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Clinching with divided punch to prevent critical neck thicknesses

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Abstract. Clinching thin sheet metal into a thicker part can result in low neck thicknesses or even neck cracks. How these critical low values for neck thickness can be counteracted is described in this paper, using a two-part punch, which is devided in an inner and outer unit. At the beginning, both move parallel in the direction of the die until the outer punch stops at a defined position and only the inner one moves further down and forms the clinch point, with its characteristic contour and the geometric values of interlock and neck thickness. Due to the large punch diameter at the beginning of the process, more material initially flows into the neck area than in conventional clinching, so that a greater neck thickness can be achieved. Numerical simulation was used to create the concept and verify it experimentally. The greater neck thickness has a positive effect on the shear tensile strength and can also be transferred to the typical joining direction for clinching (thick into thin material).

Introduction

Mechanical joining technology is widely used to join different sheet materials with different thicknesses and tensile strengths. In contrast to welding, for example, the sheet metal partners can be of different types, as is the case when steel is joined into aluminum. Depending on the specific joining process, there is a recommended arrangement of the sheets (see Fig. 1). For example, in self-pierce riveting, the thinner part, which is more difficult to form, should be positioned on the punch side for optimum joint formation [1]. This is different for clinching, where the harder material should also be on the punch side, but it is recommended that the thicker sheet should be joined into the thinner part [2].

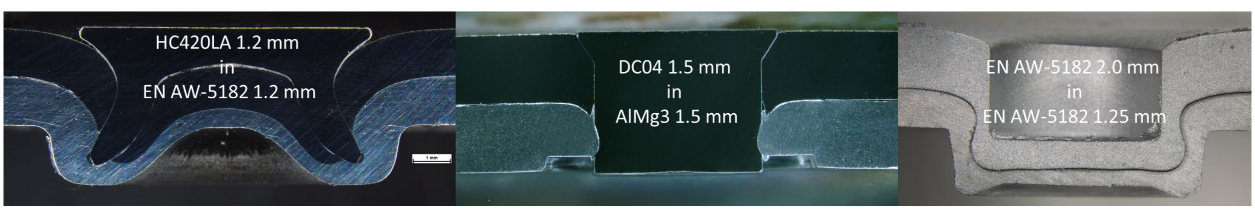


Fig. 1. Cross sections of three different mechanical joining processes (materials and blank thicknesses in the figure): Self-pierce riveting with semi-tubular rivet (left); Self-pierce riveting with solid rivet (middle); Clinching (right).

Clinching

In general, clinching is a simple way to join two or more sheets mechanical. It is frequently used because this joining process does not require a rivet or any other auxiliary joining part and is therefore easier to implement in terms of equipment and has weight advantages over other joining processes. On the other hand, clinching cannot compete with other mechanical joining processes regarding to joint strength. [3]

There are several process variants for clinching, such as clinching with cutting component [4], clinching with preformed hole [5], clinching without point elevation [6] or clinching with flat die [7]. Since these and other special variants are not used in this paper, their description will not be discussed in detail.

In current automotive production, rigid and radial opening clinching dies are mostly used. The rigid dies are characterized by their simple, rotationally symmetrical design. The advantage of radial opening dies is that the material flow is positively influenced by flexible, movable segments, thus the formation of interlock is supported [8].

The actual joining process is similar for both presented die variants. First, the sheets are positioned between the blankholder and die (Fig. 2, I), the moving punch presses the sheet partners toward the die contour (Fig. 2, II), and the joining point is finally formed by radial material flow (Fig. 2, III). This results in a strength-relevant interlock with a sufficiently large neck thickness. [2]

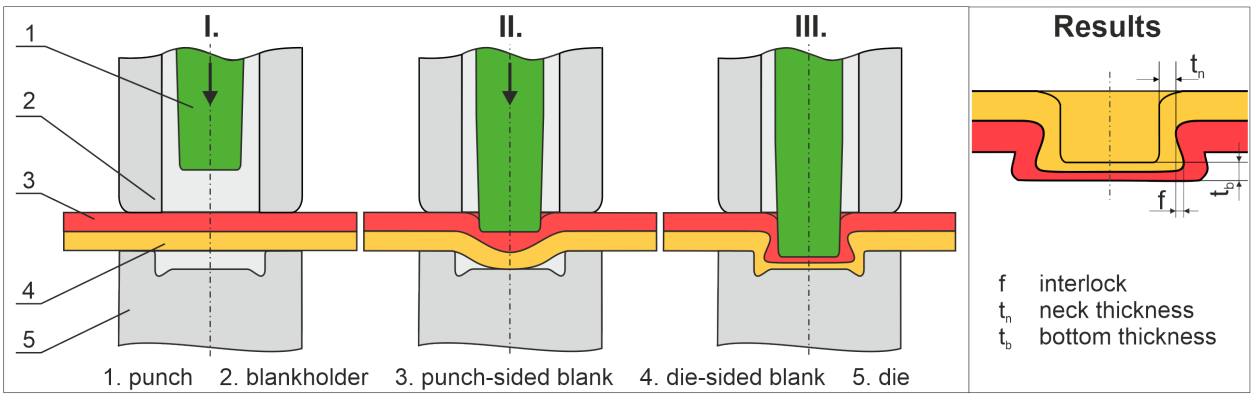


Fig. 2. Three steps of a clinching process (left); characteristic results of a clinching joint (right).

Due to the relatively simple joining process (no intended material cutting as, for example, in the case of semi-tubular self-piercing riveting when piercing the punch-side blank), the clinching process can be simulated easily with the help of numerical computation. Particularly when rigid, rotationally symmetrical dies are used, but also certainly in the case of radial opening dies, it is even possible to use two-dimensional simulations [9], which significantly reduces the complexity and calculation time. Thus, in addition to the pure joining point contour and force-displacement data, critical neck thicknesses and cracks can also be identified and predicted by numerical simulations, as shown in Fig. 3.

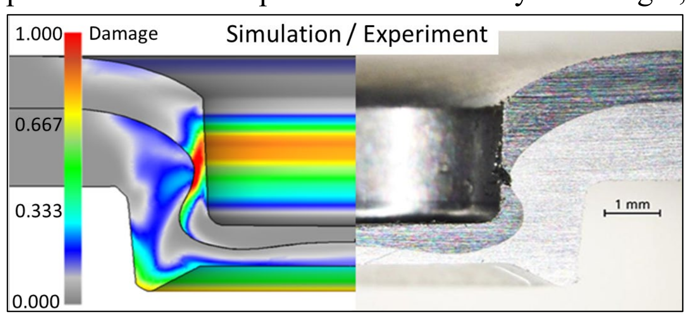


Fig. 3. Comparison of numerical simulation (left) and experimental result (right): HC340LA t = 1.0 mm in EN AW- 5754 t = 1.5 mm) [9].

Sampling

For this study of increasing the neck thickness, a joint with unfavorable sheet metal arrangement and small thickness in the neck region is used. As described above, this tends to be the case for clinching when joining thin into thick material. A steel joint of S350GD $t_1 = 2.0$ mm into S350GD $t_2 = 3.0$ mm is selected (as presented in [10]). As can be seen in Fig. 4(left), a bottom thickness of 1.06 mm results in a clinch point that has significantly lower values for neck thickness than interlock, with average $t_n = 0.25$ mm and $f = 0.42$ mm. A maximum joining force of 80 kN was required for this joint. The rather high force value for clinching can be explained by the large thicknesses and the die diameter of 10 mm.

Furthermore, the cross-section for the typical joining direction is shown on the right in Fig. 4. With an identical joining force (80 kN), almost the same bottom thickness of $t_b = 1.05$ mm is achieved. The neck thickness, averaging $t_n = 0.72$ mm, is significantly greater. The thicker steel sheet on the punch side almost triples the neck thickness but the the interlock ($f = 0.30$ mm) is decreasing. However, the loss of 29 % interlock is not as extreme as the increase of the neck thickness.

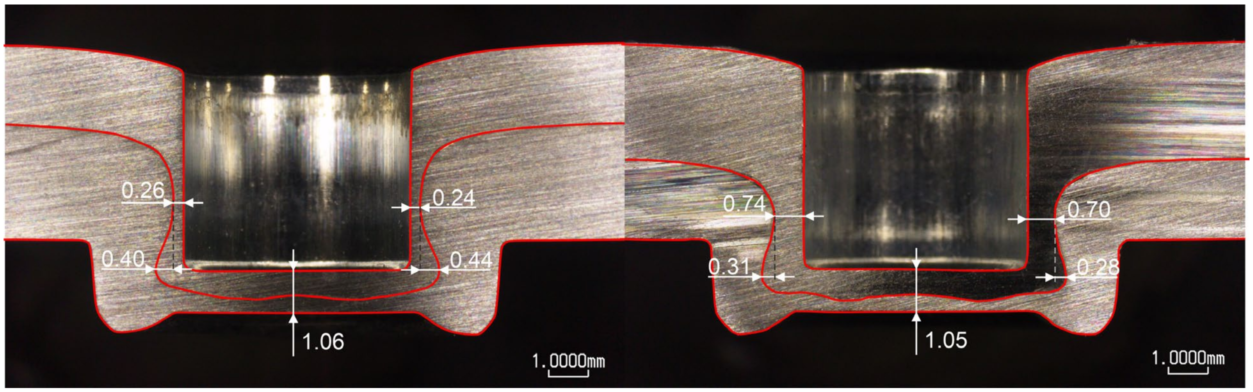


Fig. 4. Cross-sections of S350GD t = 2.0 mm in S350GD t = 3.0 mm (left) and opposite joining direction (right); red line added afterwards for better detection of the contour.

Numerical Simulation

In addition to the available information of the geometric dimensions of the tools, the spring rate of the blankholder and the joining speed, the friction conditions as well as the material properties are important for an exact modeling of the numerical simulation. Due to numerous past projects in which clinch simulations were considered [9, 11, 12], the gained expertise is used and the shear approach is applied for the friction. The selected friction factors have been determined on the base of the already performed numerical computations of the clinching process.

For the integration of the material behavior into the simulations, compression tests [13] are first carried out (Fig. 5, left). Since significantly higher degrees of deformation are achieved during clinching than can be determined in the compression tests, an extrapolation of the data is necessary [14]. For this purpose, individual factors are obtained for different approximation approaches with the experimental data in the initial range and the different results are compared with each other. The least squared error can then be used to find the extrapolation approach that most appropriately reflects the material behavior. For the used S350GD the approximation approach by Orowan is the best fit for the experimental data. The extrapolated and in the simulation used flow curve is shown in Fig. 5 (right).

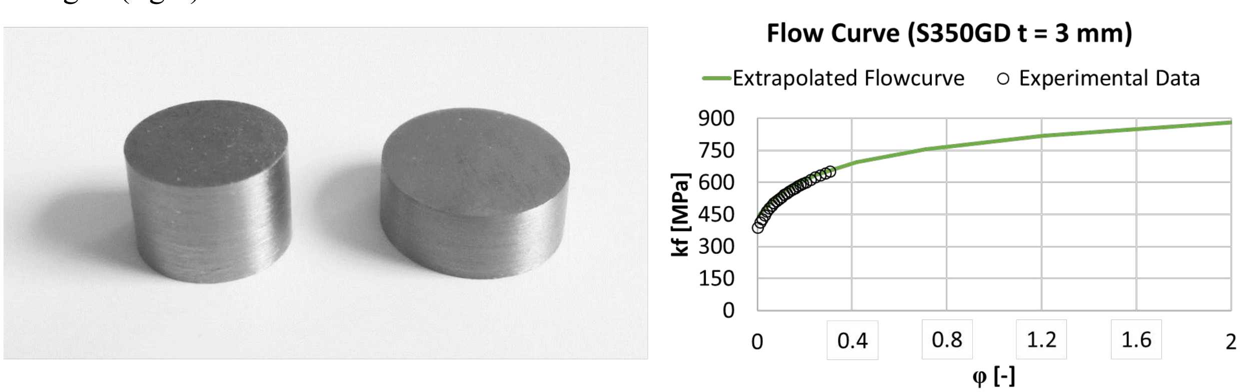


Fig. 5. Original and compressed cylinder sample of the compression test (left); extrapolated flow curve of S350GD t = 3.0 mm with approximation approach by Orowan.

Since only rotationally symmetric tools are used for the experiments, the more simple 2D simulations are used as mentioned above. Using the FEA software DEFORM, a simulation model was built, which can be seen in Fig. 6. Only the two blanks are modeled as elastic-plastic, the tools punch, blankholder and die are defined as rigid for simplification.

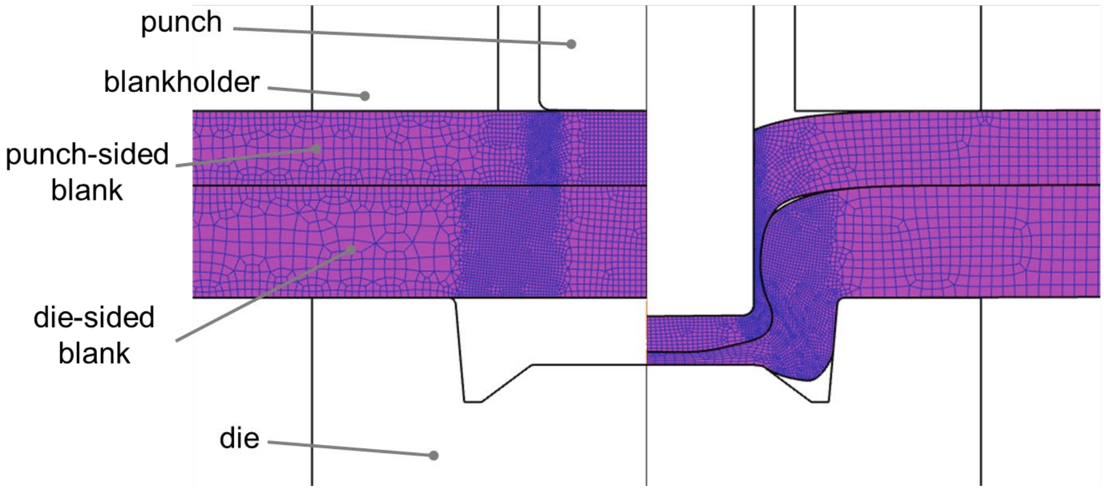


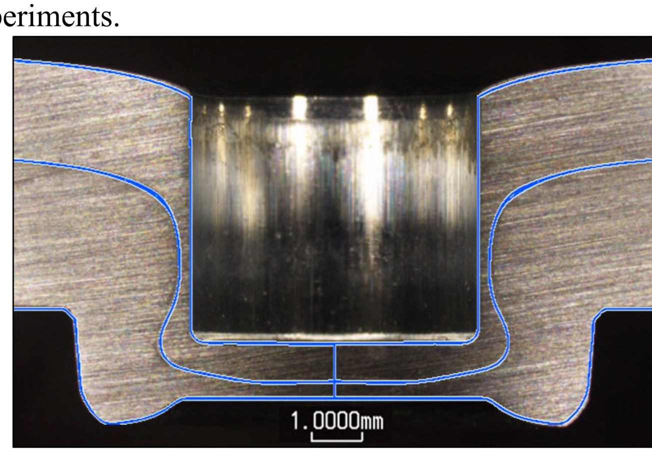
Fig. 6. Numeric simulation model of the clinching process build with the software DEFORM.

Verification

To ensure that the simulation can be used in further investigations, a comparison must be made between the experiment and the numerical calculation. Only if the results of both match sufficiently (geometry and load-stroke-curve), further use is reasonable.

Unlike in Fig. 4, in the following graph (Fig. 7) the colored contour is the result of the simulation. The results of the numerical simulation were generated using Deform V12 software from SFTC. In it, the minimum bottom thickness t_b achieved in the experiments was defined as a stopping criterion in the simulation. With these, areas of high deformation such as interlock and neck areas are generated finer meshes than at the edge of the simulated blanks. For the implementation of friction, a constant shear friction value per contact pair (such as punch/upper blank or die/bottom blank) was determined in parameter studies.

The difference between experimental cross-section and calculated clinch contour is hardly visible. The values of the characteristic geometrical parameters generated by the simulation are also at the same level as those of the experiments. Therefore, the simulation can be considered to have a high accuracy and prediction and can be used in further investigations instead of costly experiments.



Experiment/ Simulation		left	right
t_n [mm]	Exp.	0.26	0.24
	Sim.	0.22	
f [mm]	Exp.	0.40	0.44
	Sim.	0.39	
t_b [mm]	Exp.	1.06	
	Sim.	1.06	

Fig. 7. Comparison of experiment and simulation: cross-section and simulated contour of the clinch joint (left); characteristic geometrical values (right).

Divided Punch

One approach to bring joints with small neck thicknesses into a non-critical state is to allow more material to flow into the neck area at the beginning of the clinching process. The idea developed here is to use a larger punch diameter which displaces more volume into this neck area. The joining point is then formed by a smaller punch. This does not necessarily have to involve a punch change; the division of the punch into two different diameters is already used in shear clinching [15] (Fig. 8, numbers in the figure are part of the patent [16], where all components are explained by numbers).

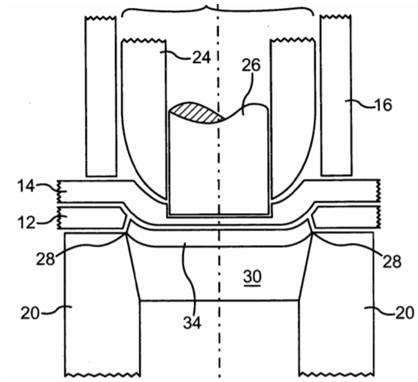


Fig. 8. Division of the punch for clinching with cutting components [16].

Described in more detail, clinching with a divided punch can be structured into four phases. First, just as in the conventional method, the sheets to be joined are positioned between the die and the blankholder (Fig. 9, I.). Then the larger outer punch and the smaller inner punch move simultaneously until a defined stroke is reached (Fig. 9, II.). At this point, the outer punch stops, and only the inner punch continues to move towards the die (Fig. 9, III.) and, as in the conventional case, forms the joining point with its characteristic contour (Fig. 9, IV.).

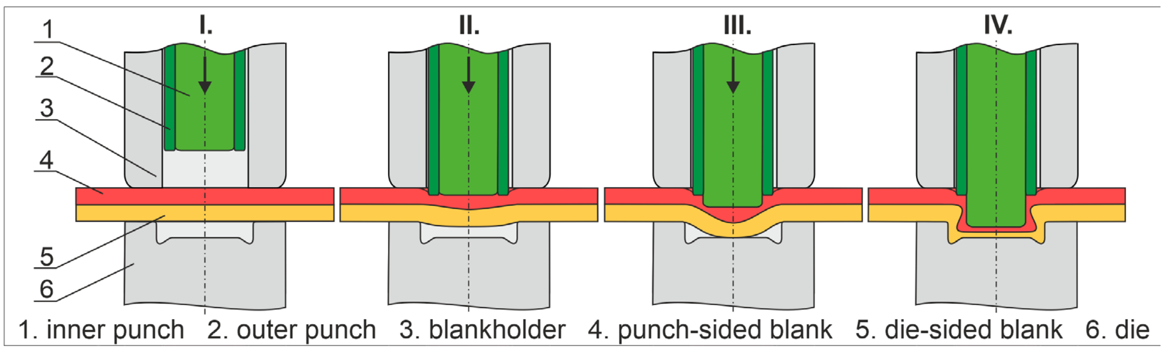


Fig. 9. Four steps of clinching with divided punch.

The validated simulations and the concept of punch division are now being used to first develop simulative tool combinations that generate an increase of the neck thickness. In the case of the outer punch, it is not only the pure geometry that is important, but also at which stroke it should stop moving.

In order to show whether a compression of the material at the end of the process has the same effect as pre-compression, a stepped punch is also considered. This stepped punch has a smaller diameter which, after a defined height, has a shoulder where the diameter becomes larger. This punch shape is one-piece and therefore much simpler in design than a tool division.

Fig. 10 shows the results of the simulations and at the same time also those of the experiments. The left subgraph is already known from Fig. **7** and is only included here for better comparison. First of all, it is noticeable that for all three punch variants the simulation accurately predicts the actual experimental result. This is the case for the pure contours as well as for the measured values for neck thickness and interlock.

The differences between the two conventional punch designs (left and center) are marginal, there is no increase of neck thickness by using the stepped punch. The situation is different with the divided tool (the punch contour is based on the one of the stepped punch): Due to the large outer punch, so much material flows into the neck area at the start of the process that the average neck thickness could be increased from 0.25 mm to 0.39 mm (+77 %). Since experience shows that neck thickness and interlock are always in opposite trends, it is not surprising that the interlock decreases with the divided punch. Compared to the significant increase in neck thickness, however,

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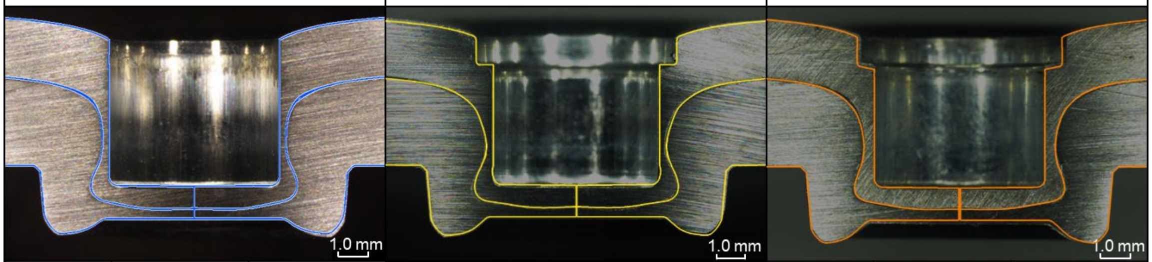
the loss of only 17 % (from 0.42 mm to 0.35 mm) is significantly lower.

Conventional simple punch			Conventional stepped punch			Divided punch		



Result	Simulation	Experiment	Result	Simulation	Experiment	Result	Simulation	Experiment
t_n [mm]	0.22	0.26 / 0.24	t_n [mm]	0.23	0.24 / 0.23	t_n [mm]	0.36	0.37 / 0.40
f [mm]	0.39	0.40 / 0.44	f [mm]	0.41	0.45 / 0.42	f [mm]	0.32	0.36 / 0.33

Fig. 10. Comparison of experiments and simulations (colored contours): conventional simple punch (left); conventional stepped punch (middle); divided punch (right).

The declared goal of increasing neck thickness by using a two-part punch appears to be successful. The concept developed is appropriate for the present case. How and whether the larger neck thickness with simultaneously smaller interlock affects the joint strength will be determined in the next step.

Strength Analysis

Since the use of the stepped punch does not have any advantage in the present case, this punch variant is not included in the joint strength investigations. Fig. 11 shows results from shear tensile tests. As discussed in the last chapters, the sheet pairing S350GD 2.0 mm in S350GD 3.0 mm as well as the reverse joining direction can be found in it. In addition, a distinction is made in each case between the conventional simple punch and the divided die.

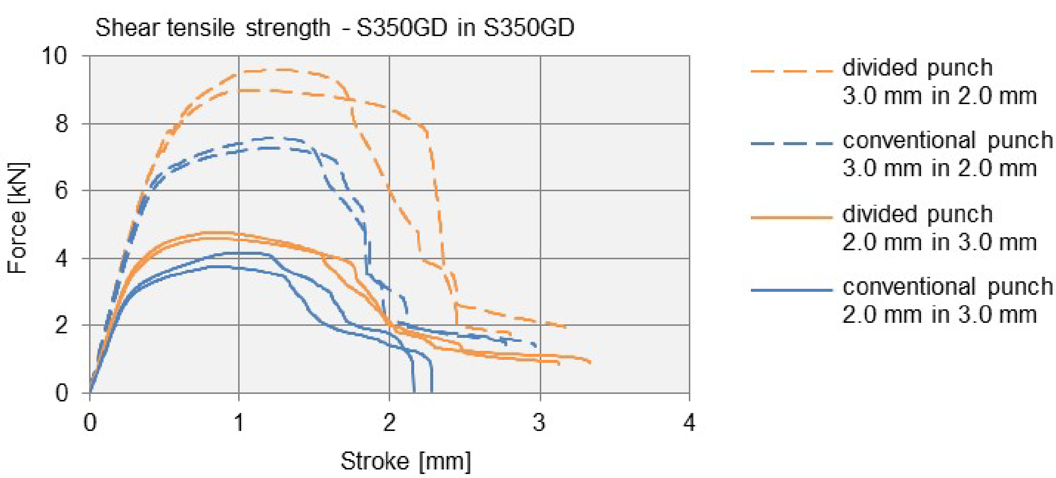


Fig. 11. Results of shear tensile strength: S350GD (2 mm in 3 mm) vs. (3 mm in 2 mm) and conventional simple punch vs. divided punch with pre-stamping.

It can be seen, that for both joining directions (thick in thin and thin in thick) the use of the divided punch has a positive effect on the joint strength under shear tensile load. This is the case both for the maximum forces and for the energy absorption capacity (in connection with the extended strokes). The fact that the use of the thicker blank on the punch side achieves fundamentally higher values than the thinner blank reflects experience. For the untypical blank arrangement for clinching (2 mm in 3 mm), the average maximum force for the variant with pre-stamping can be increased by 19% with the larger punch compared to the simple tool. For reversed blank positioning, even an increase of 25% on average is achieved.

Further Investigations

For the outer punch, not only the diameter is essential, but also how far it moves with the inner punch has an influence on the joint contour. For the sheet pairing S350GD $t = 2$ mm in S350GD $t = 3$ mm investigated in this paper, a small sensitivity analysis is therefore carried out with the help of simulation in order to be able to evaluate the effect on neck thickness and interlock.

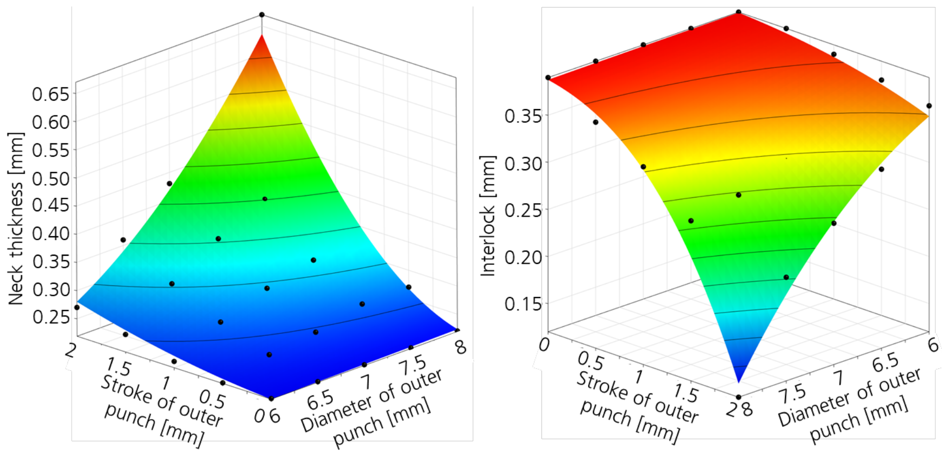


Fig. 12. Results of a sensitivity analysis to show the influence of stroke and diameter of the outer punch on neck thickness (left) and interlock (right).

Fig. 12 shows that the larger the diameter and stroke of the outer punch, the greater the neck thickness. Here, the stroke has a greater influence than the diameter. On the other hand, increasing punch stroke and diameter of the outer tool have a negative effect on the interlock. Depending on the initial situation and requirements, it is therefore also necessary to find a tool setup for the espective compound. The punch division can help to achieve a balanced and target-oriented relationship between neck thickness and interlock.

In further investigations, other joint components should be tested and whether the punch division has a positive effect on the joint contours and strengths. Both different sheet thicknesses and materials (steel, aluminum) in different strengths are of interest here and will be part of the project in the future work. For these other materials, it is also planned to test not only the shear tensile strength but also in head tensile direction, in each case for the reference experiments as well as the optimized with punch division tests. If there is an upper limit of material strengths that can be used with respect to the divided punch, these future investigations will show.

In addition to the rigid dies used here, further studies should analyze the influence when using more flexible designs such as dies with radially opening segments.

The sensitivity analyses presented above could be extended to consider all tools and kinematics and thus provide a fully comprehensive picture of neck thickness increase using punch division. Of course, not only the stroke and diameter of the outer punch influence the relationship between neck thickness and interlock, so the interaction of all parameters should be investigated in more detail.

The obvious disadvantage of the punch division presented here is the need for two decoupled drives. The subject of further research should therefore be whether there are alternative possibilities for pre-stamping. It is conceivable, for example, to use spring units instead of several drives, to carry out the stamping by using a modified blankholder with an integrated stamping ring. This simple tool geometry naturally leads to a loss of flexibility in terms of a freely adjustable punch stroke for pre-stamping.

Summary

In this paper, the issue of small neck thicknesses in clinching was first described and demonstrated using the joint S350GD 2.0 mm in S350GD 3.0 mm. By using a validated simulation model, the concept of punch division and the positive effect on a neck thickness increase were first simulatively proven. This could be verified by experiments, the comparison to the simulation was convincing and consequently the neck thickness could be increased in these real investigations as well. This led to significantly higher shear tensile strengths for the above-mentioned joint, but also for the joining direction more typical of clinching (thick material joined into thin material).

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