Process Simulation of Resistance Weld Bonding and Automotive Light-weight Materials

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Abstract

This paper presents the latest developments in numerical simulation of resistance welding especially with the new functions for simulation of microstructures, weld bonding and spot welding of new light-weight materials.

The fundamental functions in SORPAS® are built on coupled modeling of mechanical, electrical, thermal and metallurgical processes, which are essential for simulation of resistance welding process to predict the welding results and evaluate the weldability of materials. These functions have been further extended with new functions for optimization of welding process parameters and predicting welding process window, for weld planning with optimal welding parameter settings, and for modeling microstructures and hardness distribution after welding.

Latest developments have been made on simulation of resistance welding with nonconductive materials for applications in weld bonding with combination of adhesive bonding and spot welding, and in spot welding of the new lightweight sandwich steels.

1. INTRODUCTION

Increasing demands on reduction of carbon dioxide (CO2) emissions from cars have intensified research and development with innovations on refining the engine technologies to increase fuel efficiency, improving the aerodynamics of cars, decreasing the rolling resistance and reducing the weight of cars.

For reducing the weight of cars, various new lightweight materials have been developed and introduced in manufacturing of cars including advanced high strength steels, hot-stamped steels, aluminum and magnesium alloys, and the new lightweight sandwich steels [1] with combination of plastic and steel sheets.

Resistance welding is one of the most productive and cost effective joining technologies widely applied especially in automotive industry. Comparing to resistance welding of conventional steels, it is much more challenging for welding the new lightweight materials and for welding conventional steels to the new lightweight materials.

Great efforts with a lot of experiments and studies have been made by material producers and manufacturing companies to understand the weldability of new materials and optimize the welding processes. For example, many companies have been facing problems with three-sheet spot welding of advanced high strength steels to low carbon steels.

The advantages of numerical simulations for resistance welding are obvious for saving time and reducing costs in product developments and process optimizations.

In the past three decades, a lot of theoretical developments and experimental verifications have been carried out for numerical simulations of resistance welding [2-7]. Recent developments with the welding software SORPAS® have also extended the process simulations to more comprehensive functions for process optimizations and weld planning for welding schedule settings near production [8-10].

In this paper, the recent developments are presented with the following new functions:

- Modeling of microstructures and hardness distribution after welding.
- Simulation of resistance weld bonding.
- Simulation of spot welding lightweight sandwich steels.

2. PROCESS SIMULATION AND OPTIMIZATION OF RESISTANCE WELDING

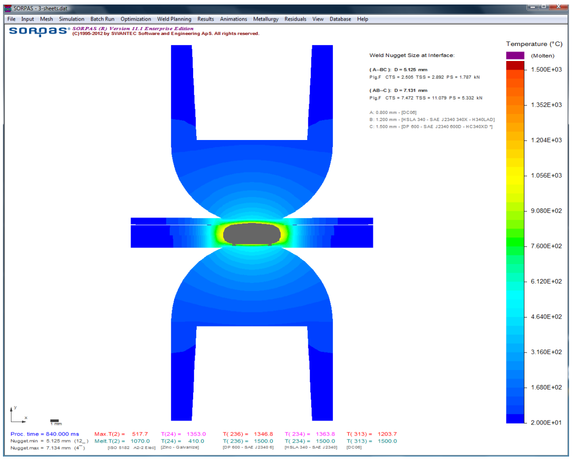
After more than ten years industrial applications, a lot of improvements have been made in SORPAS® on the accuracy and reliability of the numerical models for process simulations and optimizations. Some key functions are summarized in Figure 1.

Figure 1a shows an example of process simulation of three-sheet spot welding with 0.8 mm DC06 low carbon steel sheet, 1.2 mm HSLA340 steel sheet and 1.5 mm DP600 steel sheet. The electrode is Type F1 with a tip face diameter of ø6 mm. The results of simulation indicate the final welding nugget sizes of 5.1mm at the weld interface between DC06 and HSLA340 and 7.1mm at the weld interface between HSLA340 and DP600. The weld strengths are also predicted at each weld interface.

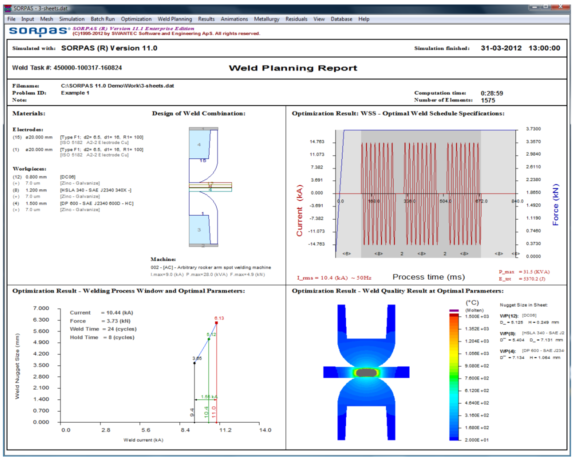
Figure 1b shows an example of the Weld Planning report for the abovementioned three-sheet spot welding. Based on the weld task description (WTD) with information of the sheets, electrodes and type of welding machine, SORPAS® automatically analyzes the sheet materials and thickness combination to determine the weld force and weld time and then obtain the welding process window with the range of weld current. Thereby the optimal Weld Schedule Specifications (WSS) can be obtained with the optimal weld current, force and time. This is a useful function for setting up the start welding process parameters.

Figure 1c shows an example of the simulated weld growth curve for spot welding of 1.0mm low carbon steel sheets with weld nugget diameters increasing as function of the weld current. The black points (square markers at the left side) mean no weld or undersized weld. The red points (square markers at the right side) indicate expulsions (or splashes). The green points (round markers) in the middle are good welds. The welding process window is indicated on the weld growth curve with the working range of weld current.

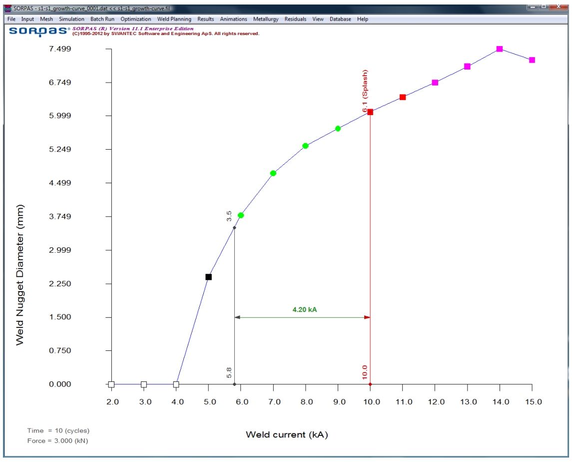
Figure 1d shows an example of the simulated weldability lobes for spot welding of 1.0 mm low carbon steel sheets with varying weld current and force at a given weld time. The black points (open and solid square markers at the left side) are no weld or undersized welds. The red points (square markers at the right side) are oversized or expulsion (splash) welds. The green points (round markers) indicate the process window and range of good welds.



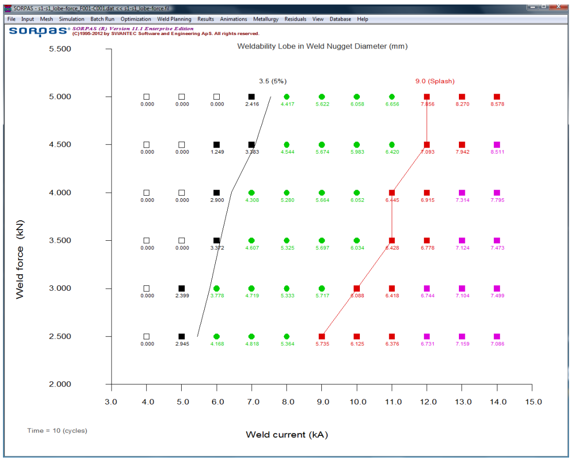
(a) Resistance welding process simulation.



(b) Weld planning for optimal welding parameters.



(c) Weld growth curve with welding process window.



(d) Weldability lobe with welding process window.

Figure 1: Process simulation and optimization with SORPAS®.

3. MODELING OF MICROSTRUCTURES AND HARDNESS DISTRIBUTION AFTER WELDING

The microstructures and hardness distribution after welding are modeled with the simulated cooling rates and metallurgical data of materials.

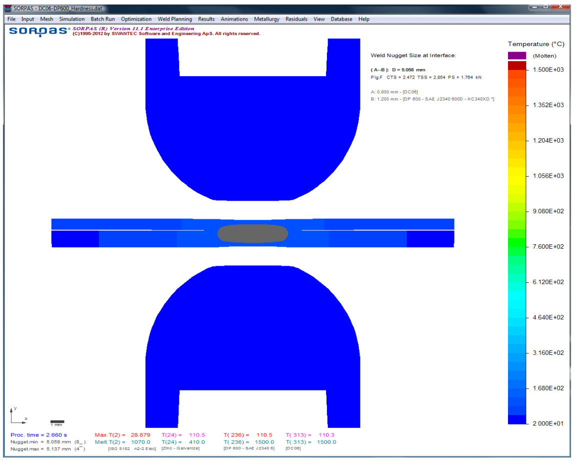
Figure 2 shows an example of metallurgical modeling for spot welding of 0.8 mm DC06 low carbon steel to 1.2 mm DP600 steel.

Figure 2a shows the final weld nugget form and weld nugget sizes.

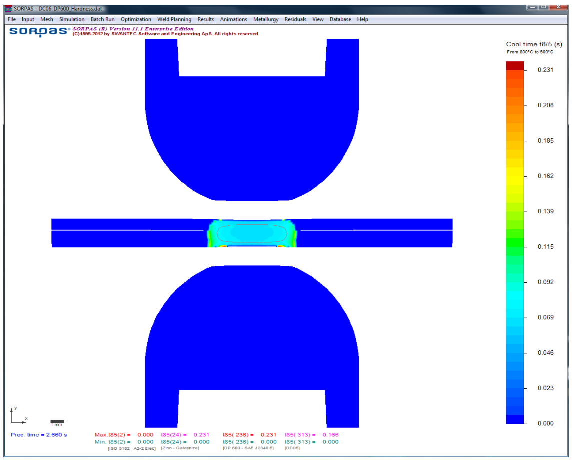
Figure 2b shows the cooling time from 800°C to 500°C calculated during simulation of the cooling process after welding. They are used for calculating the cooling rates thereby modeling the transformation of phases with reference to the continuous cooling transformation (CCT) diagrams of the materials.

Figure 2c shows the distribution of pearlite/ferrite, where the cooling rates after welding are lower than the critical cooling rate for pearlite/ferrite formation. Figure 2d shows the distribution of bainite. Figure 2e shows the distribution of martensite, where the cooling rates are higher than the critical cooling rate for martensite formation.

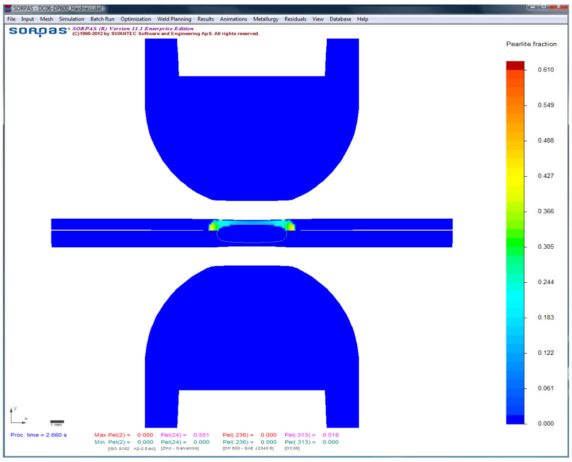
Figure 2f shows the distribution of hardness obtained by combining the hardness contribution of all phases.



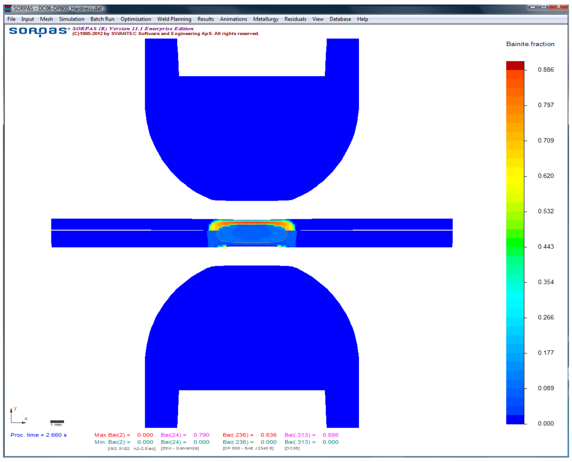
(a) Weld nugget form and sizes.



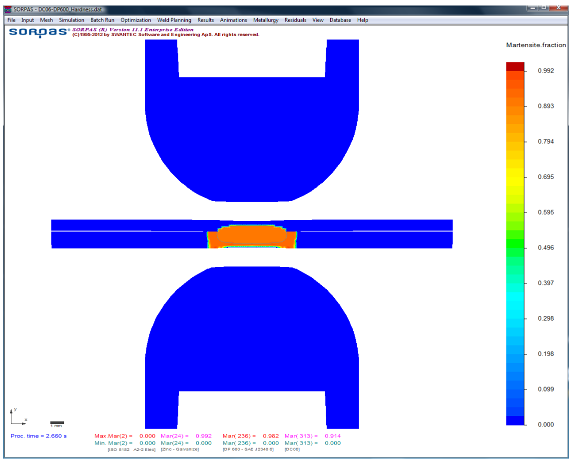
(b) Cooling time from 800°C to 500°C.



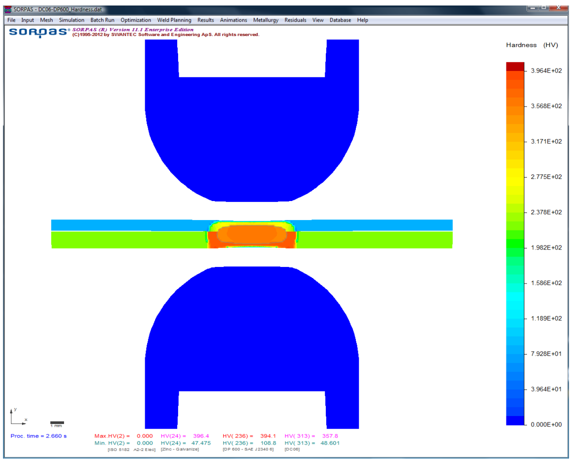
(c) Distribution of pearlite/ferrite.



(d) Distribution of bainite.



(e) Distribution of martensite.



(f) Distribution of hardness.

Figure 2: Simulation results with microstructures and hardness distribution.

4. SIMULATION OF RESISTANCE WELD BONDING

Weld bonding is a combination of conventional resistance spot welding and adhesive bonding. It can significantly improve the static, dynamic and impact toughness and stiffness as well as the corrosion and noise resistance of sheet metal joints.

Figure 3 shows a schematic outline of the process of weld bonding in which the adhesive is applied to the faying surfaces of the sheets to be joined and subsequently spot-welded.

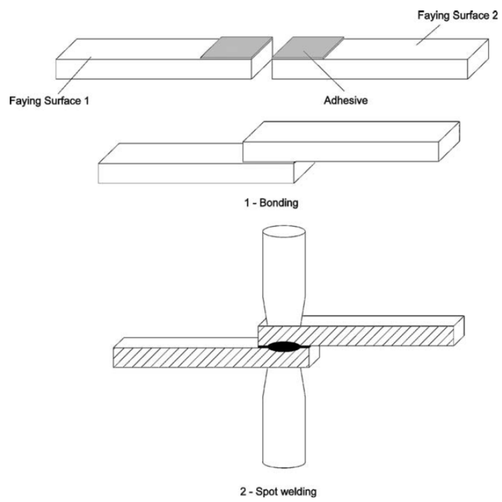


Figure 3: Schematic outline of the weld bonding process [11].

Depending on the viscosity and the curing condition of the adhesives, there are two situations:

- The adhesive layer is fluid and fully squeezed out of the weld zone under weld force before welding thereby allowing current flow between sheets to start spot welding.
- The adhesive layer is thick enough to separate the sheets thereby preventing current flow between sheets at beginning of spot welding.

In the first case, the weld bonding may be realized similar to spot welding. The simulation can also be done simply by increasing the contact resistance between sheets to take into account the influence of the adhesives at the contact interface [11].

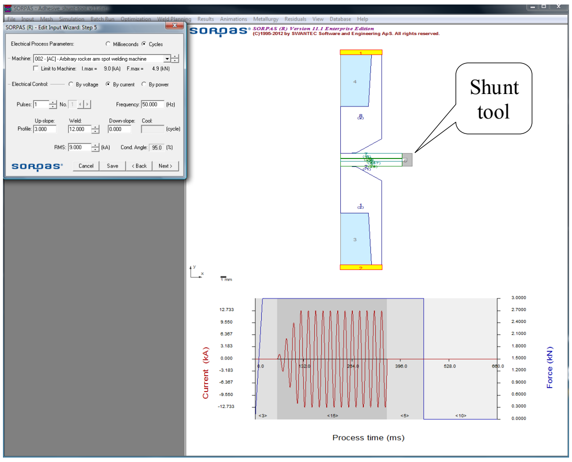
In the second case, the weld current cannot flow directly through the weld interface. The spot welding can only be realized with help of a shunt connection to allow current flow in the sheets at beginning of spot welding. When the weld current flows in the sheets through the shunt connection, the sheets will be heated up thus melting down the adhesive thereby bringing the sheets into contact. The spot welding can then be realized.

Figure 4 shows an example for modeling of weld bonding of two 1 mm low carbon steel sheets with nonconductive adhesives.

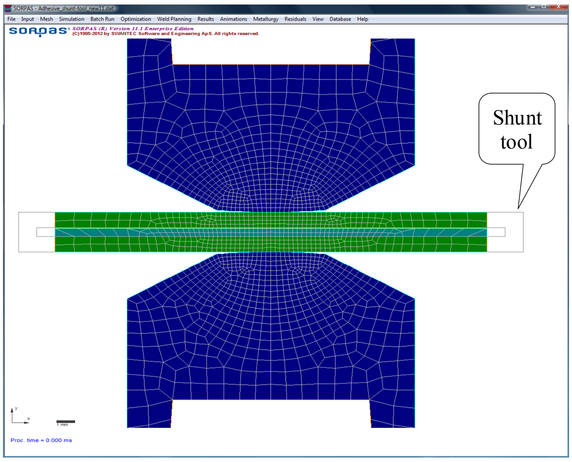
Figure 4a and Figure 4b show the models of sheets and adhesive with shunt connection tool.

Figure 4c shows the weld current distribution in the sheets before breaking down of the adhesive layer. The current flows in the sheets through the shunt connection tool but no current flows crossing the weld interface. Figure 4d shows the weld current distribution after breaking down of the adhesive layer with current flow directly crossing the weld interface.

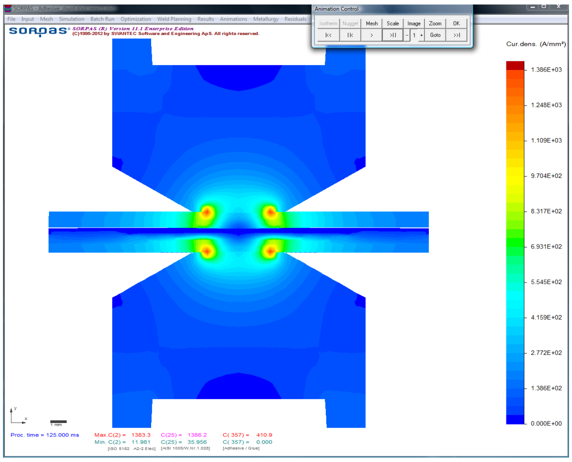
Figure 4e shows the temperature distribution immediately after breaking down of the adhesive layer. Figure 4f shows the final spot weld nugget.



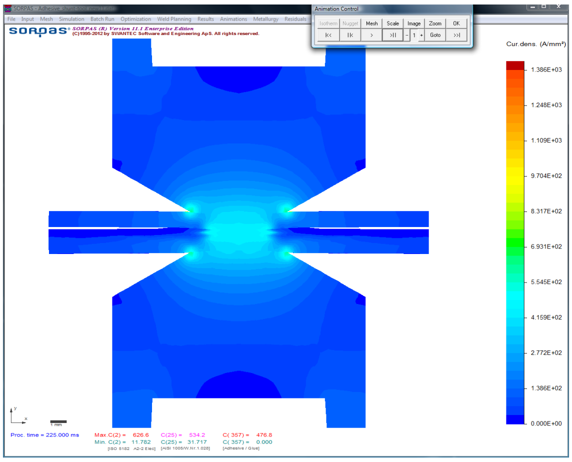
(a) Shunt connection tool and welding parameters.



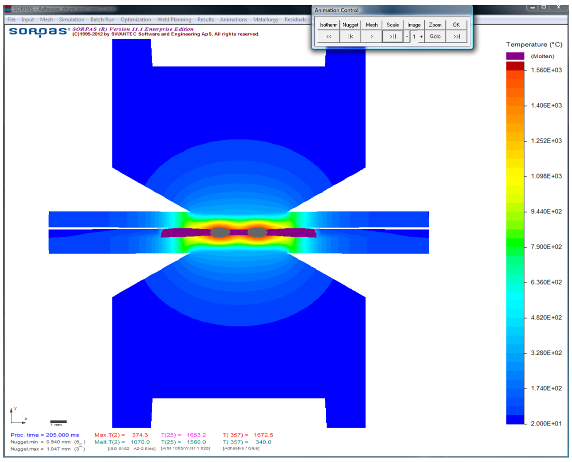
(b) Mesh of weld bonding model with shunt tool.



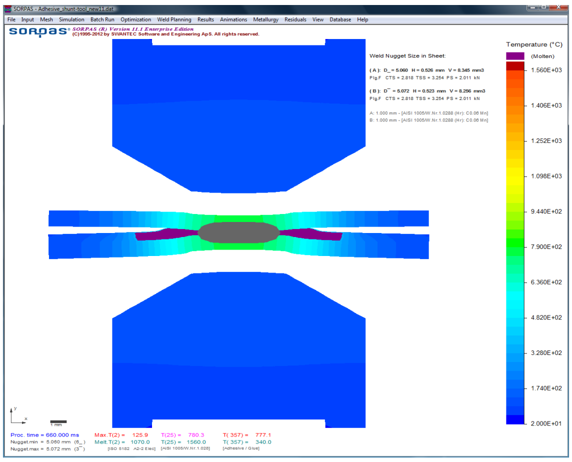
(c) Current flow in sheets through shunt tool.



(d) Current flow through contact between sheets.



(e) Heating and breaking through the adhesive layer.



(f) Final spot weld nugget formation.

Figure 4: Simulation of weld bonding with nonconductive adhesive.

5. SIMULATION OF SPOT WELDING LIGHTWEIGHT SANDWICH STEELS

With intensifying climate debate on reduction of CO2 emission and increasing demands on cost efficiency, various new lightweight materials have been developed and invented for automotive applications. These lightweight materials include high strength steels, hot-stamped steels, aluminum and magnesium alloys, and the new lightweight sandwich steels.

The sandwich steel is a newly invented lightweight material by ThyssenKrupp Steel, which is produced with two thin outer layers of 0.2-0.3mm steel sheets and a core of 0.4-1.0mm polymer compound, see Figure 5 [1].

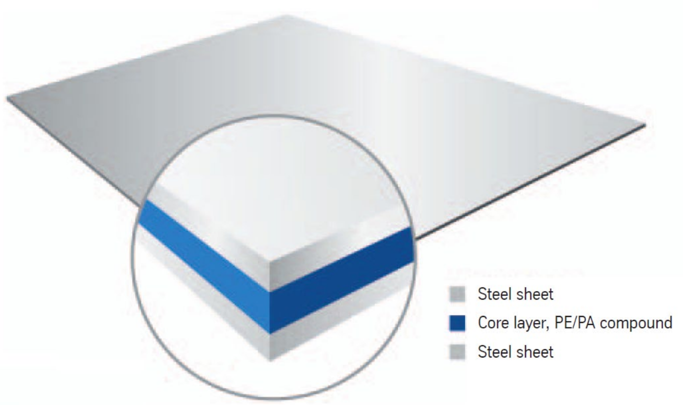


Figure 5: Structure of sandwich steel invented by ThyssenKrupp Steel [1].

Taking the car roof as an example, Figure 6 illustrates the global warming potential estimated over the life cycle of a car by comparing the production and weight effects of different materials. Due to much higher energy consumption for production of aluminum, its advantage of lightweight is only meaningful comparing to the conventional mild steel, whereas the advantage of the new lightweight sandwich steel is quite obvious [1].

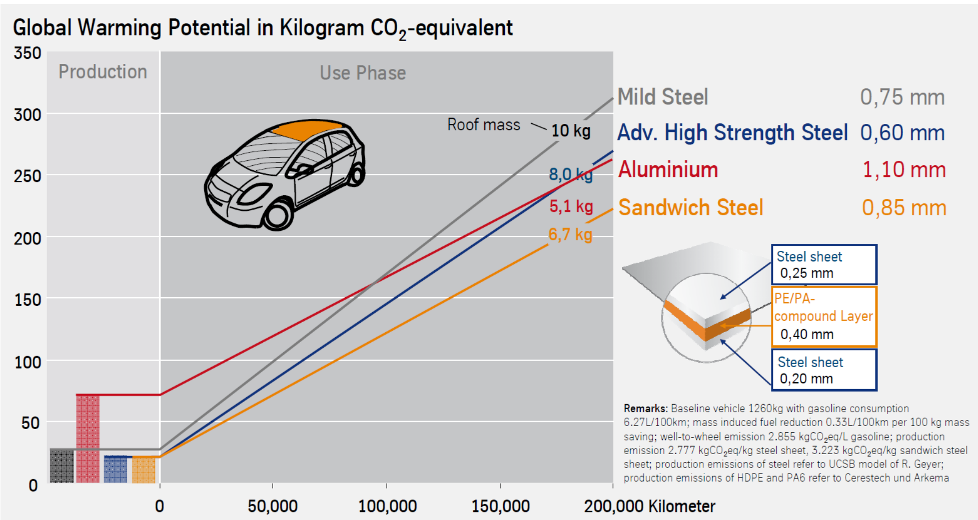
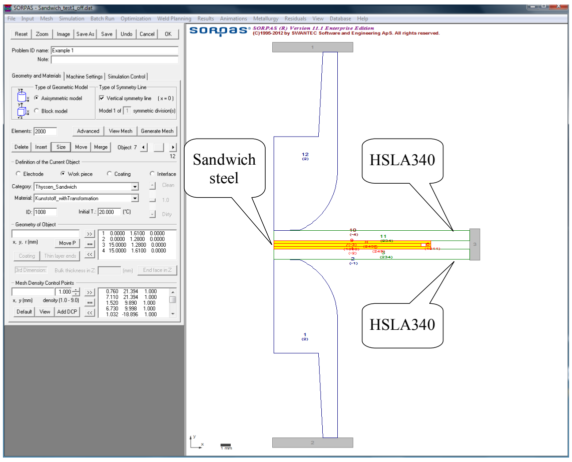


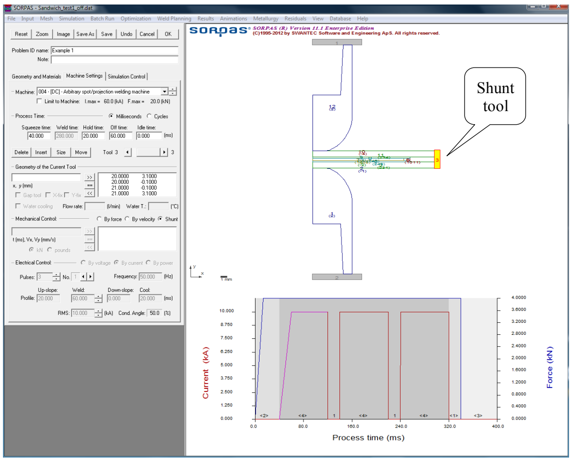
Figure 6: Comparative life cycle assessment of car roof [1].

Preliminary studies by ThyssenKrupp Steel have proved that the lightweight sandwich steels can be resistance spot welded to other steel sheets with a special setup of shunt connection.

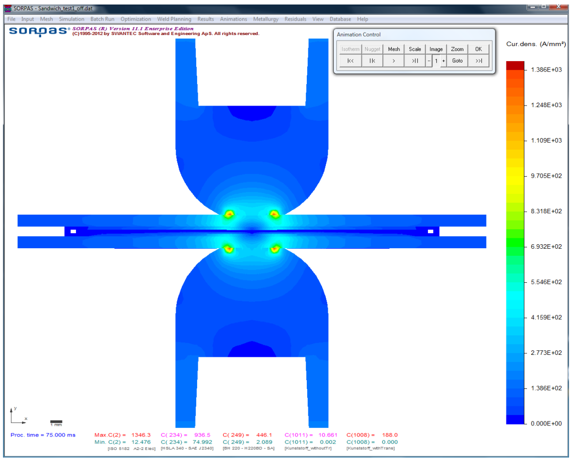
Figure 7 shows the numerical modeling of spot welding of the sandwich steel to two sheets of HSLA 340. To realize the spot welding, a shunt tool is introduced for electric conduction between sheets at beginning of spot welding.



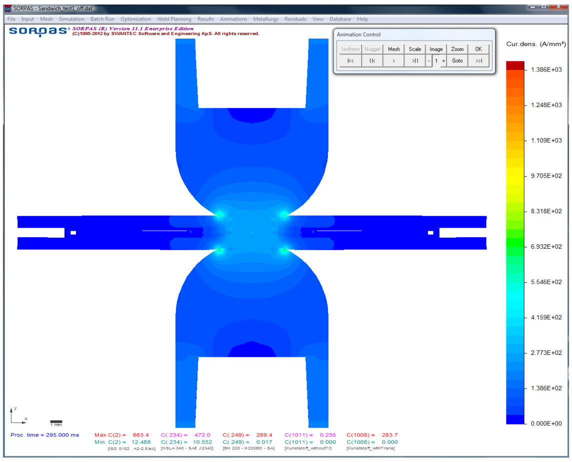
(a) Model of sandwich steel with a polymer core.



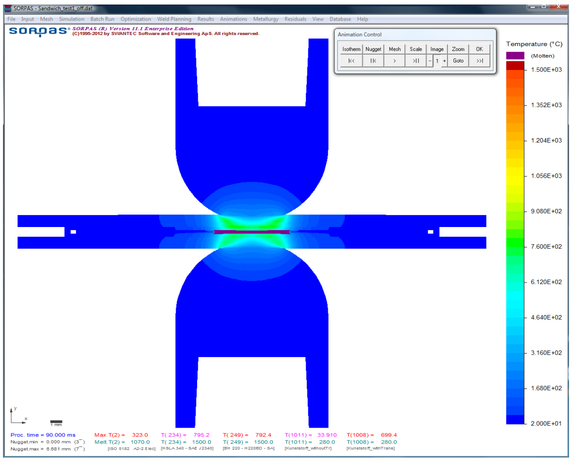
(b) Model of weld combination with shunt tool.



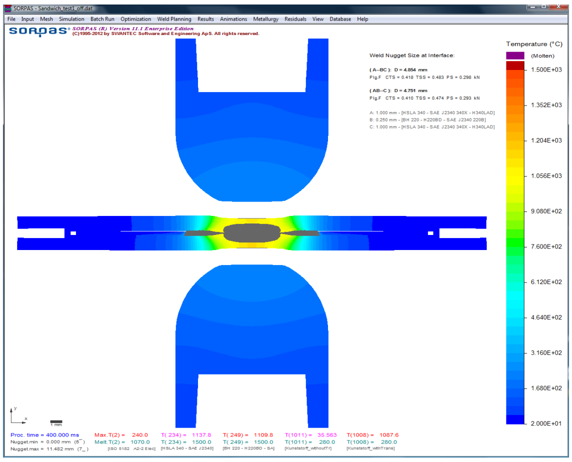
(c) Current flow in sheets through shunt tool.



(d) Current flow through contact between sheets.



(e) Heating and breaking through the polymer core.



(f) Final spot weld nugget formation.

Figure 7: Simulation of spot welding of sandwich steel to two HSLA340 sheets.

In order to realize the simulation of spot welding of sandwich steel, special material data have been prepared and implemented for the polymer core material in the material database.

Similar to the simulation of weld bonding, the shunt tool is introduced for conducting current in the sheets through the shunt connection, see Figure 7a-7d. When the sheets are heated up, the polymer core in the sandwich steel will be melted and the outer sheets of the sandwich steel will be pressed into contact under the weld force, see Figure 7e. Therefore, the spot welding process will be realized when the steel sheets getting into contact, see Figure 7f.

6. CONCLUSIONS

Numerical simulations and optimizations of resistance welding are summarized with key functions with process simulations for evaluation of the weldability of new materials and process optimizations for planning and setting up welding process parameters.

New functions are developed and implemented for modeling of microstructures and hardness distribution after welding of steels.

Special functions are developed and implemented for modeling of nonconductive materials and for simulation of weld bonding and spot welding of lightweight sandwich steels with shunt tools.

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