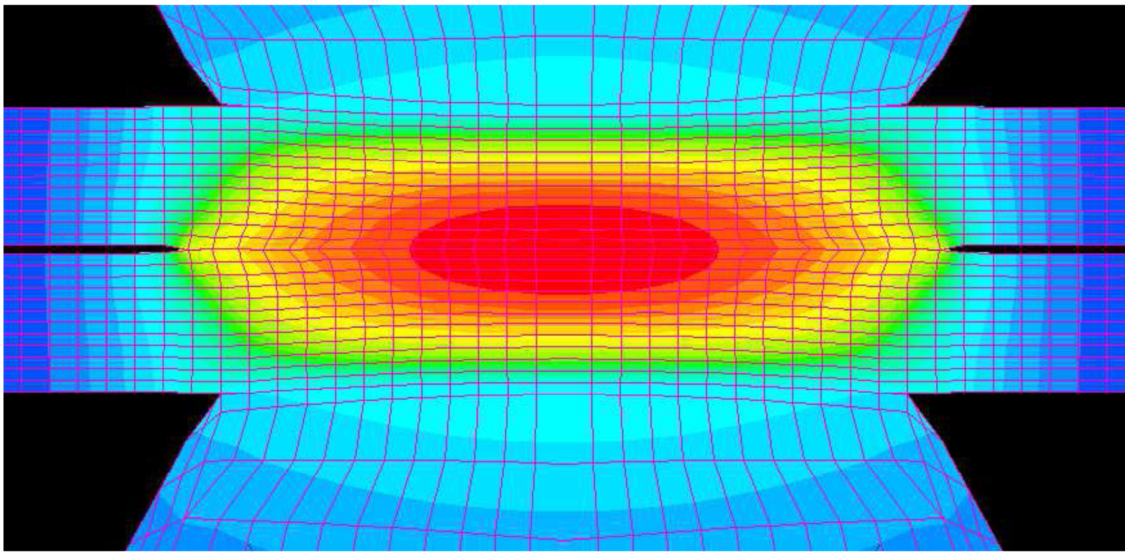
FORDONSSTRATEGISK
FORSKNING OCH INNOVATION

# Spot welding for light weight design SPOTLIGHT



Författare Arne Melander, Oscar Andersson, Johannes Gårdstam, Fredrik Wredenberg, Paul Janiak, Mattias  Linden, Karl Fahlström, Anna Runnemalm, Ola Albinsson, Åsa Lundevall

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# Innehåll

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 .

Swedish vehicle industry must be on the international front line regarding production processes and technologies in order to stay internationally competitive. This project aims to strengthen Swedish research environments in this area.

The project contributes with solutions for spot welding for light weight car bodies and truck cabins. Designs in high strength steel and aluminium are included. There are many limitations in the use of high strength materials regarding spot welding and this project aims to reduce those limitations.

The project targets are:

- Develop and verify simulation methods for spot welding so that process planning times and costs can be reduced.
- Develop cost efficient spot welding techniques for new steels and combinations of many steel sheets.
- Develop spot welding processes for aluminium.
- Develop innovative technologies for formation of spot welding electrode tips.
- Develop and build a demonstrator for NDT of spot welds.
- Develop methods to optimise the number of spot welds in a body so that the number of welds can be reduced without loss of strength and reliability.
- To make guidelines based on the results of the project.

The following results have been achieved:

- The project has satisfied the formulated targets to develop and verify methods for virtual process planning of spot welding with regard to weld size and weld sputter.
- The project has worked with so called impossible combinations of steel sheets which will become frequent in tomorrow`s bodies. The boundaries have been moved with regard to what is possible and not. Up to 5 sheets have been spot welded and combinations with surface sheets down to 0.55mm have been treated successfully.

- The degradation of electrodes during spot welding of aluminium alloys has been studied and methods have been identified so that spot welding of aluminium alloys in production appears a realistic alternative to other joining techniques .
- In the electrode part of the project it was investigated how long intervals could be used without milling the electrodes and still retaining spot weld quality. It was found that significantly longer intervals could be used than usually used in production.
- An innovative method for NDT of spot welds was developed and implemented in a cell for inspection of welds of a back hatch of a passenger car. Thermography was used. The new technology is suitable for robotized manufacturing and NDT.
- A new technology was developed to minimize the number of spot welds so that component properties are maintained. The method takes into account the scatter in weld sizes so that the reduction in weld number does not influence the robustness of the welded component.
- Education material has been produced for the different results and both videos and power point presentations have been produced. A road show was carried through to the large Swedish body plants with presentation of the results.

## 2. Background

It is important to be in the knowledge front line regarding manufacturing processes and manufacturing technologies in order to strengthen Swedish vehicle industries competitiveness and keep production in Sweden. The project supports long term strengthening of research environments within production technology in order to find solutions to problems arisen by increased environmental demands and demands for crash performance. The project also supports cost savings by improving methods and supplying methods for optimization.

Requirements for less fuel consumption are increasing. This is driven by both environmental concerns and fuel cost. The requirements leads to increased usage of materials that contributes to lighter bodies and cabs with kept or increased strength performance. Simultaneous requirements for increased crash performance tend to increase weight, and low weight materials have to be used to counteract.

An earlier project (MERA, Spot welding of UHSS steels) studied problems that were anticipated for new high strength steels in vehicle production, how strength is affected and how to avoid the problems. The project partners were mainly the same as in the now planned project.

The focus for this project is, however, different. The project will develop solutions for spot welding of materials and combinations of materials that contributes to lighter bodies and cabs. Both spot welding of high strength steel and aluminium will be covered. There are today limitations for spot welding of steel regarding thickness ratio for the different sheets and for the total joint thickness. The project will find ways to exceed those limitations without neglecting process robustness.

The vehicle industry in general is today not using resistance spot welding for aluminium due to the production process problems. Spot welding of aluminium would give considerable advantages compared to the today used joining methods, when solutions to the process problems are developed. There are exceptional examples from the USA of spot welding of aluminium body assemblies in low volume production but, at present, no other known examples. The project will evaluate methods for aluminium spot welding. And the project will develop solutions to a major problem, namely electrodes and maintenance of those.

The determination of parameters for spot welding is today based on physical testing. The project will develop and verify methods for parameter determination by simulation. This will support shorter manufacturing engineering lead time for spot welding processes.

# 3. Objective

**Program targets**

The project contributes to reduced emission of $CO_2$ and other vehicle emissions by facilitating reduced body- and cab weight. The reduction is achieved by increased use of advanced lightweight materials in innovative and environmentally friendly products, materials which the industry today has limited experience of. The project will deliver new joining knowledge for those materials.

The project also contributes to more efficient manufacturing engineering of joining processes for vehicles by developing methods for simulation of spot welding parameters, and by developing methods for optimisation of number of spot welds. This will result in cost savings by more efficient manufacturing engineering with shorter lead time, and by reduced investment level.

Spot welding of aluminium is expected to be considerably more cost efficient than e.g. self piercing rivets, a today often used method for joining of aluminium. Another advantage with spot welding is that the joint gets “flat” surfaces on both sides, which sometimes is a function or design requirement.

The project is also focusing on development of automated NDT of spot welds. Automation will increase competitiveness by cost saving and by increasing the quality level.

This will all together contribute to increased competitiveness by increased competence and lower cost for Swedish industry. It will also contribute to less environmental impact from Swedish vehicles. It will be an enabler for knowledge based production in Sweden which contributes to secured employment.

The project is a good example of strengthened cooperation between industry, university and research institutes.
The project results are highly interesting also for companies outside the group of project partners, and will get industrial impact when spread.

**Project targets**

In brief the project will:

- Develop techniques for virtual simulation of process parameters in order to shorten the lead time for manufacturing engineering.
- Develop methods for spot welding of thicker joints and a greater number of sheets than now allowed in the vehicle industry.
- Develop cost efficient spot weld processes for new steels and for aluminium alloys
- Propose an innovative tip dressing technology for electrodes used for steel .
- Develop, build and evaluate a demonstrator for automated non destructive testing (NDT) of spot welds. The choice of technology will partly be based on experience from earlier projects.
- Develop techniques for quality assured optimization of spot weld number, in order not to weld more than justified by product strength requirements.
- Develop new directions and guide lines for spot welding based on the project achievements.

# 4. Project realization

The project is divided in work packages (WP), each with specific targets and milestones. The manning is not the same in all WP, but matched to fit need, knowledge and available resources. Some WP will have common meetings to improve communication and reduce administration and travelling.

The project partners have positive experience from this way to organize a big project. All tasks/WP can be, and are, clearly specified, and the partners individual competence is utilized efficiently.

In brief the project will:

- Develop techniques for virtual simulation of process parameters in order to shorten the lead time for manufacturing engineering.
- Develop cost efficient spot weld processes for new steels and for aluminum alloys
- Develop methods for spot welding of thicker joints and a greater number of sheets than now allowed in the vehicle industry.

- Propose an innovative tip dressing technology for electrodes used for steel and aluminium respectively.
- Develop, build and evaluate a demonstrator for automated non destructive testing (NDT) of spot welds. The choice of technology will partly be based on experience from earlier projects.
- Develop techniques for quality assured optimization of spot weld number, in order not to weld more than justified by product strength requirements.
- Develop new directions and guide lines for spot welding based on the project achievements.

# 5. Results and deliverables

### WP1 Development and verification of simulation method for spot welding

Statistical variations which occur in spot welding in laboratory and in production has been evaluated as a reference to the virtual prediction models which will be developed in the project

Based on a large data base of spot welding data regression models were developed for the relation between spot weld size and material and process parameters. The models show a scatter in predictive power which is in the order between the scatter in laboratory to production tests.

Finite element simulations were also used to predict spot weld sizes and the risk of spatter.  New input data were used for the simulations. The results were compared to experimental laboratory trials.  The simulations show a predictive power which is similar to the one shown by the regression models.

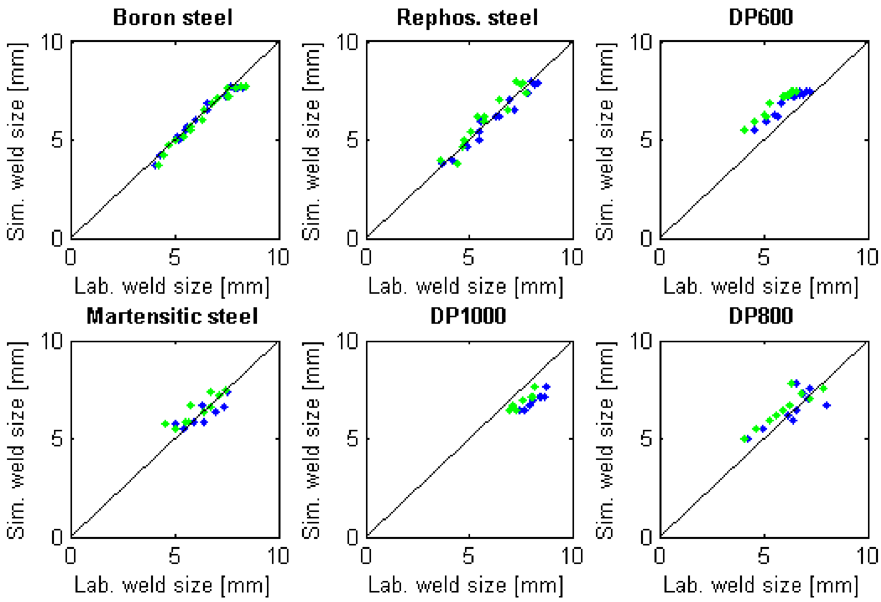



**Figure 1 Comparison between measured and predicted spot weld size at first weld location (green) and at second (blue).**

New finint element models were also developed for tensile tests of spot welded joints. The models show good results, Fig 2.

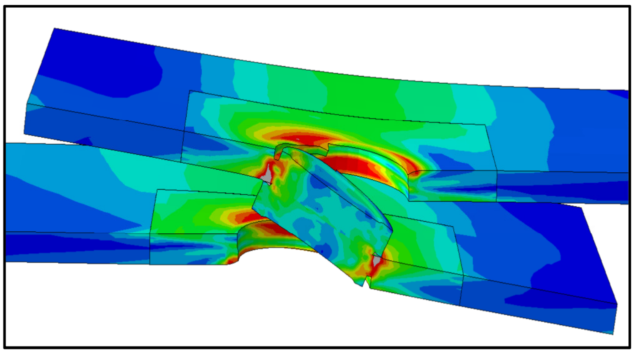


**Figure 2 Simulation of tensile test of spot weld joint on boron steel.**

### WP2 Challenging spot welding

In this subproject challenging steel sheet combinations were studied which can contain up to five individual sheets and combinations of thick and thin sheets. Innovative methods are often needed to manage such combinations. The following results were obtained:

- Thin sheet thicknesses below 0.6mm could be welded together with thicker sheets primarily using sequenced welding techniques using several current pulses.

- Sequenced pulsing was found to be a good solution to many spot welding problems.

## WP3 Spot welding of light metals

It has for a long time been considered very difficult to spot weld aluminium. The primary reason is degradation of the electrodes. In the sub project it has been investigated if different electrodes can solve the spot welding problems. It was found that electrode variants which are quite different from the ones used for steel was best suited for spot welding of aluminium alloy, Table 1. The electrode type A was found be behave better than type B.

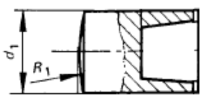
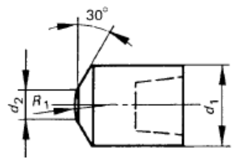
| Typ A elektod | Typ B elektrod |
|---|---|
|   |   |

**Table 1 – Schematic picture of electrode type A and B [3-2].**

## WP4 Innovative technique for electrode tip dressing

Electrode tip deressing was studied for two different sheet combinations corresponding to light and severe spot welding. It was found that spot welding could be performed a significantly larger number of joints than normally used in production before tip dressing. The period was 500 welds for light welding to be compared to normal tip dressing at 100 welds. It was estimated that the interval to tip dressing could be significantly increased compared to normal industrial practice with significant economical advantages.

## WP5 Automated quality checking of spot welds

Initially in the project it was studied which NDT methods could be suitable for measurement of spot welds. It was concluded that Thermography had interesting properties. No commercial equipment was however available so a new equipment was developed. The technology is based on an IR camera which measures the surface temperature after heating of the component. A demonstration cell was designed for a back hatch of a passenger car and good results were obtained, Fig 3.

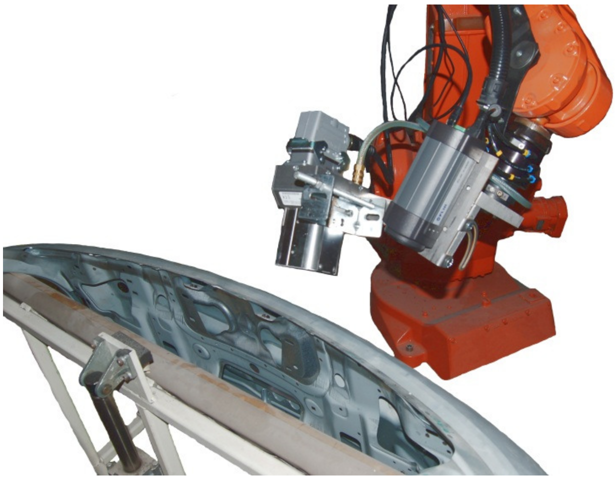


**Figure 3. Automatic inspektion cell based on thermography.**

**WP6 Robust techniques for reduction of spot weld quantity**

The number of spot welds increases in each new generation of car bodies though the introduction of higher strength materials. This means that it is desirable to reduce the number of welds. In this project an optimising proceedure was developed to find where spot welds should be located so that the numbers were reduced but the properties of the component were retained. This should be done in a robust way. One beam was selected and it was found that the number of spot welds could be reduced with 25% without inflicting the selected beam properties, Fig 4.

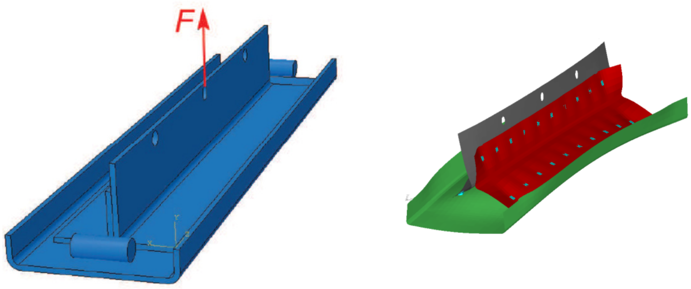



**Figure 4. Beam selected in the project for optimisation of weld positions.**

**WP7 Documentation of guidelines and dissemination of results**

In sub project 7 guidelines were formulated and distributed. Videos were generated and power point slides from all sub projects. A road show was conducted to all the major body plants in Sweden where the results were presented to all staff in spot welding engineering.

## 6. Delivery to FFI-goals

The project contributes to reduced emission of $CO_2$ and other vehicle emissions by facilitating reduced body- and cab weight. The reduction is achieved by increased use of advanced light weight materials in innovative and environmentally friendly products, materials which the industry today has limited experience of. The project will deliver new joining knowledge for those materials.

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The project is also focusing on development of automated NDT of spot welds. Automation will increase competitiveness by cost saving and by increasing the quality level. This will all together contribute to increased competitiveness by increased competence and lower cost for Swedish industry. It will also contribute to less environmental impact from Swedish vehicles. It will be an enabler for knowledge based production in Sweden which contributes to secured employment.

The project is a good example of strengthened cooperation between industry, university and research institutes. The project results are highly interesting also for companies outside the group of project partners, and will get industrial impact when spread.

### Contribution to project targets

- WP1 has fulfilled the targets to develop and verify virtual methods for spot welding with respect to weld size and sputter. This was done for a spectrum of future body materials.

- WP2 was directed towards ”impossible” combinations of steels sheets from the spot welding point of view. New ways were developed for welding of joints with up to five sheets and with the smallest thicknesses even down to 0.5mm.

- I WP3 developed electrode solutions for spot welding of aluminium alloys. This means that it is today significantly more feasible to spot aluminium alloys in productin than before the project.

- WP4 showed that it is possible to use significantly longer times between tip dressing of electrodes than normally used in production. This means that significant economical advantages can be gained.

- In WP5 a new method for NDT of spot welds was developed and it was applied to a bach hatch of a passenger car body. Very promising results were obtained and the method is suitable for robotized manufacturing.

- In WP6 an optimisation methodology was developed for location of spot welds. It was tested on a simple beam. It was shown that the number of spot welds could be reduced significantly compared to present practice.

- In WP7 education material was developed from all the sub projects.  Slide shows and videos were produced. A road show was conducted to all the major body plants in Sweden where the results were presented to engineering staff involved in spot welding.

# 7. Dissemination and publications

### Dissemination of results

In the project dissemination to Swedish spot welding companies has had high priority. This specially applies to the body plants of the vehicle industry. We believe we have had a high hit rate to reach the staff concerned with spot welding in those industries which means that the results of the project will be implemented.

One especially encouraging result is that one of the companies has introduced virtual process planning based on finite element methods as a tool which partly replaces physical testing. This introduction is a clear effect of the Spotlight project.

One more example of the effect of the project is the introduction of one particular innovative method of spot welding of difficult sheet combinations which was introduced in one of the companies

So there are a number of examples that the project has led to results in industry. It is also clear that a active research environment has been created in university/institute/industry which will have great possibility to create a good knowledge in spot welding for the future.

**Publications (in open conferences and journals)**

| Titel | Publiceras | Författare |
|---|---|---|
| Statistical analysis of variations of resistance spot weld nugget sizes | IIW International Conference on Global Trends in Joining, Cutting and Surfacing Technology, Chennai, India, 2011. | Oscar Andersson, Arne Melander |
| General regression models for spot weld sizes | IIW International Congress Advances in Welding Technology & Science for Construction, Energy and Transportation Systems, Antalya, Turkey, 2011. | Oscar Andersson, Arne Melander |
| Verification of the capability of resistance spot welding simulation | AWS Sheet Metal Welding Conference XV, Livonia, USA, 2012. | Oscar Andersson, Arne Melander |
| Verification of the capability of resistance spot welding simulation | Submitted to Science and Technology of Welding and Joining, 2012. | Oscar Andersson, Arne Melander |
| A new method of resistance spot welding for light-weight design | Awaiting publication | Oscar Andersson, Arne Melander, Joel Lundgren, Gert Larsson |
| Statistical Analysis of Variations in Resistance Spot Weld Results in Laboratory and Production Environment | The 5th Swedish Production Symposium, Linköping, Sweden, 2012. | Oscar Andersson, Arne Melander |

# 8. Conclusions and future research

As can be understood from the presentation above the project has been successful and has reached most of its targets. The good knowledge that was generated has of course also created suggestions for future research, some examples of which is presented below:

WP1: The virtual process planning tools have been shown to have good predictability for joints between two sheets. More work will be needed to bring predictions for three or more sheet joints to that level.

WP2: There are still many impossible sheet combinations which design engineers would like to introduce into future bodies but which cannot be spot welded. This includes many combinations with thick sheets in the inner structure ant very thin skins.

WP3: The results of Spotlight indicate that longer intervals between tip dressing can be used than is normal practice today. More results are needed to verify this and models should be formulated so that tip degradation can be modelled..

WP4: Spotlight has shown that spot welding of aluminium alloys has great potential. Models should be developed for electrode degradation so that the effect of geometry and process parameters can be understood better.

WP5: NDT of spot welds by thermography shows great potential. The industrialization has however to be brought one step further before the technique can be used extensively.

WP6: The possibilities of optimisation of the location of spot welds in a body has been demonstrated in Spotlight for a rather simple beam. The technique has to be taken one step further to demonstrate it in a full body.

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# 9. Participating parties and contact person

| **Företag** | **Namn** |
|---|---|
| Volvo Personvagnar | Lars-Ola Larsson |
| | Joel Lundgren |
| | Martin Olsson |
| | Benny Andersson |
| | Martin Strömblad |
| Volvo Lastvagnar | Lars-Ove Karlsson |
| Scania | Rickard Ottosson |
| Gestamp Hardtech | Håkan Andersson |
| SSAM EMEA | Tony Nilsson |
| SAPA | Lina Ek |
| SAAB Automobile | Sven-Ove Olsson |
| | Tage Västerstig |
| | Tore Rönnhult |
| | Lennart Malmsköld |
| Swerea KIMAB | Arne Melander |
| | Paul Janiac |
| | Mattias Linden |
| | Johannes Gårdstam |
| | Fredrik Wredenberg |
| | Karl Fahlström |
| | Eva Lind-Ulmgren |
| | Joakim Hedegård |
| Swerea IVF | Ola Albinsson |
| | Åsa Lundevall |
| KTH | Oscar Andersson |
| Högskolan Väst | Anna Runnemalm |
| | Anders Appelgren |