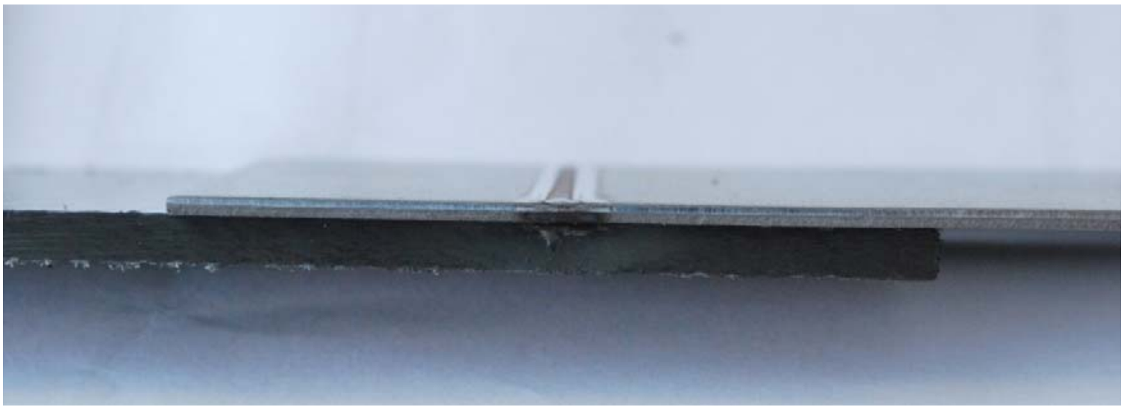
# Dense-Arc joining of hybrid thermoplastic composite - metal structures (DENSARC)



Project within FFI – Sustainable Production Technology

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# Content

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# 1. Executive summary

This hypothesis project has evaluated the possibility to join thermoplastic composite to zinc coated steel sheet using TIG arc for heating the metal sheet and through heat conduction melt the joint faces.
Two types of thermoplastic composites have been included (one with long continuous carbon fibres woven to laminated mats and the other with short fibres randomly oriented).

The objectives with the hypothesis project were:

- Test if TIG is suitable as a heat source in joining thermoplastic composite to steel.
- Define characteristic properties the of a lap joint of thermoplastic composite to steel, measure and relate the result to specified demands
- Define future need for development in order to have a joining method that is robust, gives high productivity and high quality as well as cost advantages.

It is concluded that joining thermoplastic composite with short fibres to zinc coated steel using TIG as heat source is possible. Fairly good shear strength can be achieved, shear strengths better than 10MPa was measured in the tests and can most likely be improved a bit further. This shear strength level is comparable to the lower end of adhesives joints used in the automotive industry. The travel speed was rather high, about 1m/min, for a zinc coated steel sheet with 1.2mm thickness. There is however a curing time before the thermoplastic composite becomes stiff and the sheets have to be clamped which prolongs the total joining cycle time.

The joint strength with the laminated composite with long fibres was low, only about one tenth of that with the short randomly oriented fibre composite.

This joining technique has future possibilities mainly in non-loaded applications or for temporary fixation. To achieve good shear strength there will also be some restrictions in selectable materials (type of thermoplastic composite, metals and metal coating). The joint surface area on the metal, on the opposite side of the actual joint, is very smooth and will after painting be almost invisible. The joining technique has single sided access even if clamping support may need access from both sides.

# 2. Background

The background for this hypothesis project is:

- Future low weight designs will increasingly be of hybrid type, in many cases with metal load carrying structure and thermoplastic parts.
- It is important to develop joining methods with increased efficiency and reduced cost for the joining of composite-metal structures. Automotive demands are: high volume capacity, availability and robustness, sufficient joint strength, preferably single-sided access, invisible joints and freedom in design.

The hypothesis is based on joining thermoplastic composite to metal by just melting the composite so that adhesive joining to the metal occurs.

- As the heat source a TIG arc will be used, the arc is constricted to limit the influence of the heat on the metal.
- The arc will burn to the free side of the metal and heat the composite through heat conduction.
- The method will therefore be single sided.
- Compared to other heat sources, as laser, the investment cost can be kept low.

# 3. Objective

In this project the idea is to use the polymer in the composite to form an adhesive bond to the metal. To do this the polymer has to be heated to above its melting point. This is made by heating the free side of the metal with an electrical arc, heat conduction will then transport the heat to the joining side of the metal, heat and melt the polymer on the surface of the composite and when curing, under pressure, form an adhesive bond to the metal.

The objectives with the hypothesis project were:

- Test if TIG is suitable as a heat source in joining thermoplastic composite to steel and find suitable welding parameters.
- Specify demands on a joint between thermoplastic composite and steel
- Characterize the properties of a lap joint between thermoplastic composite and steel in relation to specified demands
- Define future need for development to have a joining method that is robust, gives high productivity and high quality as well as cost advantages.

# 4. Project realization

The project is performed in co-operation between Swerea KIMAB, Volvo CC and Volvo LV.

The role of Swerea KIMAB was to manage the project, to perform the welding and mechanical testing and evaluation of tests. The budget for Swerea KIMAB was 500 kSEK.

The role of Volvo CC together with Volvo LV was to specify demands, decide conditions for the welding tests, participate in evaluate and discussion of the results and judge practical usability of the joining technique. Both Volvo CC and Volvo LV had a project budget of 100 kSEK each.

# 5. Results and deliverables

## 5.1 Delivery to FFI-goals

The project is classified within:

- The area manufacturing processes
- The research area manufacturing technology
- The product area bodies for vehicles and trailers

In the FFI program sustainable production technology new light materials are identified as a key area.

This project aimed to evaluate the possibility to use of conventional welding equipment in a novel way for joining thermoplastic composite to metal. The main conclusion is that it is possible but with some limitations both in strength and selection of materials. The results are described in detail in the technical report and the conclusions are reported also in this report in the chapter Conclusions and future work.

# 6. Dissemination and publications

## 6.1 Knowledge and results dissemination

The knowledge is spread within the project group. There is some technical novelty that might be patentable but neither Volvo CC nor Volvo LV has, at present, suitable applications and the value of a patent is therefore low. The result will be spread by including it in articles and conference papers.

## 6.2 Publications

The results are not published yet but there are plans to include the results in an article in the trade magazine Svetsen and in conference papers.

# 7. Conclusions and future research

In this hypothesis project joining of thermoplastic composite to zinc coated steel sheet has been tested using TIG arc as the heat source for the joining.
Two types of thermoplastic composites have been evaluated (one with long continuous carbon fibres, woven to laminated mats and the other short fibres randomly oriented).

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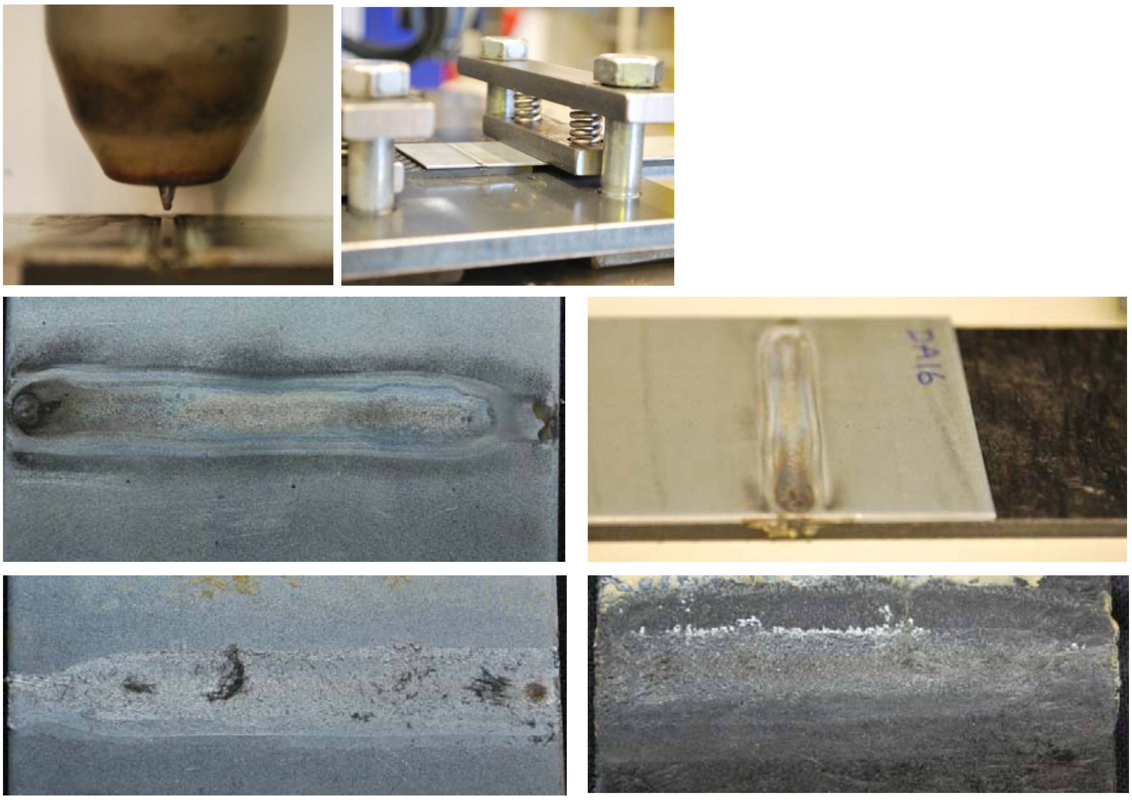

*Joining of thermoplastic composite with short fibres to zinc coated steel*
*Heat source TIG with constricted arc: EWM forceTIG,*
*Steel with sheet thickness 1.2mm and with approx. 7µm zinc coating*
*Travel speed: 0.85m/min*
*Shear-tensile test:* $F_m$*: 4.0kN*    *Joint fracture area:* $\approx 288mm^2$ *(48 x 6)  Shear strength 13.9MPa*

In summary the conclusions are:

- Joining between thermoplastic composite (with short fibres) and zinc coated steel using TIG as heat source is possible. Fairly good shear strength can be achieved, strengths better than 10MPa was measured in the tests.
- This shear strength level is comparable to the lower end of adhesives joints used in the automotive industry (typical values for epoxy adhesives are in the range of 20-30 MPa).
- The elongation before fracture is low.
- The joint strength with the laminated long fibre composite was only about one tenth of that with the short, randomly oriented, fibre composite
- The clamping force has an influence on the joint strength (too high may however deform the sheets depending on support)
- Different thickness of Zn coating did not seem to affect the joint strength
- The top surface becomes very smooth especially with long electrode distance to work piece
- The joint needs some cooling time (preferably more than 15s) to become stiff
- forceTIG and conventional TIG give almost similar results (forceTIG allows higher welding speed)
- Different sheet thickness demands different heat input

For the future it would be interesting to test the proposed joining technique in a true application. This application should probably be a non-loaded joint or a temporary fixation.

It would also be interesting to test a fillet joint with a composite with long continuous fibres as the web sheet, i.e. with cut face from the composite to have open ends of the fibres, to a zinc coated sheet.

Other possible ways to improve the joint strength that could be of interest are the use a primer or an adhesive film. It would also be interesting to test a fibre mat between the composite and the zinc coated steel that would bind both to the polymer and the zinc coating. Joining in combination with mechanical joining methods are also of interest.

Optimized heating of the metal and optimized clamping (both force and curing time) are of course also of interest.

Future development areas of the joining methods are mainly concerning improved strength and improved elongation of the joint.

# 8. Participating parties and contact person

Participant companies and contact persons:

- Volvo Cars - Johnny K Larsson
- Volvo Trucks - Håkan Sundberg
- Swerea KIMAB – Kjell-Arne Persson, Marie Allvar, Karl Fahlström, Joakim Hedegård