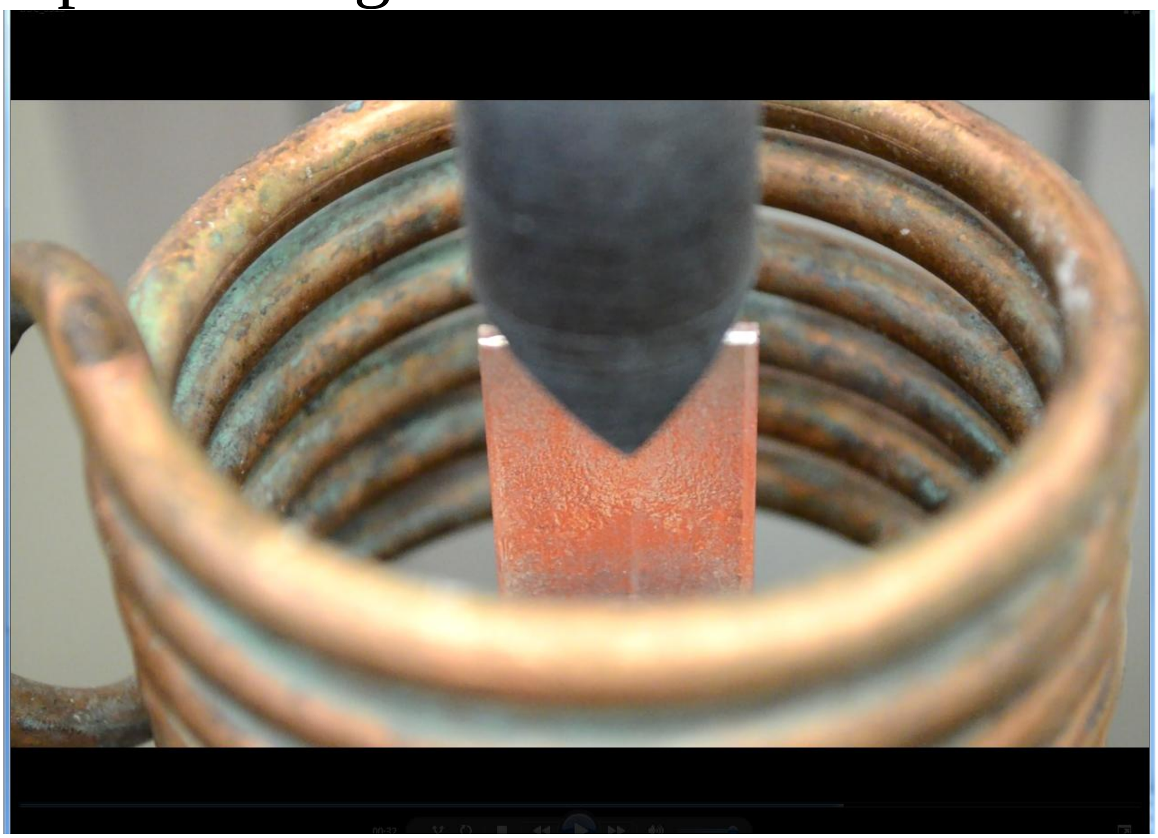
Pre-study – Press hardening with rapid heating



Project within FFI: Fordonsutveckling

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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.**

For more information: www.vinnova.se/ffi

1. Executive summary

Developments in the automotive industry have moved towards producing lighter and stronger cars which place greater demands on the performance and characteristics of the materials in the vehicle. One technique that is increasingly used today to achieve lighter construction is press hardening of boron steel. This technique has mainly been used for components such as A or B pillars in the car body. The technique is based on the use of boron steel, usually coated with AlSi coating to provide corrosion protection, which is heated to austenitizing temperature at which the material is easy to shape. The heated steel sheet are then quenched and formed in a moulding tool which simultaneously forms and hardens the component. This creates a high strength component with fatigue strength up to 1500 MPa. In this project the aim has been to investigate the feasibility of using this technique in a simplified version adapted to smaller components in the vehicle structure. A prerequisite for achieving this solution is to find an alternative heating source to the conventional furnace, as this is highly space-and time-consuming. However, it needs to be evaluated how rapid heating affects the properties of the material and coating.

This pre-study study has been conducted to verify and evaluate the technical feasibility of a hypothetical concept to heat coated boron steel using an alternative rapid heating technology followed by simultaneous forming and cooling. The purpose was to create a basis for a possible future main project in which the technology would be further developed.

The pre-study has primarily generated results regarding opportunities and challenges related to the process technology as well as existing patents and patent applications. An application for funding of a main research project has been submitted.

2. Background

Press hardening is a technique that could be an option for some components currently produced as high-volume products with conventional cold forming. The advantage of press hardening is the possibility to obtain a high-strength component with high form stability and minimal springback. Compared to conventional cold forming material the boron steel for press hardening has higher strength which means components can be made thinner and lighter.

The press hardening process utilizes the hardenability of boron steels when the steel is austenitized and then quenched in a forming tool. During forming the boron steel is simultaneously quenched by the chilled tool that rapidly cools the workpiece and creates the desired hardness increase in the material by martensitic transformation. This rapid cooling puts specific requirements on the tool design since large amounts of heat has to be transferred from the manufactured component.

One of the major production challenges of press hardening is the time it takes to heat the steel sheets to the right temperature, as this now is done in a furnace. Another challenge associated with heating in a furnace is that much material must be heated to allow for relatively short cycle times resulting very space consuming furnaces.

This means that there is a great interest in replacing heating technology from furnace to technologies that are faster and require less space to reduce investment and production costs.

3. Objective

Studies are found in the literature that describes tests employing inductive heating as a method for heating boron steel sheet. With induction heating it is possible to heat the steel sheet quickly with relatively small equipment. However, it is not fully investigated whether the corrosion protective coating is capable of withstanding rapid heating. Several studies show that the process have to have a hold time during the heating in order to allow the coating to diffuse into the sheet steel which is needed in order for the coating to remain intact. There is however other studies which show that it is possible to implement a rapid heating without this holding time and still get a coating that remains intact. Whether the coating can withstand a rapid heating by induction heating needed to be investigated further, focusing on the small-scale process that is of interest to the project partners in this project.

The other aspect that needed to be investigated is whether it was possible to heat smaller components quickly with inductive heating in a good way. The inductive heating process is complex. Above all, it is difficult to predict how the currents flow in a component, even if the component has a flat geometry. Hence, it is difficult to predict if a process is will generate a uniform heating. How this could be done and what problem that may occur was investigated in the project.

4. Project realization

The project was divided into three work packages with research content and a fourth work package containing project management as follows.

1. Definition of requirements for steel sheet details regarding mechanical properties and quality of the coating. Define one or more requirements that some selected components must meet.
2. Investigation of the commercial space. There are a number of patents in the field. How these may limit the continued technical and commercial development of the technology must be studied in order to provide the conditions for a future main project.
3. Investigation of the sheet material and how its coating is affected at different heating rates. The purpose is to examine in detail the impact on the coating depending on the heating rate where furnace heated samples are used as reference.
4. Continuous project management and reporting.

5. Results and deliverables

5.1 Patent investigation

This part of the project involved the investigation if there are patents that prevent us to continue to develop the technology as intended, and if so, how we should relate to these obstacles. Essentially, two existing patent where evaluated with the following results.

For one of the patents, DE102012021031, *Procedure and Device for the Production of presshardened Sheet Metal Components*, it was found that it was very widely drawn and basically includes what we want to do i.e. heating the boron steel with induction heating. The patent is still in the application stage, and was submitted for review 2012-10-27. The assessment shows that the application is very broad and it covers several other patents, which means that it will be difficult to get the patent approved as it now stands. Presumably, additional requirements that narrow down the patent will be required before the application can be granted. One can interpret this broad patent as a strategic document to prevent others from seeking patents in the field.

The second patent, WO2011131174, METHOD AND DEVICE FOR HOT FORMING AND HEAT TREATING OF COATED METAL SHEET, describes in principle the new concept of this project and goes into detail on how a two-stage variant of heating heats with inductors that will be designed in a specifica manner. However, differences between the process described in the patent application and the process evaluated in this pre-study were identified.

5.2 Process development

As a case study in this project a safety belt component was used. Already in the early stages experiments showed great challenges to get uniformly distributed heating as illustrated in Figure 1. In this picture you can see how the flat so called pancake inductor primarily heats the narrower sections of the buckle and the middle section of the piece is about 200 °C lower.

Figure 1 Overview of heating experiments with a flat pancake inductor.

After further work on the adaptation of process parameters and geometry of the inductor it was found that a more uniform distribution of heating could be achieved. The tests showed that the design of the inductor and the selected process parameters have a great impact on how uniformly distributed the heating becomes. Heating concepts needs to be specifically designed for each component to be manufactured using this technology.

Further tests were conducted to evaluate how the corrosion protective coating was affected by this rapid heating. This was done on simple rectangular geometries. Figure 2 illustrates how the sheet is heated to different temperatures for different hold times.

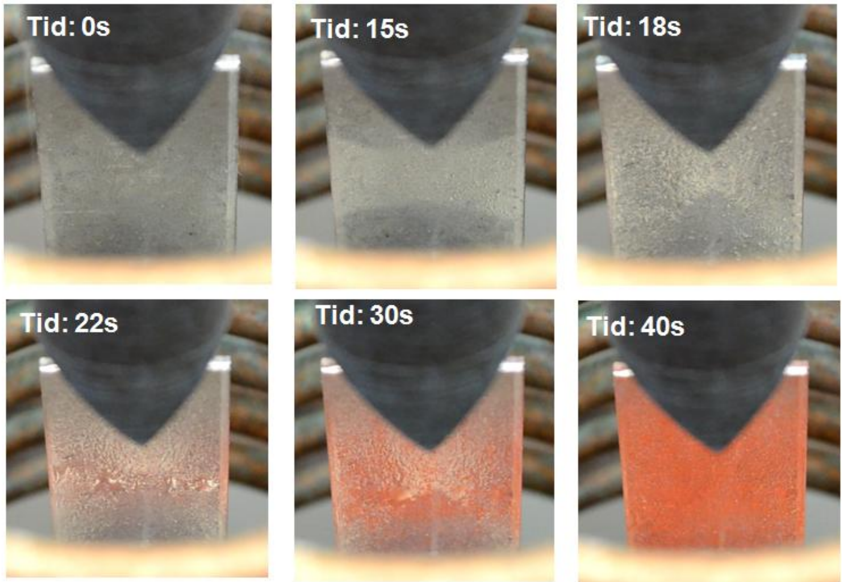

Figure 2 Overview of heating experiments with immersive inductor of rectangular samples.

The evaluation of the surface layers was made on cross section of the samples. From these cross-sectional measurements, one can evaluate whether the coating remains, how much cracks it contains and get an indication of if there has been some diffusion of the coating into the bulk and vice versa. What one can see is that samples in the non quenched state have two layers. The outer layer mainly contain aluminium with smaller inclusions of silicon. Under this layer, one can distinguish a layer having higher silicon content.

The evaluation of the cross sections shows that the layers are sensitive and demand care during sample preparation before evaluation. Figure 3 shows the results from test done with 20% heating power with different holding times. From this, one can clearly see that the layer is destroyed, the longer holding time that is used. Only the sample with the shortest holding time seems to keep the layer intact. This sample just had the layer melted before it was cooled. However, one cannot see much change in this layer compared to the unheated reference layer. In the layer with holding time of 30 seconds, one can distinguish some difference with more of the gray phase in the layer compared with the whiter aluminium-rich phase. For holding times longer than a minute the complete coating will crack and disappear altogether.

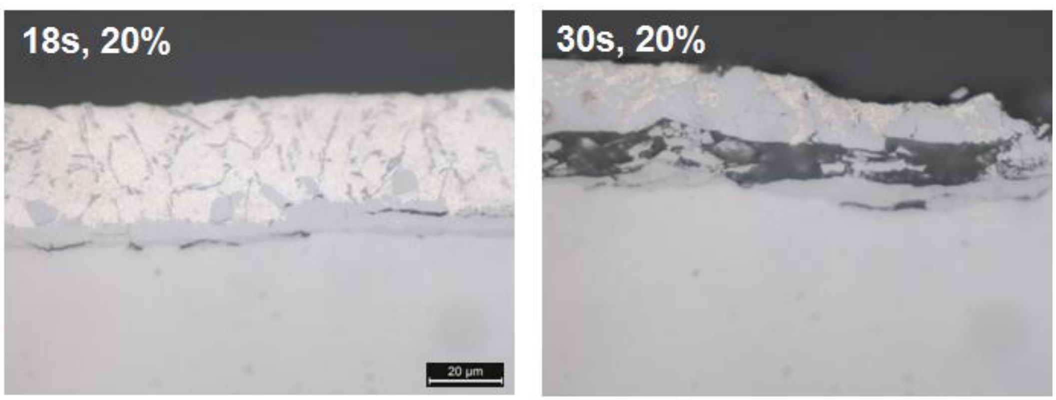

Figure 3 Overview of heating experiments with immersive inductor of rectangular samples for different holding times.

After continued testing a successful heating concept was found that generated samples with complete martensitic structure as well as intact coating according to Figure 4.

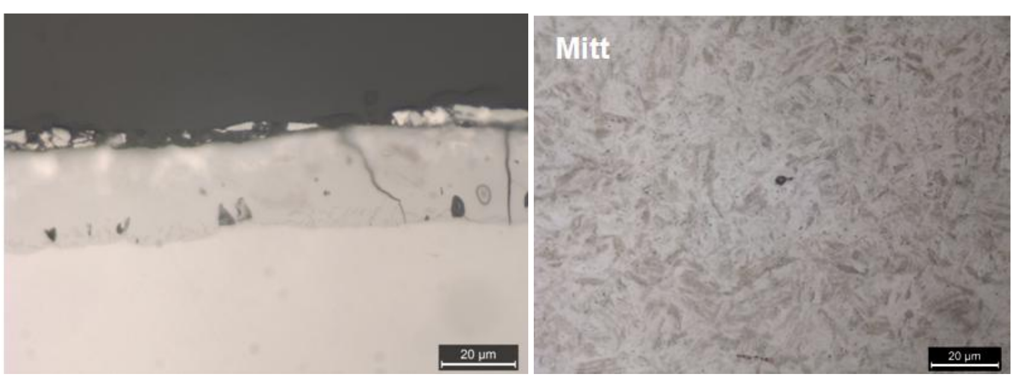

Figure 4, the left picture shows the retained coating on the steel sheet heated with a two-stage induction heating and the right picture shows the martensitic structure in the middle of the sample.

The results of this pre-study show above all a great opportunity for the investigated technology. However, in order to implement the technology further research has to be carried out in a main project. Regarding the objectives set for the FFI program these could not be reached for this short pre-study but certainly after a main project. As for the environmental aspect of the goals, this technology will enable vehicle with reduced weight with more use of higher strength boron steel. For individual components, it may also mean that much of both process and transportation costs can be reduced because the components do not have to be sent to external suppliers for hardening.

5.3 Delivery to FFI-goals

If a main project is successful and the technology can be implemented into production, it will give a clear competitive advantage both domestically but also internationally where Gnotec as component supplier will have a big advantage against their competitors and gain a clear role as the owner of this new manufacturing concept. The other participants in the project will also be taken to a new level and make tools and equipment for this new concept that is not available in the market at present.

Goals within the VINNOVA/FFI-program Fordonsutveckling	Project achievement of goals
Raise the technical level of maturity (by measuring the "technology readyness level", TRL), and streamline practices in product development for more rapidly industrialize results and increase customer value.	The goal will be met in a master project
Substantial (measurable) weight reduction	The goal will be met a main project where the new manufacturing concept enables the use of high strength steel with less weight.
Substantial cost reduction	The goal will be met in a master project that production concept will involve the processing steps such as hardening may be skipped.
Significantly better material properties	The objective is met when the use of boron steel means a much higher strength of the steel.

6. Dissemination and publications

6.1 Knowledge and results dissemination

The planned main project includes publishing suitable results from the project as scientific papers as we see that there is great interest in this technology and that the project is well advanced in the research front.

6.2 Publications

Non from this pre-study.

7. Conclusions and future research

The results of the project showed opportunities with this new technology but a total concept must be evaluated in a larger main project. This project identified a heating concept that created the conditions for a hardened material while maintaining the corrosion protection. However, the heating needs to be adapted to existing part geometries. This will govern the design of the heating concept and process settings as well as the design of heating inductors and cooling tools.

The critical test for approval of press hardened components is corrosion testing. This needs to be done for a larger series and in a more controlled manner in a future main project in order to validate the complete process.

8. Participating parties and contact person

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