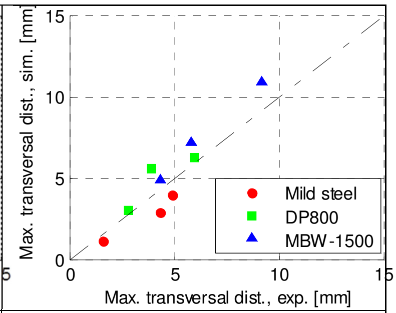

Fig 5c Full coupled simulation

The results from the studies on the idealized beams were finally applied to an A-pillar of a Volvo XC90 car body. This pillar is composed of three components of press hardened boron steels which are spot welded and laser beam welded. In industrial practice the beam is located in the body structure during laser beam welding. This was not a practical situation for the present trials so a special fixture was developed the A-pillar where it was mechanically fixed at the lower and upper ends in a similar way as in the car body during manufacturing. The beam and the fixture are illustrated in Figs 6.

Fig 6a. A-pillar

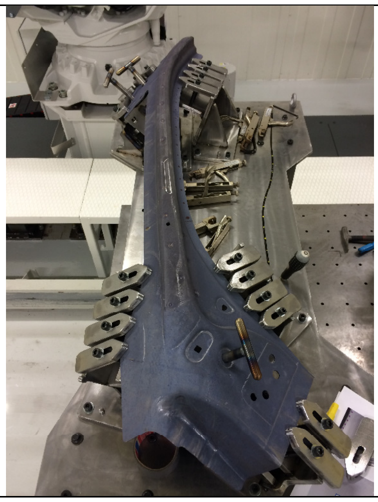

Fig 6b. Fixture for welding trials

The distortions of the A-pillar during welding were both measured with an optical 3D measurement system where the distortions could be represented with iso-plots as in Fig 7a. Measurements were also made of displacements of single points in the pillar. The trials showed that independent of welding method and amount of heat input three dominant distortion modes were found. Firstly, the narrow mid-section of the A-pillar exhibited longitudinal bending distortions, similarly to the single hat beam. Secondly, the narrow mid-section exhibited a torsional distortion mode. Thirdly, the top section bridging to the roof, perpendicular to the driving direction was vertically lifted after welding. The magnitude of the mentioned distortions was dependent of welding method and heat input. Laser beam welding caused higher distortions compared to equivalent resistance spot welding patterns.

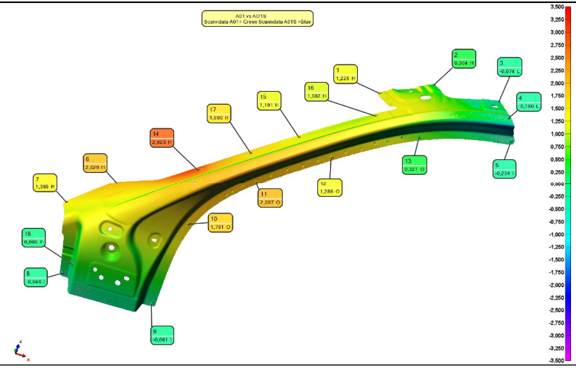

Fig 7a. Iso plot of experimental distortions

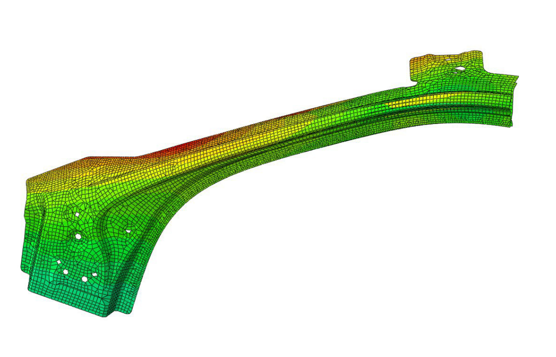

Fig 7b. Iso plot of distortions from Andersson model

A shell element FE-model was generated from the CAD models of the components of the A-pillar and simulations were performed with the Andersson model for laser beam welding. It was considered unrealistic for the presently available computer power to use the fully coupled model. The simulation was completed by simplified modeling of the spot welds which joined by sheets. The spot welds were modeled as a cylinder around the center of the spot weld.

In order to compare the simulations and the manual measurements from the trials, the simulation model included a final step with displacement and rotational boundary conditions which mimicked the measuring method.

Fig 8 illustrates the agreement between trials and simulations. The Andersson model shows good agreement with experimental trials on the A-pillar and the model can predict the effect of varying welding method and welding parameters accurately.

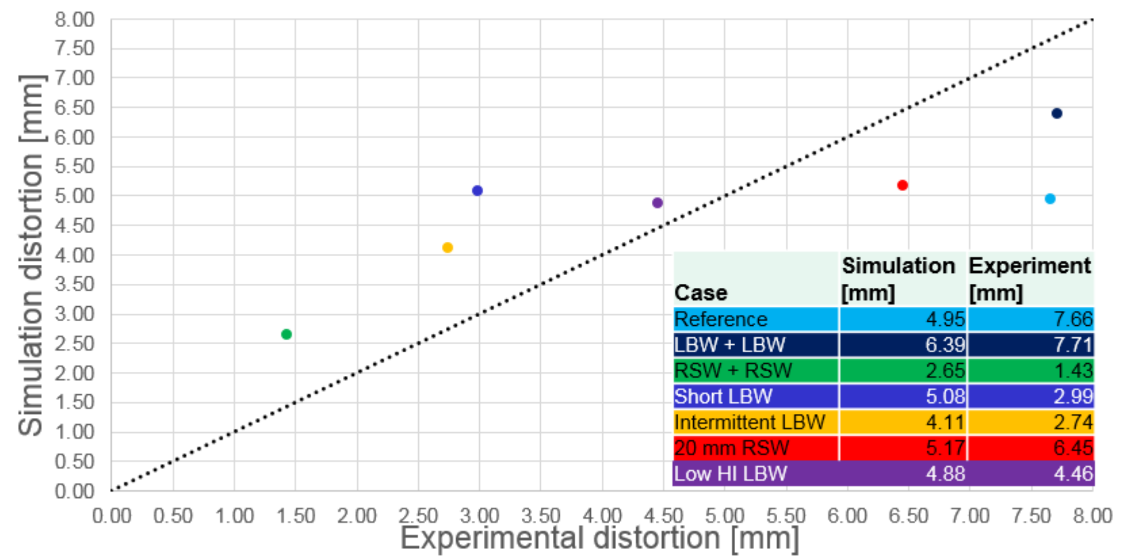

Fig 8 Correlation between experiments on A-pillar and Andersson model.

It can be concluded from the trials on simplified beams and the demonstration on A-pillar that different levels of simulation to model distortions during laser beam welding can be used. The more complicated models give better accuracy in the prediction but also require more programming time and execution times. We believe that the Displacement model and the Andersson model can be useful in the design and manufacturing process planning processes to speed up response times by avoiding experimental trials. The Displacement model is preferable in the early cycles of body development where more qualitative answers are required on distortions in order to rule out or proceeding with proposed design concepts. The Andersson model can be used in later development cycles where more accuracy is required but also more time will be available for the simulations, and when more exact geometries, material combinations and process parameters have been defined. The accuracy will be especially important in the manufacturing process planning to assure robust large-scale production with high repeatability.

The project formulated at start a number of goals to be met by the tools developed in the project. They were:

- Weight reduction of body by 35%.
- Reduction of process planning times by 50%.
- Reduction of distortion during laser beam welding by 70%.

It is considered that the first goal is on the limit of what can be achieved with UHSS designs. If the tools developed in the project are used to eliminate physical trials on car bodies the second goal is realistic to reach. We have found that the most efficient way to reduce distortions is by reducing laser energy per joint length. There seem not to exist other smart ways by e.g. fixturing schemes. So the third goal is not realistic to reach.

5.1 Delivery to FFI-goals

The primary goals of the FFI program on sustainable production is to facilitate new environmentally adopted product solutions for vehicles and to strengthen the competitiveness of the Swedish vehicle industry. Low weight of vehicles is a main focus in this effort.

The present project contributes to the goal by making the design and process planning of laser beam welded UHSS components more efficient. The suggestions made to reduce the magnitude of distortions and to reduce the process planning times are important contributions to the future utilization of UHSS in car bodies and truck cabins. It is clear that laser beam welding of UHSS structures offers many challenges and efficient and verified simulation tools are important in order to meet these changes. By delivering such tools the project contributes to the competitiveness if the Swedish vehicle industry. It will assist to realize low weight bodies with high crash resistance and low weight for future driveline solutions based both on conventional and electric solutions.

Low weight of products is not only important to the vehicle industry. Also in other product where low weight is important can the present project by its solutions to effective process planning for laser beam welded UHSS solutions.

6. Dissemination and publications

6.1 Knowledge and results dissemination

The project has been executed with a close cooperation between the academic and industrial partners to secure the future utilization of the results in industry.

The project results have been presented to a group of industrial product and manufacturing process developers in a road show combined with a work shop and a set of guidelines for further distribution.

As presented below a large fraction of the results of the project have been published in international conferences and journals. The results are part of two doctoral dissertations.

6.2 Publications

#1:
Oscar Andersson, Nesrin Budak, Arne Melander and Niclas Palmquist
Distortions of overlap laser welded thin sheet steel beam structures
Curved and layered structures (Submitted)
#2:

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Oscar Andersson, Karl Fahlström, Arne Melander
Experiments and efficient simulations of distortions of laser beam welded thin sheet close beam steel structures
Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture (Submitted)
#3:
Oscar Andersson, Karl Fahlström, Arne Melander
Prediction of geometrical distortions by laser beam welding of thin sheet UHSS structures (tentative)
Science & Technology of Welding and Joining
#4:
Karl Fahlström, Oscar Andersson, Urban Todal, Arne Melander
MInimization of distortions during laser welding of ultra high strength steels
ICALEO 2014
#5:
Karl Fahlström, Oscar Andersson, Urban Todal, Arne Melander, Lars-Erik Svensson, Leif Karlsson
Distortion analysis in laser welding of ultra high strength steel
SPS 2014
#6
Karl Fahlström, Oscar Andersson, Arne Melander, Leif Karlsson, Lars-Erik Svensson
Correlation between laser welding sequence and distortions for thin sheet structures
Science & Technology of Welding and Joining (Submitted)
#7
Karl Fahlström, Oscar Andersson, Arne Melander, Leif Karlsson, Lars-Erik Svensson
Laser welding of thin sheet structures – Correlation between metallurgical effects and distortions
Science & Technology of Welding and Joining (Tentative)

7. Conclusions and future research

1. Ways to reduce distortions in laser welding have been suggested
2. Simulation tools to predict distortion in laser welding have been developed and verified.
3. The simulation tools have been demonstrated on an A-pillar of a car body
4. The simulation tools can significantly reduce development times in car body development by avoiding time intensive trials on full car bodies.

   The utilization of laser welding for UHSS bodies has been facilitated by the results of this project. For future applications the combinations of laser welding with other joining techniques will be important to find efficient ways to design and produce vehicle bodies of UHSS.

8. Participating parties and contact person

Swerea KIMAB, Arne Melander and Karl Fahlström
KTH, Dept Production Engineering, Arne Melander and Oscar Andersson
Volvo Cars, Gert Larsson, Urban Todal
Volvo AB, Samuel Bäckström
SSAB, Anders Olsson

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