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Joining TWIP-Steel Simulation Models

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Abstract

JoiningTWIP project aims to support the introduction of TWIP-steels for automotive applications (in cars, trucks and buses) by identifying possible applications and further developing mechanical and low-heat joining technologies to be able to implement multi-material design with TWIP-steels. To guarantee a full view of the project team members from steel industry, car manufacturers, joining technology suppliers and universities are working together.

This work describes the simulation stage of the different technologies. During the project, the materials described in the scope of the project were tested in order to obtain material characterization. Also, the different multi-material joints were tested to describe the joining process and the joining quality. These results will be used to build complex simulation models and prototypes, which show the performance and the behavior of the joining processes of TWIP-steels. Five different technologies were analyzed in the scope of the project: clinching, high-speed bolt setting, resistance element welding (REW), friction element welding (FEW) and flow drill screwing (FDS). To guarantee the performance of the simulation models, the results were compared to the sampled joint and processes. An optimization process of the different technologies was applied to improve the quality and the performance of the different joints.

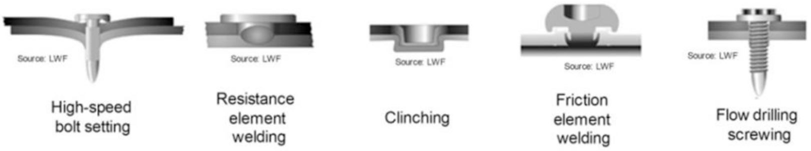

Fig. 1. Technologies described in the JoiningTWIP project

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1. Introduction

JoiningTWIP supports the introduction of TWIP-steels in applications for automotive and transportation industry as well as public transportation by providing reliable joining technologies for multi-material design of TWIP-steels with conventional steels and lightweight materials (Aluminum, CFRP/GFRP). The partners involved are steel makers ThyssenKrupp Steel Europe GmbH, Salzgitter Mannesmann Forschung GmbH (both from Germany), the supplier for joining technology EJOT GmbH (Germany), a service provider in steel research COMTES FHT (Czech Republic), the research entity of automotive manufacturer Fiat Centro Ricerche Fiat (Italy) and universities Leibniz-University Hannover (UWTH) and the University of Paderborn (LWF), both from Germany.

The structure of the project starts identifying the car body applications where TWIP-steels can be used. As a result of this survey, the joining tasks for multi-material design will be defined. After that, a new state of the art concerning the proposed mechanical and low heat joining technologies will be elaborated. In addition, all materials for JoiningTWIP will be characterized in static tensile tests, high rate tests and in fatigue tests. First joining trials will be performed adjusting the processes, the element geometries or their coatings. The measures of optimization will be accompanied by FE-simulations, where strategies to optimize joints will be virtually tested. After that, the joints will be fully characterized according to the needs of the future applications.

The chosen technologies described in the scope of the project are Clinching, High Speed Bolt Setting, Resistance Element Welding (REW), Friction Element Welding (FEW) and Flow Drill Screwing (FDS). This work is focused on the description of the simulation process and evaluation of its results comparing them with the tests performed by the partners of the project.

2. Material model

Five different sheet materials were used for joint combinations: TWIPSteel, DP600, 22MnB5, Al6000 and Tepex. The material behavior of metallic materials during the simulation can be characterized considering the mechanical, thermal and electrical model. These models are sufficient to describe the behaviour of the different materials for all the technologies described in this project. In order to create these models, the data obtained during the experimental phase was analyzed (quasistatic, high strain rate, fatigue...). To complete the material behaviour for the different models (mechanical, thermal and electrical), JMatPro (2016) software was employed to create the prediction of the material properties using the chemical composition of the material.

2.1. Mechanical model

The mechanical model can be described in a simplified manner by a tension test. Generally, tension tests present three different regions in the way that the material performs. The first segment of the tension test is the elastic region described by the Hooke's Law given by the Poisson ratio (ν) and the Young modulus (E). The second region is the plastic segment that can be described with the Johnson-Cook model, because it can reflect the influence of strain rate and temperature:

$$\sigma_y = \left(\boldsymbol{A} + \boldsymbol{B}\bar{\varepsilon}^{p^{\boldsymbol{n}}}\right)\left(1 + \boldsymbol{C}\ln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)\right)\left(1 - \left(\frac{T - T_{room}}{T_{melt} - T_{room}}\right)^{\boldsymbol{m}}\right)$$

To define the flow stress behavior, the tensile test at different strain rates (quasistatic, 1, 10 and 100 [s^{-1}]) and room temperature (25°C) were considered. To complete the material behavior at different temperatures, the JMatPro software was employed to create the prediction using the chemical composition of the material. Five parameters (A,B,n,C and m) and the constants are fitted to obtain the stress behavior shown in the test and the JMatPro prediction.

The third region of the test is the fracture region. In order to define the fracture model, it is necessary to take all the tests performed for each material into account. Although, the damage or fracture models are really dependent on the application and the mesh size, so the models will be fitted and adapted to each technology and element size. The fracture models used and considered are: Cocroft-Latham, Gurson, Johnson-Cook...

2.2. Thermal and electrical model

The thermal model is described using three material parameters: thermal conductivity, specific heat and density. Density was considered as a constant for all used material ($\rho Fe=7850kg/m^3$ and $\rho Al=2625kg/m^3$) and the rest of the properties were considered as temperature dependent function using the JMatPro prediction.

Electrical properties of the material are described by electrical resistivity (ρ). The temperature dependent values of electrical resistivity were generated by JMatPro software.

2.3. Tepex

Tepex is the only non-metallic material used in the project. The material parameters identification was created using the tests performed by CRF and the datasheet of the Tepex material. This material can be analyzed in two different conditions: dry and wet in accordance to Fiat standards. The behavior of the Tepex presents a different behavior in both conditions. It also behaves differently according to the load that is applied to it. It is possible to see that there is a small difference between wet and dry conditions, but there is a bigger difference in the orientation of the loads to the fibers.

JMatPro software cannot be used for predicting the Tepex material properties. These properties were obtained using the information gathered in the material datasheet as density 1.8 [g/cm^3], melting temperature 220 [°C] and thermal expansion coefficient 17 [e^{-6} 1/K]. The material will be considered as non-conductive material.

3. Clinching

Clinching creates a permanent joint by partially drawing, subsequent compression and radial extrusion. During the clinching process the sheets are formed by the punch and die to generate the interlock *f* between the punch-sided and the die-sided sheet metal.

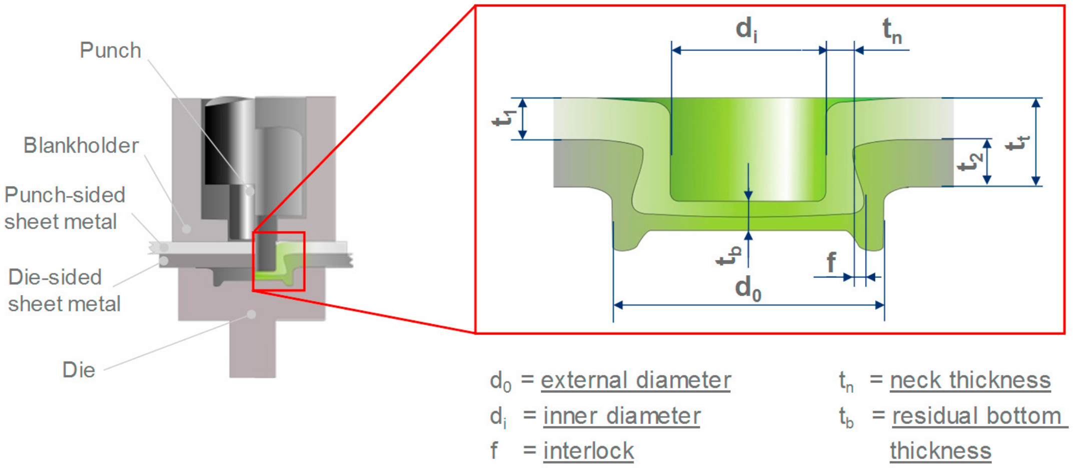

Fig. 2. Qualitiy criteria and referenced dimension on a clinching joint section

For this technology, the scope of project has defined four different material combinations, using TWIP-steel, DP600 and Aluminium, as done for the testing of the joining process and that can be seen in the following table:

Table 1. Clinching material combinations

Clinching combinations	1	2	3	4
Punch side sheet	DP600 (1.5mm)	TWIP (1.4mm)	AA6000 (1mm)	TWIP (1.4mm)
Die side sheet	TWIP (1.4mm)	DP600 (1.5mm)	TWIP (1.4mm)	AA6000 (1mm)

This technology was simulated using MSC Marc. A 2D axisymmetric model with implicit solver has been chosen in order to reduce the calculation time. The size of the element was set to 0.1mm for all combinations and a remeshing procedure was implemented to maintain the element size (considering the strain changes, the body penetration and the mesh density)

The geometry consists of two sheets, die, punch and blankholder (Fig. 2). The dimensions of the models were created using the tool codes provided by LWF. The geometries punch, die and blankholder are considered as solid.

The only process parameters provided are the blankholder force (used as a simulation input) and the total press force (used to compare the results). As the information of the process time has not been given, the process has been defined as static with 1 second duration for all material combinations (approx. similar to the joining process). The displacement of the piston related to the die is adapted to obtain the same residual bottom thickness.

Contact conditions were adapted in order to achieve results that follow the shape obtained during the sample testing. The simulations were performed using Coulomb friction condition (Fig. 3). Values of friction coefficient were obtained from literature and adapted to obtain accurate results.

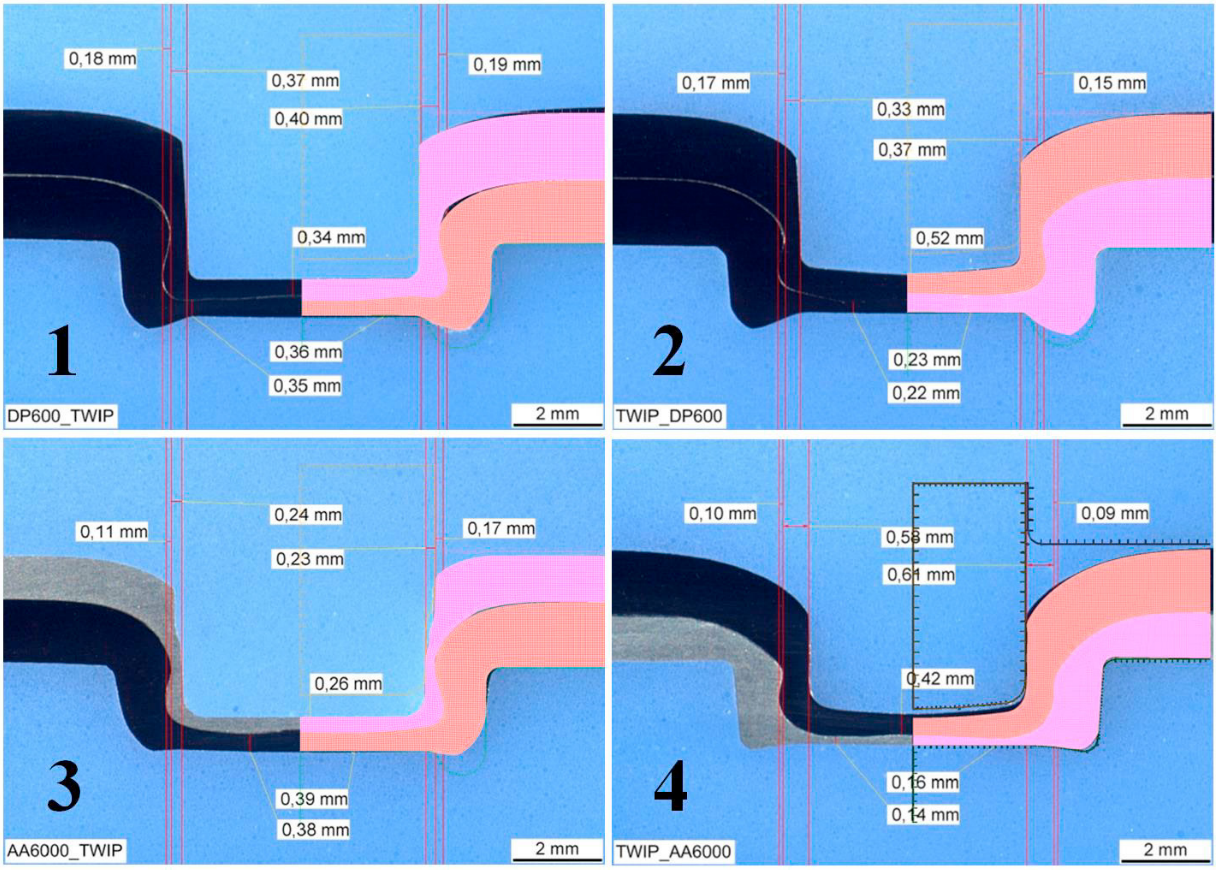

Fig. 3. Clinching simulation results

Clinching simulation results show a good correspondence with the reality observed in the testing stage, predicting both the final shape and the total press force of the actual joining process. The material data provided is enough to describe this joining process because low temperature and conventional strain rate is reached during the process. The process parameters are not defined completely, only providing data of the total press force and blankholder but no time reference. The tools geometry is just described using naming codes and pictures of the sample sections which are not accurate enough to simulate the process accurately.

The biggest problem to predict the behaviour of the process happens in the TWIP-Al6000 combination because there is a big influence of the geometry of the sample and the material inside the die has to fill the whole geometry (as seen in AA6000 and TWIP combinations). Also, there are some discrepancies due to lack of process parameters but with a lower influence in the results.

4. High speed bolt setting

High-speed bolt setting (also named tack setting) is a joining technology which allows one-sided accessibility. The nail-like auxiliary joining part is accelerated to 20-40 m/s and directly driven into to joining components. Furthermore, especially at high strength materials like TWIP-steels, the connection is realized by springback of the materials which results in compressive forces on the tack-shank.

For this technology, the scope of project has defined four different material combinations, using TWIP-steel, DP600, aluminum (extruded profile) and Tepex as done for the testing of the joining process:

Table 2. High speed bolt setting material combinations

High speed bolt setting combinations	1	2	3	4
Cover sheet	TWIP (1.4mm)	DP600 (1.5mm)	TWIP (1.4mm)	TWIP (1.4mm)
Base material	DP600 (1.5mm)	TWIP (1.4mm)	AA6000 (3mm)	Tepex (1mm)

This technology was simulated using ABAQUS FEM. A 2D axisymmetric model with the explicit solver has been chosen to reduce calculation time. The geometry of each combination consists of two sheets, tack, tube and support (Fig. 4). The dimensions of the geometries were created using the models provided by LWF and the geometry of the tack was created measuring the dimensions of the actual tack.

Only the sheets are defined as deformable body. The size of the element was set to 0.05 mm for deformable bodies. The tools (tack, tube, support) have been defined as rigid body. As the tack material identification is not reflected in the scope of the project and the data is not enough to create the material model, it was defined as rigid, simplifying the simulation process and the interactions between bodies.

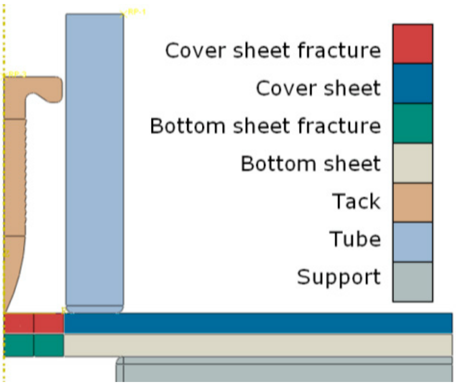

Fig. 4. Tack setting geometric model

Process parameters provided are described by pictures of the graphs for each process. The parameters described in the graph are the displacement of the piston and the force measured in the top of the machine based on the reaction force caused by the displacement of the piston. Based on the initial displacement slope, the initial velocity of the tack when reaching the plate has been calculated. The velocity was about 24 m/s, depending on each material combination. It was also included the information of the pressure applied to the pneumatic piston as a total value.

The fracture has been modelled using the Johnson-Cook criterion (available only in Abaqus/Explicit), it is a special case of the ductile criterion in which the equivalent plastic strain at the onset of damage is assumed to be a function of the triaxiality, strain rate and temperature:

$$\bar{\varepsilon}_D^{pl} = [d_1 + d_2\exp(-d_3\eta)]\left[1 + d_4\ln\left(\frac{\dot{\bar{\varepsilon}}^{pl}}{\dot{\varepsilon}_0}\right)\right]\left(1 + d_5\hat{\theta}\right)$$

For the evaluation, only the $d_1 - d_3$ parameters have been considered, excluding the functional dependence on strain rate and temperature (due to the lack of data) (Arias). The influence of strain rate on damage was included based on the evaluation of material data for strain rate 10s-1 (changes of strain rate can be denied for all materials). The parameters have been adjusted for each material comparing the calculated engineering stress-strain curves with measured tensile test curves (Fig. 5).

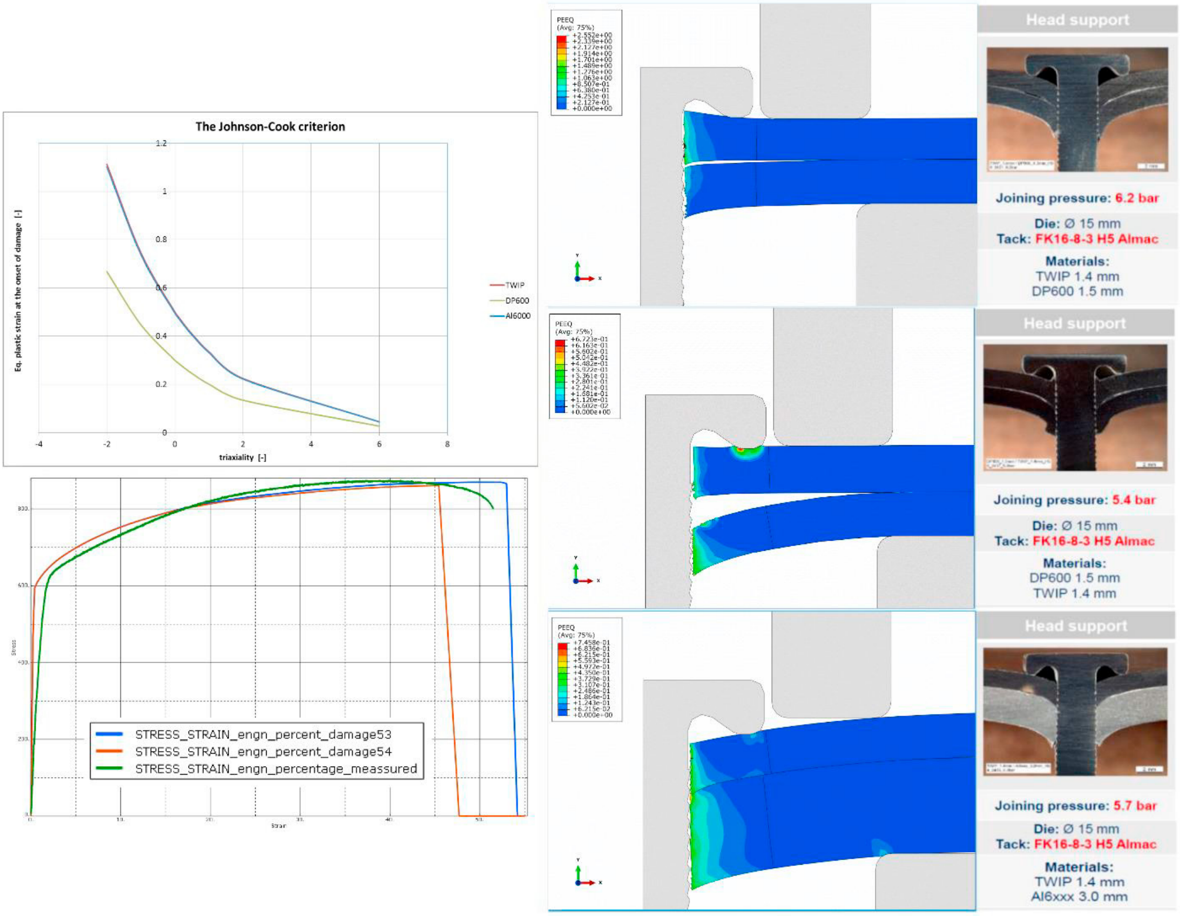

Fig. 5. (left)Johnson-Cook model and calibration example (right) simulation results

The simulations were performed using the Coulomb friction condition with 0.15 constant factor. The results obtained with the simulation were compared with the shape of the tested samples, comparing the geometry provided by LWF.

It is difficult to compare the results obtained in the simulation and the actual high speed bolt setting. The process parameters provided are not sufficient to describe the process and to compare the results achieved. So far, the only way to compare the results obtained is the final geometry. For the material combination of DP600-TWIP the results are not fully comparable with the shape obtained with physical tests, the bottom sheet is more bent than the bottom sheet in the real process. The other two combinations, TWIP-Al6000 and TWIP-DP600, have a shape similar to the real process. The main differences can be attributed to a bad definition of the process parameters, the friction conditions and the fracture model that eliminates elements and creates a different behaviour. Further steps will be using the definition of the process parameters using tabular data and adapting the fracture model for higher strain rates.

The main limitation is the accuracy of the damage model, based only on the tensile test. Due to this, further material tests will be conducted to better represent the negative triaxiality which is a main stress state represented during tack penetration. Drop Weight Tower tests will be performed to physically simulate the joining process. The weight of the tower has to be adapted to drive the tack through the material. Different material acquisition devices will be used during the process to gain the information of the test (high speed cameras...). The 3D model of the setup is described in (Fig. 6).

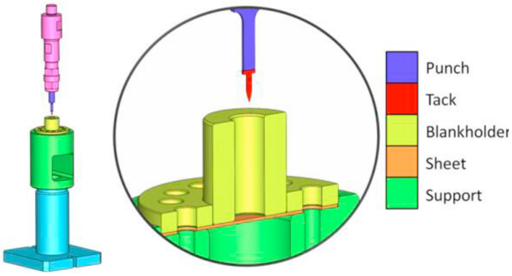

Fig. 6. Bolt setting testing 3D model

5. Resistance element welding (REW), Friction element welding (FEW) and Flow drill screwing (FDS)

These technologies are not explained in this work, just presented. Resistance element welding is an innovative thermal-mechanical joining technology based on an intelligent combination of thermal (metallic bond) and mechanical (force fit) joining principles. Using an auxiliary joining part, called welding rivet, the technology enables the usage of conventional resistance welding equipment. The welding rivet is made of steel and allows the welding with the steel-member. The joining technology is invented for multi-material-design, especially for aluminum-steel-combinations.

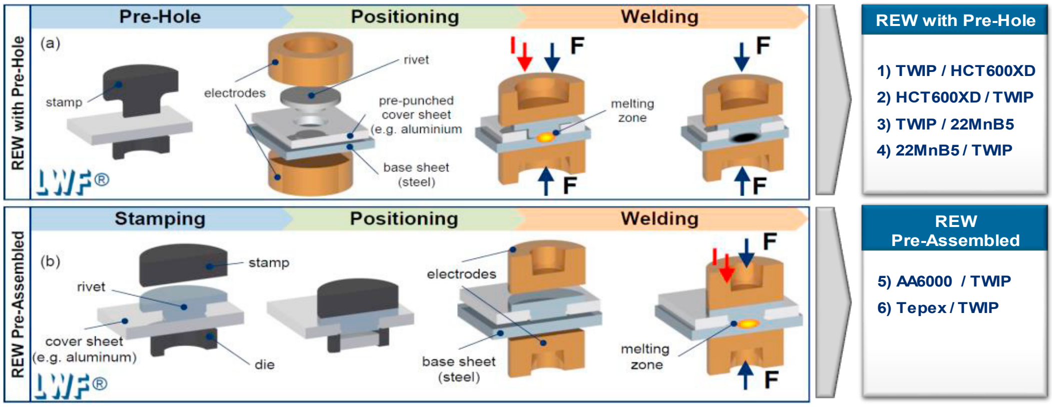

Fig. 7. REW sequence process and variants

Friction element welding (FEW) combines mechanical and thermal joining processes. This joining method is particularly suitable for multi-material assembly tasks (Fig. 8). Depending on the used materials, the joint can be made with or without pre-punching of the cover sheet. The joining direction was pre-determined because of material combination and was only possible from the softer to the harder material. By using a special weld element, the pre-hole operation was not necessary for both combinations (Awang 2005).

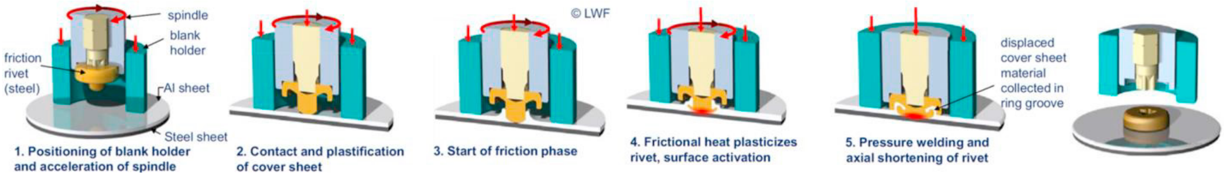

Fig. 8. FEW sequence process

Flow drill screwing (FDS) is a combination of the working principles flow punch forming and thread forming (Fig. 9). This joining technology allows joining two components without pre-holing in one process-step. The strength of these joints is comparable to the strength of rivet-nuts and welding nuts. First an extrusion is formed by high axial forces, high rotation speed and warming by friction. After that a female machine thread is formed. In case of service, one can loosen the screw and replace it by a conventional one.

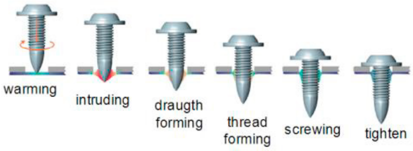

Fig. 9. FDS sequence process

6. Conclusions

At the present, the simulation models of all technologies have been created. Clinching and High speed tack bolt setting show a good correspondence with the real process. Resistance Element Welding and Friction Element Welding are not defined in this work but they are still in the trial stage.

The main problems at the moment are the lack of real material properties (thermal, electrical, friction and damage) and the lack of process parameters for some of the simulations limits the accuracy of the results and makes the comparison of the final geometry the only way to validate the obtained results.

As the project is now at its midterm stage, some of these problems will be solved in the future. The partners of the project will collaborate to provide more accurate material and process data to achieve the expected results for the simulation process of the technologies. Also, new simulations will be performed with different software to calibrate and compare the predicted results by the first simulations.

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