

## THE CHARACTERISTICS OF H320LA STEEL SHEET CLINCHING JOINTS

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### Summary

This paper presents the examination results for redrawing joints made of H320LA thin sheet metal. The joint quality has been evaluated by visual and strength examinations. The numerical model of joint forming process has been developed. The effect of die geometrical parameters on the achieved joint lock size and maximum forming force has been determined. It has been found that the die groove width is the most important parameter affecting the material plastic flow effect and energy consumption of the joining process. The results of experiments and numerical tests enable determining the effective process parameters of H320LA sheet metal joining process.

**Keywords:** clinching joints, joint strength, tools design, interlocking length, neck thickness

### Połączenia przetłoczeniowe wykonane z blachy ze stali H320LA

#### Streszczenie

W pracy przedstawiono wyniki badań połączeń przetłoczeniowych, wykonanych z cienkiej blachy ze stali H320LA. Podstawą oceny jakości tych połączeń były wyniki próby statycznej rozciągania oraz badania makroskopowe. Opracowano model numeryczny procesu kształtowania połączenia. Określono stopień oddziaływania parametrów geometrycznych matrycy na rozmiary utworzonego zamka w złączu oraz maksymalną siłę jego formowania. Stwierdzono, że szerokość rowka ma największy wpływ na efekt płynięcia plastycznego oraz energochłonność procesu łączenia blach. Wyniki badań eksperymentalnych oraz numerycznych umożliwiają ustalenie efektywnych parametrów technologicznych procesu łączenia blachy ze stali H320LA.

**Słowa kluczowe:** połączenia przetłoczeniowe, wytrzymałość połączenia, projektowanie narzędzi, długość zamka, grubość szyjki

## 1. Introduction

The trends, especially in the transport industry, towards reduced weight, increased performance and safety as well as a more rational and cost effective manufacturing has broadened the interest in high strength steels of good formability and weldability.

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For a given load respectively a fixed stress in the component high-strength steels lead to smaller cross-sections and therefore to reduced weight which results in decreasing costs. Typical fields of application: production of pressed parts (automotive industry), special sections and tubes of specified strength [1-3].

Joining of metallic sheets is fundamental in the manufacturing of thin walled structures. Some mechanical joining techniques have been developed for joining advanced lightweight materials that are dissimilar, coated, and hard to weld [4-8]. An alternate method for the joining of sheets is known as clinching. Clinching has also been developed rapidly into relatively a new branch of mechanical joining techniques [9]. Consequently, the knowledge of the clinched joints has been the subject of a considerable amount of experimental and numerical studies [6, 10-20].

In the design of mechanical structures which contain clinched joints, the information of these joints is essential. The quality of a joint made with a fixed die is evaluated by measuring the material thickness ( $X$ ) (see Fig. 1) in the middle of the base of the joint [14].

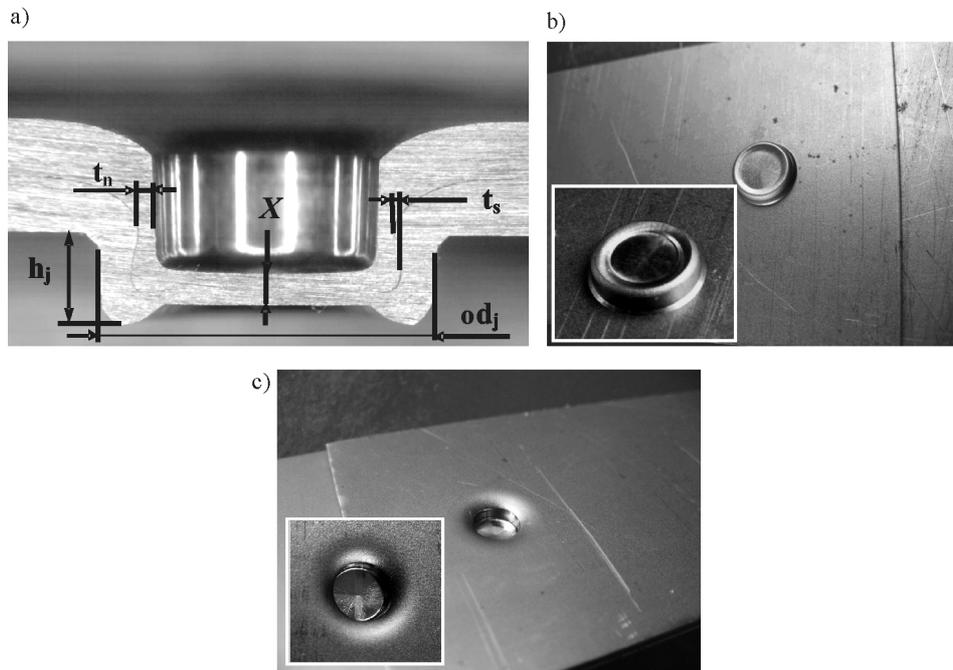


Fig. 1. Clinching joint: a) the sheet cross-section in the area of their connection ( $h_j$  – connection height,  $\text{ød}_j$  – connection diameter,  $X$  – overpress bottom thickness,  $t_n$  – thickness of necking,  $t_s$  – overlap dimensions), b) overpress, c) cavity

In clinching the tool design, the die cavity volume, including the die groove, is slightly larger than the punch penetration volume. The tools are designed in order to create an undercut which guarantees the mechanical interlock between the sheets [20].

The backward metal flow of the upper sheet would occur with the unfilling of die groove [15]. It is well known that for a given tool geometry, the clinch joint is characterized by the following parameters: the axial thickness of the sheets denoted by „X”, the thinning of the upper sheet denoted by „ $t_n$ ” (also called the nick thickness) and the clinch lock denoted by „ $t_s$ ” (Fig. 1).

To design mechanical clinching tools that can give higher strength of the mechanical clinched joint, many researchers have investigated the relationship between the geometry of clinching tools and the strength of the mechanical, clinched joint [15-19]. Lee et. al [19] has referred to ENAW-6063 aluminum sheet plate clinching, and at [15] has presented the results of DP780 steel and ENAW-5052 sheet plate joining capability analysis. Oudjene with team [16, 17] have dealt with shape optimization of tools used for aluminum sheet plate ENAW-5754 joining. The clinching capability of A231 and ENAW-5754 magnesium alloy sheet plate has been presented by Neugebauer et al. [18]. This technique can be applied in principle for joining magnesium components, but it is significantly less efficient here than if used for joining materials such as steel and aluminum.

The present work focus on clinching, a cold joining technology for thin sheets (H320LA) which is rapidly developing in the industries mentioned above. The experimental-numerical analysis using round die has been presented. The process of forming the connection was evaluated based on maps of strain intensity and average stress using FEM. The achieved results form the basis of an effective designing joints with H320LA sheet plates.

## **2. Research procedures**

### **2.1. Experimental research**

In addition to experimental studies, the numerical simulation is used to obtain information inaccessible by experiments. Thus, a finite element computer code is developed to specifically study this process. Its characteristics and performances are the purpose of the later discussions. Finally, one of the objectives of the study was to gain a better understanding of the clinching process through the numerical simulation of the process.

Experimental-numerical analysis of the connection was carried out for H320LA steel sheets with an increased yield point, destined for cold plastic working, and for which the main chemical components are shown on Table 1.

Table 1. Chemical composition of H320LA steel

Material designation	Chemical composition, % mas.							
	Al <sub>min.</sub>	S <sub>max.</sub>	P <sub>max.</sub>	Nb <sub>max.</sub>	C <sub>max.</sub>	Ti <sub>max.</sub>	Si <sub>max.</sub>	Mn <sub>min.</sub>
H320LA*	0.015	0.025	0.025	0.090	0.10	0.15	0.50	1.00

\* EN 10268/98, material number 1.0548, (Gr.50 - ASTM A1008)

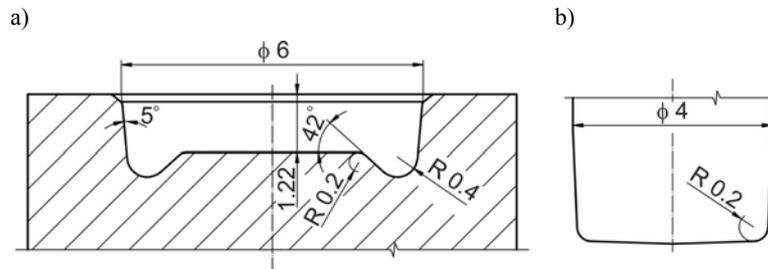


Fig. 2. Tools for forming the clinching joint: a) die, b) punch

During tests, tools used consisted of a forming punch as well as a die with a specific impression (Fig. 2). The tools had a geometry guaranteeing the creation of a correct and appropriately resistant connection. A series of connection samples were made for a connection diameter of 6 mm. Two sheets layers of identical thicknesses  $t = 1$  mm, giving 2 mm in total thickness. The sheets material behavior has been described by the stress-strain curve  $\sigma_p = 722\varepsilon^{0.193}$  which states for steel 1.0548 (EN 10268/98), with initial stress yield  $\sigma_{p0.2} = 340$  MPa determined by tensile tests.

## 2.2. Numerical research

The production of high quality joints with high resistance is the ultimate goal of the manufacturing industry. Numerical simulation allows to develop, virtually and at lower cost, product range of complex forming processes without experimental and empirical methodology. Numerical calculations were carried out in the MSC program. Marc Mentat 2007.

Numerical modeling was carried out on a FEM-based program which allowed the observation of changes occurring in the connection during its forming. Due to the incremental nature of the plastic law, the updated Lagrangian formulation (ULF) is utilized to describe the large elasto-plastic deformation process. In the finite element simulation of metal forming processes, numerical formulations have been extensively used the updated Lagrangian formulation.

Due to the symmetrical shape of the connection as well as the course of its forming, the connection forming process can be considered using a flat, axially

symmetrical model of stress and strain state. Boundary conditions were defined based on the process scheme and tool system. Connected sheets were modeled for calculations, using an elastic-plastic material model, using a type 10 quadrilateral axisymmetric element. The punch, blankholder and die were treated as rigid tools. The upper and lower sheet was initially divided into 100 elements (element dimensions amounted to 0.25 x 0.2 mm). During the creation of the clinching connection, large local plastic strain takes place in the connected sheets. In order to carry out correct and stable numerical calculations, advanced grid regeneration algorithms were used. As a criterion for grid regeneration, the maximum admissible angle of deformation deviation of elements was accepted at  $-5^\circ$ . As a parameter during grid regeneration, the maximum admissible element length was accepted at 0.07 mm. The Coulomb friction model (bilinear) was accepted for all contact surfaces with a friction coefficient  $\mu = 0.1$ .

First, the geometry of tools used in the experiment has been used to create the tool model. Nine other simulations were then performed, each one involving a type of geometry change in the die or punch, as described in Fig. 3 and Tab. 2.

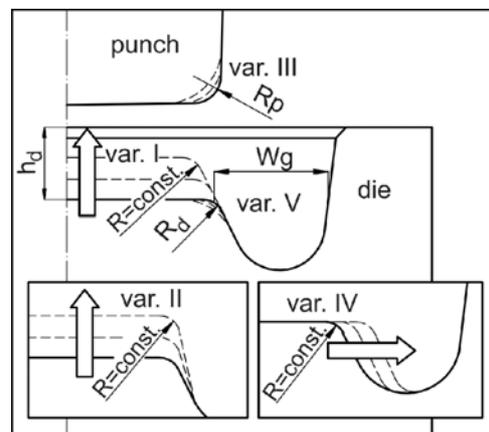


Fig. 3. The diagrams of tool shape versions used in the numerical analysis

Table 2. FE analysis conditions

Parameter	Value, %
Die radius, $R_d$	$R_d/t = 20, 30, 40$
Die depth, $h_d$	$h_d/t = 120; 110; 100$
Punch radius, $R_p$	$R_p/t = 20, 30, 40$
Groove width, $W_g$	$D-d/2t = 80, 90, 100$

All numerical models parameters have been identical to the base model, which was determined experimentally. Due to variety of possible combinations, the number of models has been limited only to several selected possible alternatives.

### 3. Results and discussion

The typical joint failure modes are the neck fracture mode and button separation mode, illustrated in Figs. 4a and 4b.

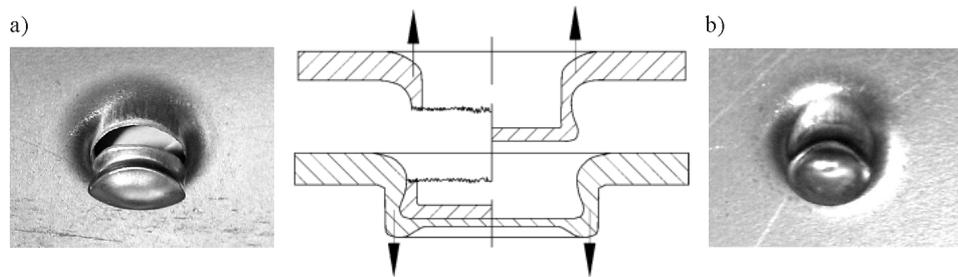


Fig. 4. Typical failure mode of mechanical clinched joint: a) fracture, b) totally disconnected

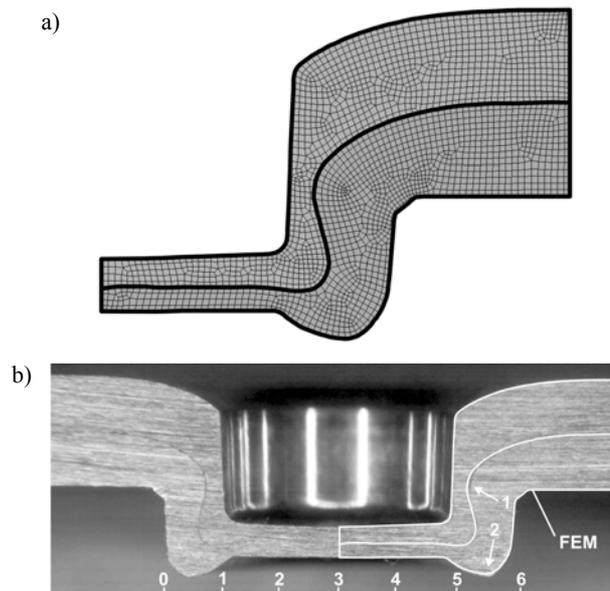


Fig. 5. Comparison of the connection shape on a connection cross-section obtained experimentally and from numerical calculations:  
a) numerical results, b) cross-section

As a result of numerical modeling of the course of the process of connection formation, good compliance of the shape of a ready connection taking return strain into account was attained. The cross-section shape between FE analysis and the experiment is compared in Fig. 5. The cross-section of the clinched joint has a similar shape and deformation mode as with the FE analysis result. The shape of the interior line in the necking area for the numerical model had slight deviations from that obtained from the experiment (detail 1). Fin size (detail 2) obtained in the experiment was slightly larger in its lower part than that obtained from numerical calculations.

The pressure force increase when joint forming causes  $t_n$  and  $t_s$  parameter change (Fig. 6). The pressure force increase forces the bottom thickness ( $X$ ) decrease, the upper to lower sheet material penetration ( $t_s$ ) increases without

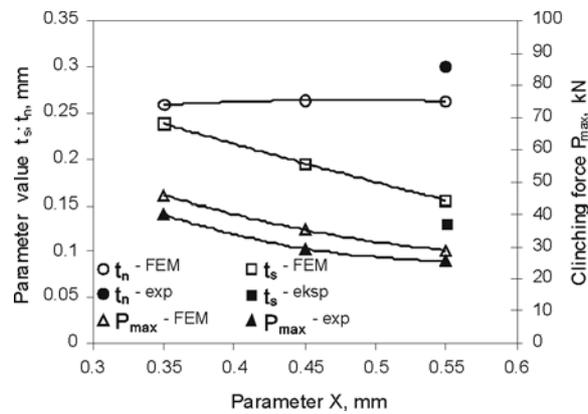


Fig. 6. The effect of pressure force on joint parameter values

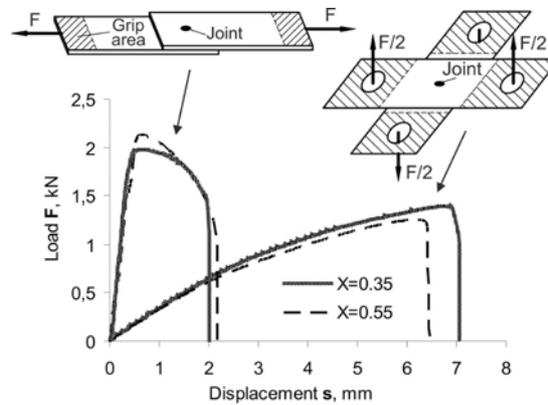


Fig. 7. The curve course determined experimentally for different X values when shearing and tearing joint

visible changes of necking ( $t_n$ ). This directly influences the joint load-carrying ability (Fig. 7).

Figure 8 shows the strain intensity distribution of the material in a ready connection, obtained as a result of numerical calculations. The highest values are observed in a wall of the interior redrawing surface (detail 1), near the necking area (neck) as well as in the connection axis near the interior sheet line (detail 2).

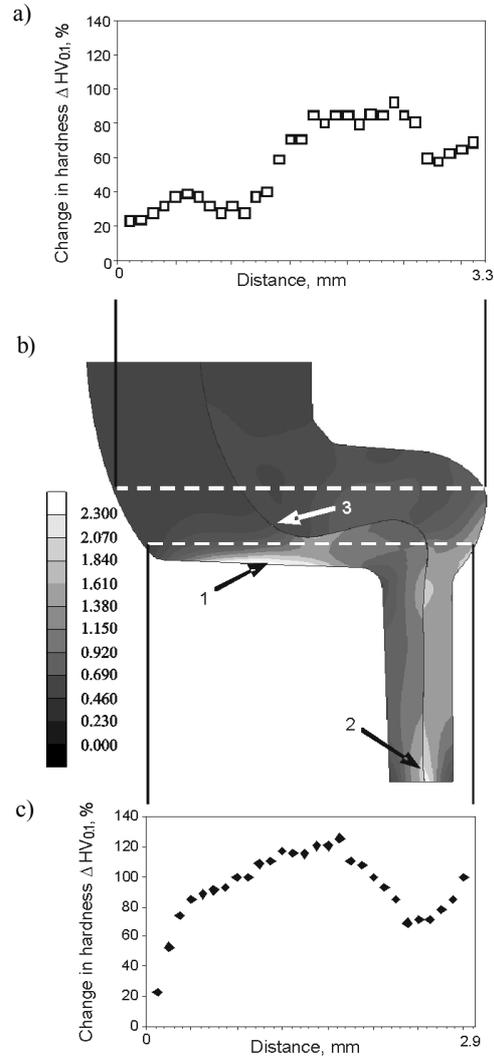


Fig. 8. The strain intensity distribution characteristics (FEM) (b) and microhardness change (EXP) for  $X = 0.55$  mm: a) detail 1, c) detail 2

This is a result of high friction between the surface of punch contact and the material. The pressure on the interior connection line from the side of the lower sheet (detail 3) makes shifting of the drawn material in the direction of punch motion difficult. In area 2 (Fig. 8), strain and pressure are highest; there, material is subjected to a state similar to hydrostatic compression (Fig. 9).

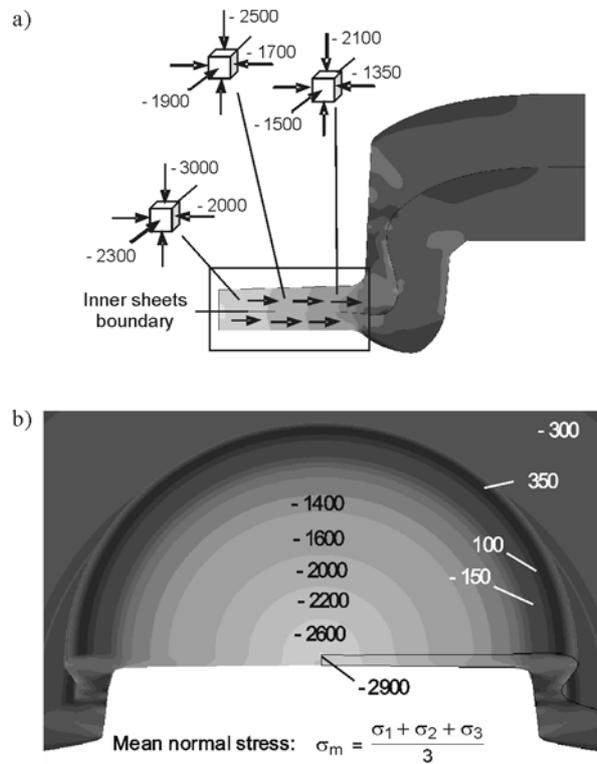


Fig. 9. Mean normal stress distribution (MPa) in connection right before tool retracting: a) main value fields in joint cross-section, b) distribution on an internal sheet plate contact surface

In the overpress bottom (the area indicated on Fig. 9a), the material hardly displaces in the radial direction. The macrostructure of an internal sheet plate contact surface in the final joint is a result of sheet plate material flow under high internal pressure (Fig. 10a). The dead zone areas (Fig. 10b) and sheet plate material displacement zones (Fig. 10c, d) are visible. The irregular structure is visible on the sheet plate surface (Fig. 10e) in the area of material immersion in the die impression.

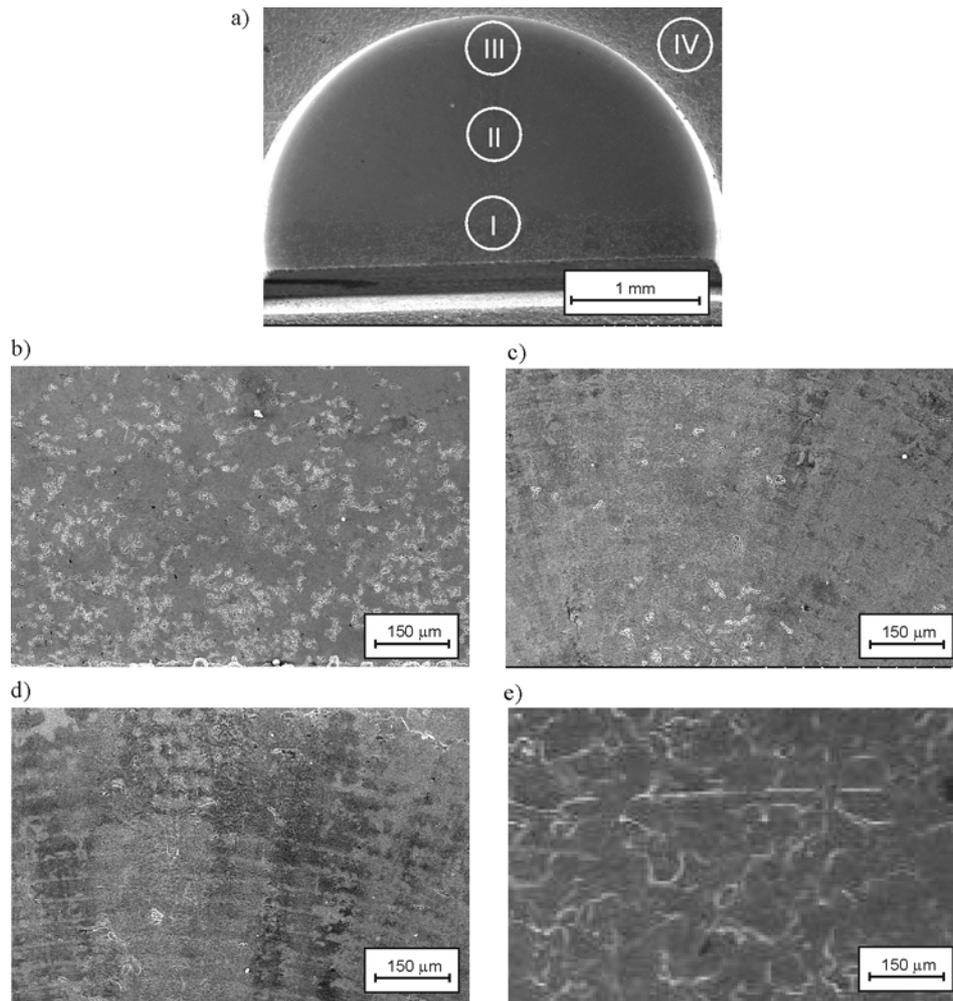


Fig. 10. The macrostructure of specific areas (b-I, c-II, d-III, e-IV) on the internal surface of joint (a)

$P_{\max}$  parameter (the maximum joining force) is very interesting one from the energy consumption of the process point of view. Its value directly indicates whether the tool size was selected properly. The shape and size of groove in the die bottom significantly influence the lock creation process and forming force value. The lower die groove width switches the sheet plate material flow direction when the lock is being created (Fig. 11). The shape change of created lock compared to the base model results (Fig. 12) is visible in the model with reduced groove width (the final phase of forming process). The lower the die groove width, the higher force is required to create the joint  $P_{\max}$  (Fig. 13). This

is accompanied by a relatively low neck thickness change ( $t_n$ ) and visible lock size change ( $t_s$ ). The low groove width generates high material flow resistance of joined sheet plates, and the forming resistance force values increases in the limited material displacement conditions.

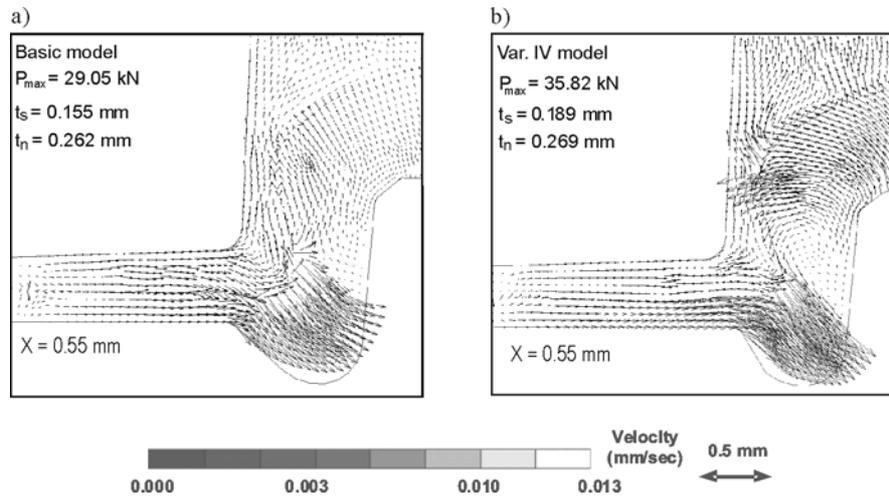


Fig. 11. Comparison of the material flow analysis during the restriking phase of the clinching joint: a) basic model, b) modification model

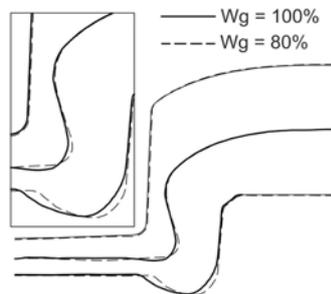


Fig. 12. The effect of a groove width on the lock line in the final joint

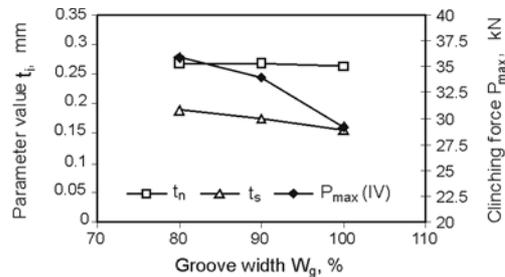


Fig. 13. The effect of relative groove width on the neck thickness ( $t_n$ ) and lock thickness ( $t_s$ ) and maximum forming force ( $P_{max}$ )

The change of punch and die edge rounding radius significantly influences the maximum forming force value. The modification of analyzed radius of tool used for joining process directly influences the lock shape (Fig. 14) and its parameters  $t_n$  and  $t_s$  (Fig. 15). The increase of relative punch radius increases the

forming force, whereas for the die – decreases its value relative to the value achieved for tools in the base model ( $R_p/t$ ,  $R_d/t = 20\%$ ) (Fig. 16).

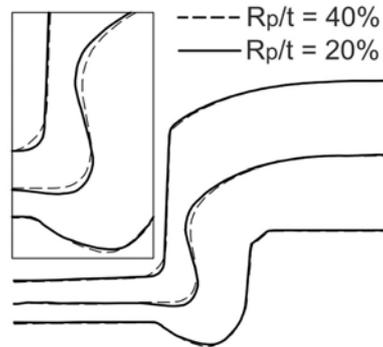


Fig. 14. The effect of punch edge radius on the lock line

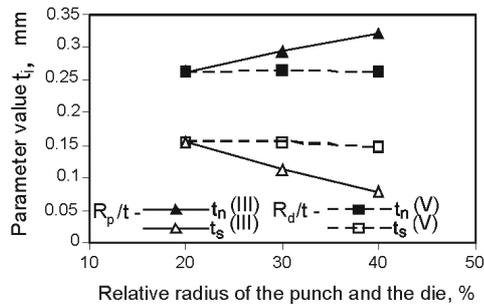


Fig. 15. The course of neck thickness ( $t_n$ ) and lock thickness ( $t_s$ ) variation as a function of relative punch radius ( $R_p/t$ ) and die radius ( $R_d/t$ )

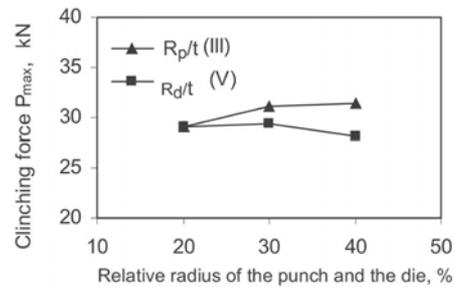


Fig. 16. The effect of punch and die edge rounding radius on maximum forming force

The variable groove width in the die is caused by modification the die impression depth (variant I and II). Based on results gained (Fig. 17 and 18) this can be stated that the die impression decrease reduces maximum joint forming force (variant I), but in variant II the force increases. The changes observed when the lock is being created, are illustrated by the final parameters (Fig. 13). The thickness of neck created ( $t_n$ ) in both cases is similar, the lock depth ( $t_s$ ) changes, though.

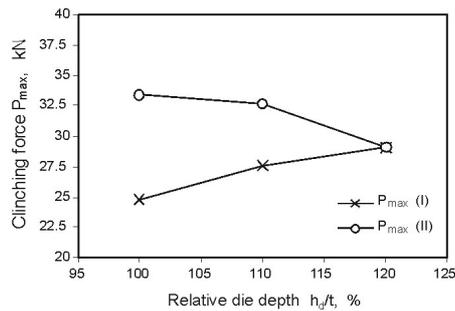


Fig. 17. The effect of relative die depth ( $h_d/t$ ) on maximum joint restamping force ( $P_{max}$ )

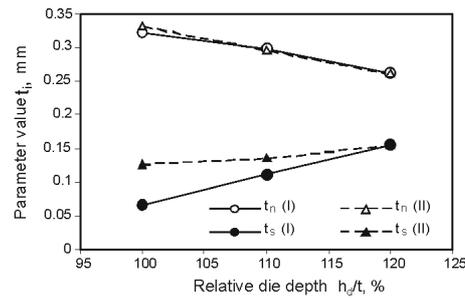


Fig. 18. The course of neck thickness ( $t_n$ ) and lock thickness ( $t_s$ ) variation as a function of relative die depth ( $h_d/t$ )

For all cases of tool geometry modification, the strain intensity distribution gained on the level not exceeding the experimental level (for a base model).

## Conclusions

The clinching technique has become an increasingly popular alternative to traditional spot welding due to the growing use of alternative materials which are difficult or impossible to weld. New sheet material and sheet combinations are constantly introduced in the automotive industry. As a consequence of this, new joining technologies are developed and old technologies are optimised.

When the experiment is supplemented with the numerical analysis, the tools can be designed and the joint quality at possibly low forming force can be accounted for. The energy consumption of the process can be reduced by effective joining process parameter selection without compromising the strength of such a created joint.

The die impression geometry, especially the groove, significantly influences the lock shape and parameters. A smaller „clinching” value shortens the time of connection. It decreases the time that the load affects the tool, which can lead to a significant increase in their life.

The results show that the mechanism of the groove width could be theoretically clarified on the basis of material flow analysis and stress distribution using the FEM.

The results obtained are the basis for effective design of the process of forming connections, taking into account the parameters of the forming process involved.

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