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DEVELOPMENT OF A MECHANICAL JOINING PROCESS FOR AUTOMOTIVE BODY-IN-WHITE PRODUCTION

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ABSTRACT: The current lightweight design is realized by the multi-material mix in body-in-white production of automotive industry. In car bodies, the proportion of high-strength steels and aluminum alloys increases. Therefore, it is necessary to join these materials. Mechanical joining processes are suitable for a multi-material mix. But in combination with high-strength steels, only processes with additional elements, like rivets, are useful. The development of a new clinching technology shows a solution for an economical method for joining these different materials. An innovative single-stage process without any additional joining elements is created to extend the current limits of mechanical joining technologies. This makes it possible to join aluminium alloys and high-strength steel by punching and clinching in one step. Using the special material behavior of the parts to be joined is most important for this mechanical joining process. A clinching sequence, a scheme and a gradual analysis support the understanding of this joining method. Some examples of connected material combinations complete this description. Further steps to improve this joining process are shown. Especially the finite element analysis will provide more process details for improving this innovative joining technology.

KEYWORDS: mechanical joining, clinching, lightweight design, multi-material mix, high-strength steel

1 INTRODUCTION

In current lightweight design the reduction in weight of body-in-white assemblies is realized by the systematic application of different materials, better known as a multi-material mix. The combination of steel and aluminum alloys describes the state of the technology in automotive engineering.

Clinching and self-piercing riveting are established, efficient mechanical joining processes, which become more important for those applications. They are inured to coating and have no thermal influence on the joined materials and in particular on their microstructures. In comparison to thermal joining technologies, the joining forces are significantly higher. These joining forces could cause a reduction of tool life, especially in combination with joined high strength materials. Therefore, the mechanical joining technology clinching has a limited application range. Joints by riveting have additional joining elements, which in turn cause extra production costs.

2 STATE OF THE ART

Clinching is the generic term for joining processes by forming, whereby permanent joints are formed without ancillary or additional materials and without introduction of heat into the sheets to be joined. This joining technique is based on local plastic deformation of metal sheet, tubular, profiled and cast parts by means of a tool set normally consisting of a punch and a die.

2.1 SINGLE STEP CLINCHING PROCESS WITHOUT CUTTING (CONVENTIONAL CLINCHING)

The joining operation process is performed in a single-step, continuous working stroke (Figure1).

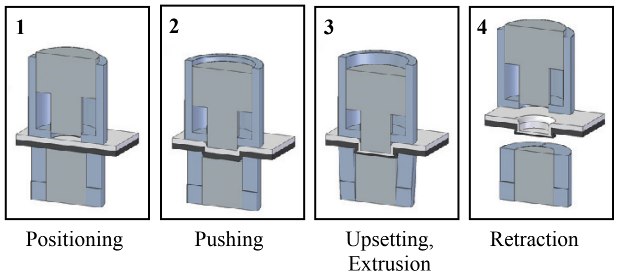

Figure 1: *Sequence of conventional clinching*

The joining punch moves to the die and exerts a pressing force on the parts to be joined. The material of the parts to be joined is placed below the punch and penetrated down to the die bottom. Then the material is upset

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between the punch and die such that a radial material flow occurs towards the outside. The die lamellae opening during the upsetting phase controls the radial material flow such that an undercut is created between the materials to be joined on the punch and die side. [1,2]

An undercut is created between the top and bottom material layers creating a positive engagement. The joint strength component resulting from the positive joint is usually increased during the forming process. It is a result of the cold hardening of the materials of the joined parts. As a result of the elastic component during joint formation, an additional non-positive (frictional) connection is created which contributes to the joint strength irrespective of the positive joint (Figure 2). In addition, cold welds may form under certain conditions (e.g. completely oil/grease-free aluminum alloy surfaces) between the joined materials which will result in a further increase in the strength of the joint. [1,2]

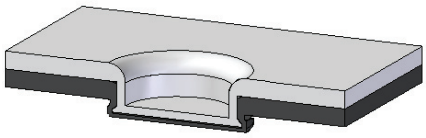


***Figure 2:** Scheme of conventional clinching point*

Conventional clinching is able to connect materials up to their tensile strength of 600 N/mm² in a serial automotive production environment. [2]

2.2 CLINCHING WITH SHEET PREPUNCHED ON DIE-SIDE

This process allows the joining of a high strength sheet metal with a very ductile one which is arranged on the punch side. The material with reduced formability on the die side must be prepunched. During the clinching process, the positioning of this hole towards the aligning punch is very important (Figure 3).

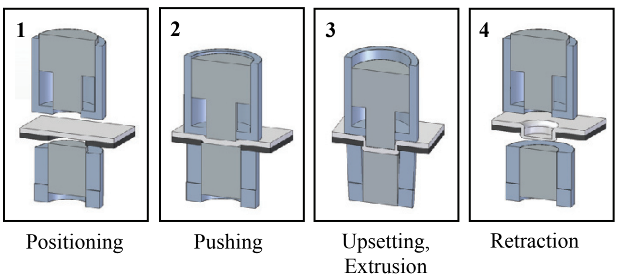


***Figure 3:** Sequence of clinching with sheet prepunched on die-side*

This clinching derivate theoretically enlarges the restrictions of clinching. The separate previous punching process increases work and costs.
Part tolerances and positioning tolerances of the robots exceed the required minimum tolerances between prepunched holes and the clinching tool, so joining is only possible under special conditions (Figure 4).

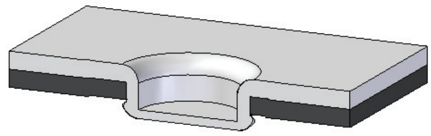


***Figure 4:** Scheme of clinching point with sheet prepunched on die-side*

2.3 FURTHER DERIVATES OF CLINCHING

For the sake of completeness there are some other special clinching processes. The main differences between these processes are the kind of clinching force introduction and kinds of tooling design.
One of the most interesting derivate to connect a ductile material and a material with reduced formability is the punch-clinching process. [2,3]

3 DEVELOPMENT OF AN INNOVATIVE MECHANICAL JOINING PROCESS

The focus of developing this joining process is to enlarge the technical restriction of using mechanical techniques in consideration of economic aspects. To meet these requirements it is necessary to combine several effects of joining processes.
Clinching is an economical mechanical joining system. With its special derivates this process is able to represent the fundament of this development.

The hypothesis for creating a new clinching system is to integrate the punching and the clinching process in a single step. Therefore, the material with high formability is located on the punch side and the high strength material is positioned on the die side. The challenge is not to damage the very ductile material by using high punching forces. [4]
As a result, two principles are combined to create this joining process. First, the geometry of the die contains a sharp punching edge, similar to a regular punching die. Second, it is necessary to realize a maximum surface on the punch side. The geometry of the hemisphere guarantees the lowest punching force over a maximum of surface. Figure 5 explains this principle. [4]

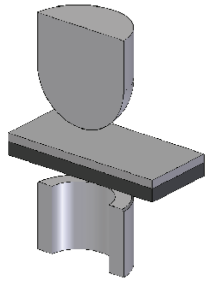


Figure 5: Tool set: punch with hemisphere geometry and punching die

Based on the verification of this hypothesis the new joining process is created. The tool consists of two punches, an outer punch for stamping and an inner punch for clinching. The die also has a movable die anvil for realizing a counter force while penetrating the material. [4]

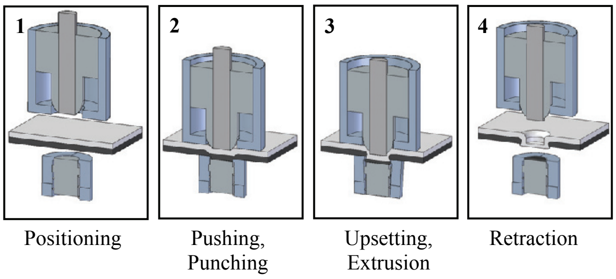


Figure 6: Sequence of new clinching process

The joining operation process (Figure 6) is performed in a single-step, continuous working stroke. The punch-set moves downwards to the die and exerts a pressing force on the parts to be joined by hold-down device. The material of the parts to be joined is placed below the punch set and penetrated down to the die anvil. In this process step an outer and an inner punch are positioned at one height to realize the hemisphere geometry. Therefore, it is possible to punch the die-side material. Then the punch-side material is upset between the punch and the fixed die anvil so that a radial material flow occurs towards the outside. The die lamellae opening during the upsetting phase controls the radial material flow. The result is an undercut created between the materials to be joined on the punch and the die-side. Figure 7 shows a scheme of this process. [4]

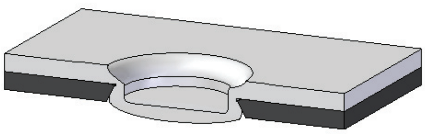


Figure 7: Scheme of new clinching point

A gradual analysis of a real joining process points out the process principle (Figure 8).

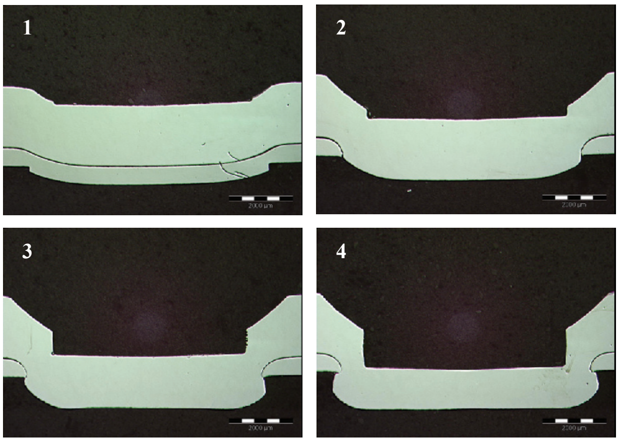
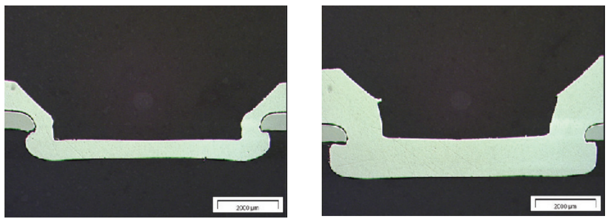


Figure 8: Gradual analysis: DC04 (2mm) in H300X (0,6mm)

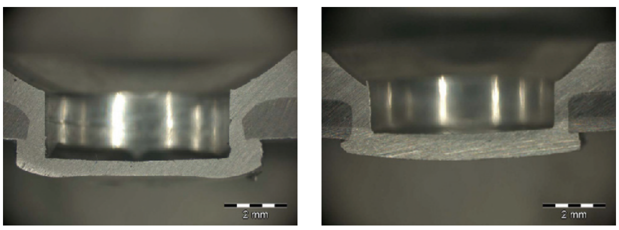
The range of use depends on material thicknesses and its strengths. Some examples are shown in Figure 9 and 10. The joinability increases as higher is the sheet thickness on die-side material grows compared to the punch side material. A greater undercut and a greater neck thickness can be recognized (Figure 9).



AW 5182 (0,92mm) in H300X (0,6mm) | AA 6014 (2,5mm) in H300X (0,6mm)

Figure 9: Influence of sheet thicknesses ratio

Figure 10 shows some examples with varied material strengths on the die-side. A higher strength supports the punching process during the clinching sequence.



AW 5182 (1,5mm) in HT700T (1,25mm) | AW 5182 (1,5mm) in 22MnB5 (1,25mm)

Figure 10: Influence of die-side material strength

The quasi-static joint characteristics of this new system are comparable to conventional clinching. It depends on the materials of the parts to be joined and their sheet thicknesses. Especially the punch-side material is responsible for the strength of the joints. The undercut ensures the tensile-strength and the shear-strength of the joint is guaranteed by the punch-side neck-thickness (Figure 11).

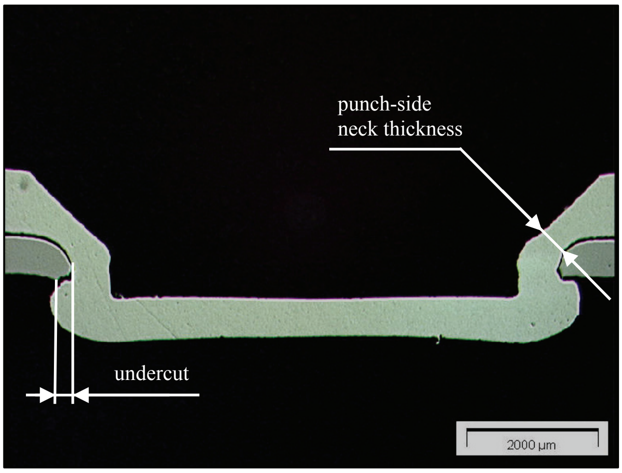


***Figure 11:** Strength parameters of clinching point*

Furthermore, the clinching joint characteristics are enhanced by the interactions of cold hardening, frictional connection and cold weld tendency.
The material combination AW 5182 (0,92mm) in H300X (0,6mm) gives an good impression for typical quasi-static joint characteristics of clinching (Figure 11). This joint fails by a tensile force of 1,1kN and a shear force of 2,1 kN. These exemplary quasi-static joint characteristics are determined on test panels.

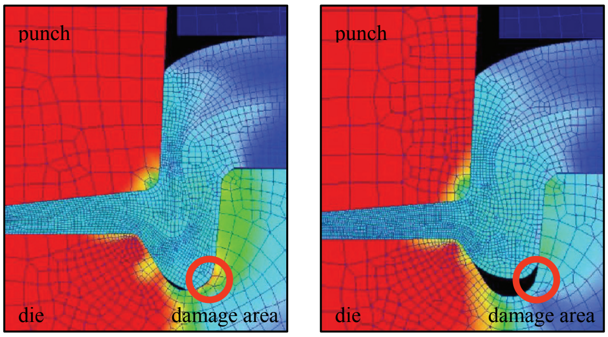
As a result, clinching is unsuitable with regard to shock-type loads (e.g. crash) due to its relatively low load threshold which will result in the failure of the joint. In combination with crashworthy structural adhesives, clinching is an ideal tacking method for fixing the components until the adhesives are completely cured.

4 CONCLUSIONS

The new joining system increases the range of materials for clinching by keeping the process times constant compared to the conventional clinching system. It is possible to develop an innovative mechanical joining technology without additional joining elements, like rivets. The basis for a new clinching process is created.

The next development steps will be realized by using the finite-element analysis. The simulation tool provides a more detailed understanding of the process. The reason is the constant monitoring of the joining sequence. It is necessary to analyze the punching and clinching effects in combination with influences caused by the materials of the parts to be joined.

Another benefit of using the simulation is the possibility of analyzing the tool loads during the clinching. This advantage is already used for conventional clinching applications. Figure 12 shows the previous and the optimized die stresses of such a testing. This makes it possible to avoid broken dies by changing the punch diameter. The result was a 50 % reduction in critical tensile stresses in the die bottom.



Without simulation After simulation

***Figure 12:** Example of simulating conventional clinching*

This means, it is possible to improve the new clinching process by using a minimum of hardware. Therefore, simulation with finite-element analysis especially reduces costs and time input for development processes. [5,6]

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