Publishing House
AKAPIT

COMPUTER METHODS IN MATERIALS SCIENCE
Informatyka w Technologii Materiałów

Vol. 15, 2015, No. 1

MODELLING OF CLINCHING JOINT PULL-OUT TEST

ZBIGNIEW GRONOSTAJSKI*, SŁAWOMIR POLAK, BARTOSZ BARTCZAK

Wrocław University of Technology, Łukasiewicza 27, Wrocław
**Corresponding author: zbigniew.gronostajski@pwr.wroc.pl*

Abstract

The paper presents the model of the tests on joints obtained by clinching (mechanical joining) high-strength TRIP690 steels. A numerical finite element analysis of the joint with a bottom thickness of 0.6, 0.7 and 0.8 mm was carried out using the MSC.MARC&MENTAT implicit software. Similarly as in the physical tests, numerical analysis predicted that the joint can carry a greater normal force when the thickness of the bottom is reduced. The model can be used in further studies aimed at determining the optimum shape and strength of such joints. In the literature, two basic modes of failure are distinguished. The first is associated with insufficient material deformation, whereas the second, with the lack of material in the joint's neck due to, for example, excessive displacement of the tools. For TRIP690 steel the only first mode of failure was observed.

Key words: high strength steel, FEM, clinching

1. INTRODUCTION

Mechanical press joining, also called clinching, is a method of joining in which parts of metal sheets are locally deformed without using any additional elements (Hahn & Horstmann, 2007; Varis, 2003). Press joining consists in the local pressing of one metal sheet into another in order to block the bottom of the pressed in sheet against the pressed out sheet. A protrusion forms in the pressed out sheet while a cavity forms in the pressed in sheet. The quality of such joints depends on the plasticity of the components being joined and on process parameters, including dimensions and shapes of the tooling and the magnitude of the applied pressure dependent on the materials being joined (Lee et al., 2010).

No heat is needed to produce this kind of joint. As opposed to conventional welding techniques, press joining proceeds without any heat effects on the layers of the materials being joined. A typical joint is formed in about 1 second. No preparation is needed, as opposed to many other joining methods, e.g., riveting requires the drilling of holes, gluing requires a bonding agent and a clean and rough surface and welding requires the preparation of the edges to be joined. A joint produced by press forming can be immediately subjected to load. The process is simple and without any unproductive time. Press joining can be used to join materials of different thickness and covered with different coatings (Oudjene & Ben-Ayed, 2008; Varis, 2006).

Studies have shown that the principal parameters determining the extent of failure of the joint are neck thickness and undercut width (figure 1) (Varis & Lepisto, 2003).

Clinched joints are increasingly often used in industry. The largest manufacturer of clinching tools is the Eckold company. It offers a wide range of press joining methods for different applications. Using Eckold tools one can join materials characterized by different properties.

Figure 2 schematically shows, how clinched joint R-PJ (round press-joining without cutting) is formed according to Eckold (Eckold). In order to make an R-PJ joint the metal sheets should be placed between the punch and the die and then a force

ISSN 1641-8581

should be applied to the punch, causing the local deformation of the sheets in the pressing operation until the force increases as a result of the contact between the sheets and the die which thanks to its segmental structure widens perpendicularly to the movement of the punch. Consequently, the material flows in the radial direction while the bottom of the joint is being compressed (press-through operation). Then the punch is released and the segment die returns to the initial position (Eckold).

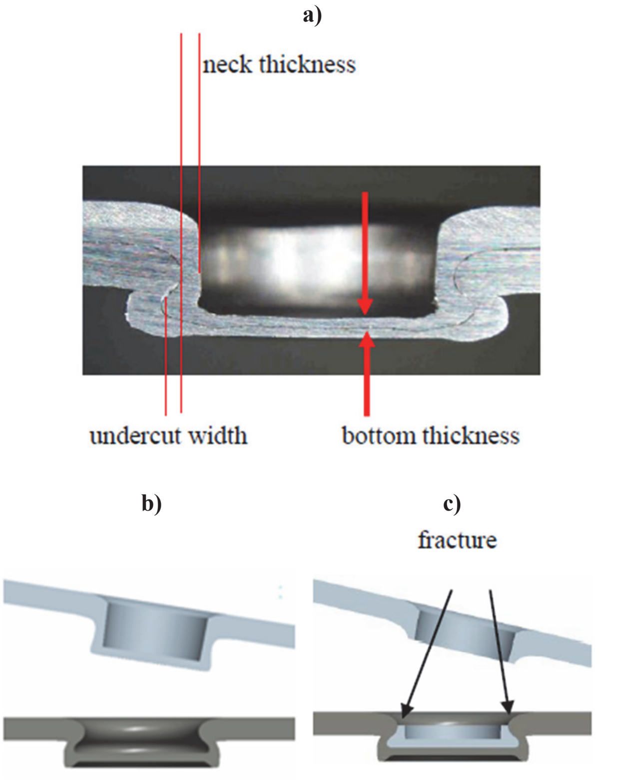

Fig. 1. Cross section through clinched joint R-PJ (a) and two types of joint failure (b),(c).

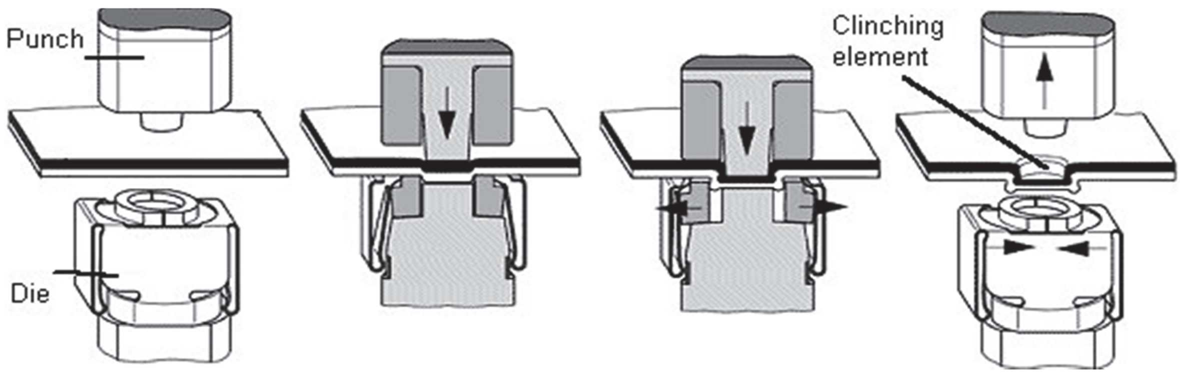

Fig. 2. Successive operations in formation of joint R-PJ (Eckold).

The special features and advantages of round press joining are:
– press joining without cutting,
– easy joining of materials characterized by different plastic properties,
– an element joined by press joining is gas-tight,
– neat appearance; there is only a slight elevation of the metal sheet on the die side,
– this press joining variant is particularly suitable for press joining sandwich plates.

The strength parameters of the joints made by clinching are determined by the pull-out and tensile tests performed according to the standards (figure 3).

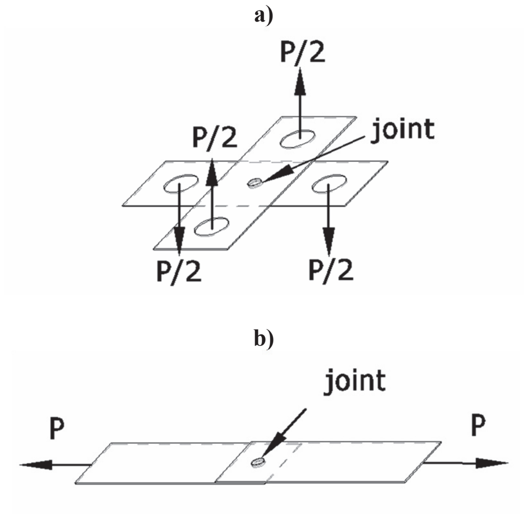

Fig. 3. Strength testing: pull-out test (a) and tensile test (b).

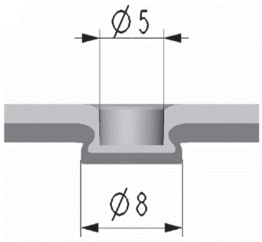

Fig. 4. Dimensions of clinching.

The aim of this research was to model the pull-out test of clinching joint with dimensions presented in figure 4 made from sheet of TRIP690 steel.

2. NUMERICAL MODELLING

A numerical analysis was carried out using the finite element method (FEM) MSC.MARC& MENTAT employing the implicit method for solving the system of equations. The formation of the clinched joint and its subsequent deformation during the pull-out test were analyzed.

Stage 1 – modelling of clinched joint

The clinched joint is not ideally but axisymmetric. However, since it would be difficult to take into account the actual small circumferential variations a simplified axisymmetric computing model, consistent with the dimensions of the tools used in the real process (figure 5), was adopted. The thickness of the TRIP690 sheet was 1.5 mm. The strass- strain curves determined in tensile test are presented in figure 6. The coefficients of friction between tools and sheet μ=0,1 and between sheets μ=0,15 were taken from previous research.

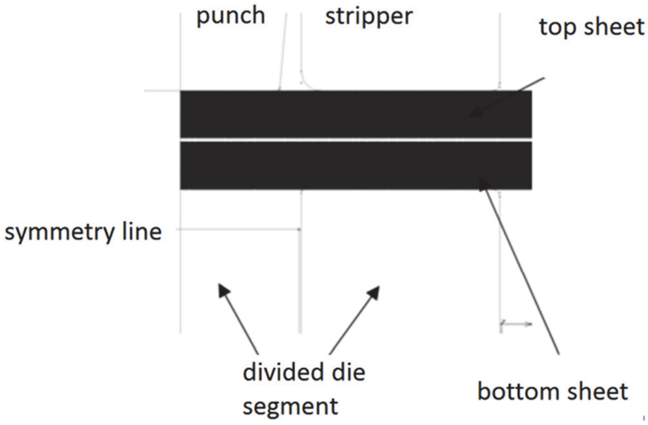

Fig. 5*. Axially symmetrical process scheme.*

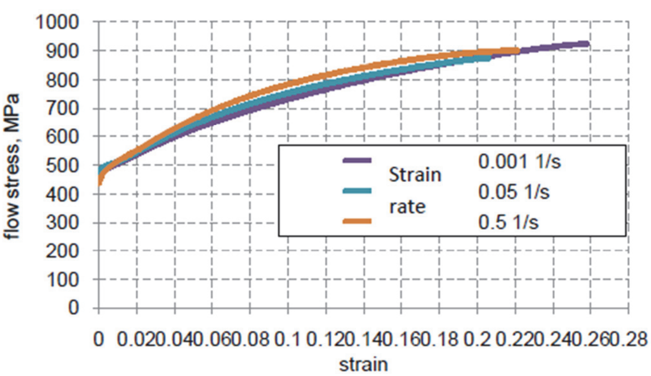

Fig. 6. *Stress-strain curve of TRIP690 steel for different strain rates.*

The shape of the joint obtained from mathematical modelling for 1.5 mm thick metal sheet TRIP690 is very similar to the actual joint (figure 7). The largest deformation occurred in the undercut region.

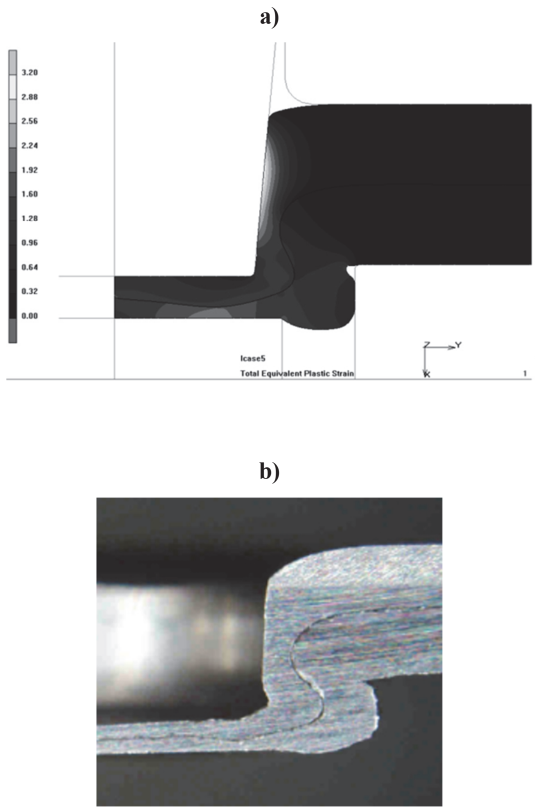

Fig.7. *Cross section of: a) mathematically modelled joint- strain distribution b) real joint.*

Stage 2 – modelling joint deformation during the pull-out test

The clinched joint model developed in Stage 1 was then used to model the pull-out test in 2D and 3D (figure 8). In the literature, two basic modes of failure are distinguished (Varis, 2003). The first is associated with insufficient material deformation (figure 1b), whereas the second, with the lack of material in the joint's neck due to, for example, excessive displacement of the tools (figure 1c). For TRIP690 steel the first mode of failure was observed.

The results of the simulation of joint tension are to a large extent consistent with the experimental results (figure 9). Similarly as in modelling, also in reality the joint undergoes local deformation and the top sheet slips off the bottom sheet as a result of plastic deformation in the undercut region.

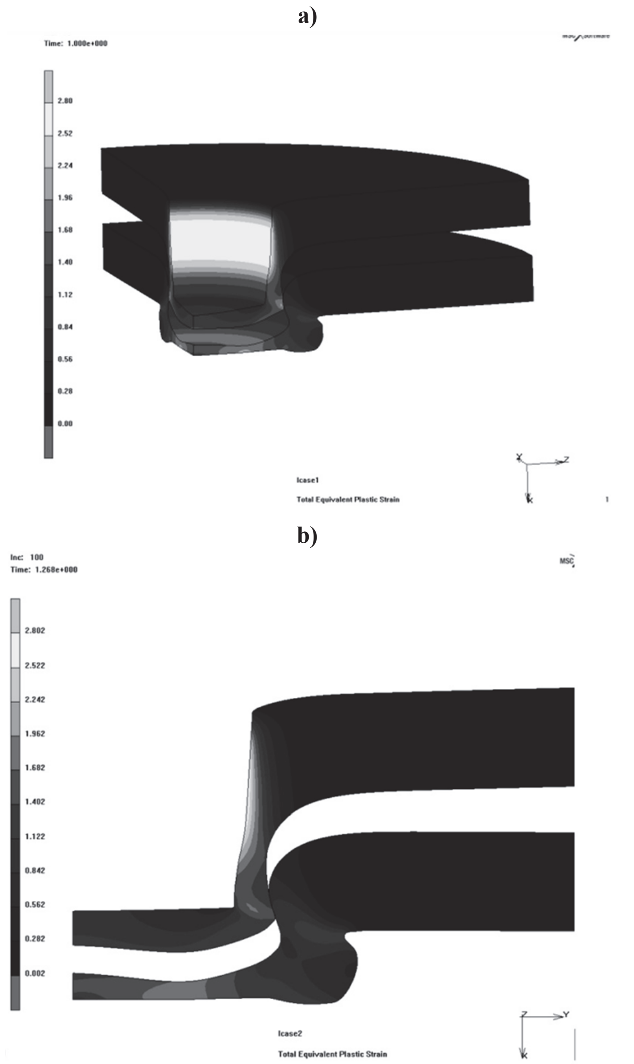

Fig. 8. Results of 3D (a) and 2D (b) pull-out test simulation for clinched joint, steel TRIP690 and 0.7 mm bottom.

greater normal force when the thickness of the bottom is reduced. The simulation results show slightly higher strength values than those obtained experimentally. The largest differences occur for the joints with a thicker bottom. For a 0.8 mm thick bottom the ultimate force amounts to 4 kN and 3.4 kN according to the simulation and the experiment respectively. For a 0.6 mm bottom the ultimate force according to the simulation amounts 4.2 kN, which is in full agreement with the experiment.

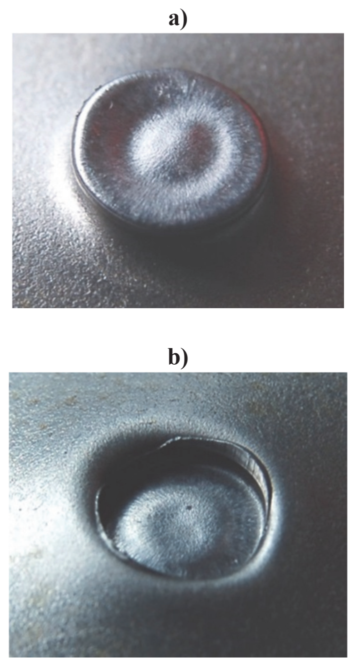

Fig. 9. View of clinched joint after pull-out test: top sheet (a) and bottom sheet (b).

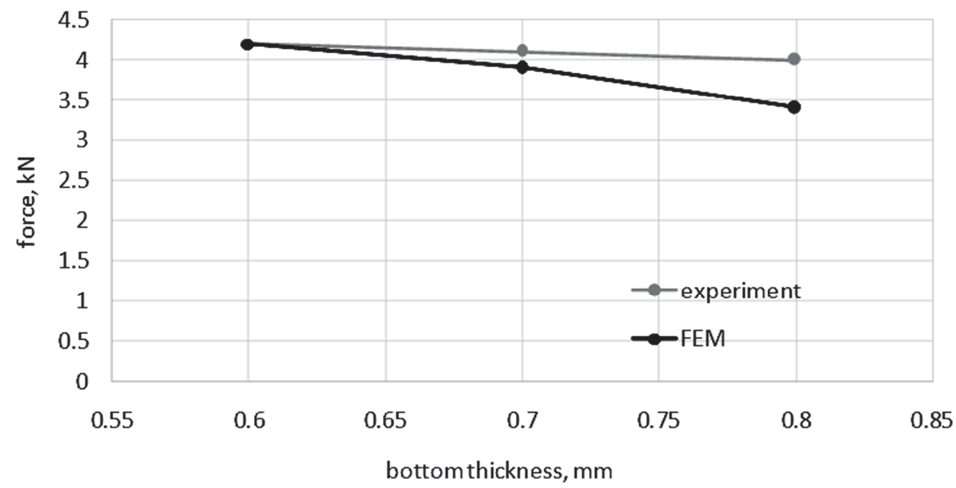

Fig. 10. Pull-out force for joints made of TRIP690 sheet metal with bottom thickness of 0.6mm, 0.7mm and 0.8mm for experiment and from FEM

The values of the pull-out force for joints made of sheet metal TRIP690, with a bottom thickness of 0.6, 0.7 and 0.8 mm, are shown in figure 10. Similarly as in the physical tests, the joint can carry a

3. CONCLUSION

The strength of materials influences the failure mode of clinching joints. In the case of soft material two modes are known. The first is associated with insufficient material deformation (figure 1b), whereas the second, with the low thickness of joint's neck (figure 1c). For the high strength material such as the TRIP690 steel the only first mode of failure was observed.

A numerical finite element analysis of the clinching joint pull-out test was divided into two steps: the formation of the clinched joint and its subsequent deformation during the pull-out test. The joints were carried out with a bottom thickness of 0.6, 0.7 and 0.8 mm. Similarly as in the physical tests, the joint can carry a greater normal force when the thickness of the bottom is reduced. The model can be used in further studies aimed at determining the optimum shape and strength of such joints.

REFERENCES

Hahn, O., Horstmann, M., 2007, Mechanical Joining of Magnesium Components by Means of Inductive Heating- Realization and Capability, *Mater Sci Forum*, 539-543, 1638-1643.

Lee, C-J., Kim, J-Y., Lee, S-K., Ko, D-C., Kim, B-M., 2010, Design of Mechanical Clinching Tools for Joining of Aluminium Alloy Sheets, *Mater Design*, 31, 1854–1861.

Oudjene, M., Ben-Ayed, L., 2008, On the Parametrical Study of Clinch Joining of Metallic Sheets Using the Taguchi Method, *Eng Struct*, 30, 1782–1788.

Varis, J.P., 2003, The Suitability of Clinching as a Joining Method for High-Strenght Structural Steel, *J Mater Process Tech*, 132, 242-249.

Varis, J.P., 2006, Ensuring the Integrity in Clinching process, *J Mater Process Tech*, 174, 277–285.

Varis, J.P., Lepisto,, J., 2003, A Simple Testing-Based Procedure and Simulation of the Clinching Process Using Finite Element Analysis for Establishing Clinching Parameters, *Thin Wall Struct*, 41,691-709.

MODELOWANIE TESTU WYRYWANIA POŁĄCZEŃ KLINCZOWANYCH

Streszczenie

Artykuł przestawia modelowanie testu wyrywania połączeń klinczowanych wykonanych ze stali TRIP6900. Analiza numeryczna została przeprowadzona dla połączeń o grubości dna 0.6, 0.7 i 0.8 mm za pomocą metody elementów skończonych (MES) przy użyciu programu MSC.MARC&MENTAT. W modelowaniu, podobnie jak w badaniach eksperymentalnych, zmniejszenie grubości denka powoduje wzrost siły normalnej przenoszonej przez połączenie. W literaturze opisane zostały dwa rodzaje zniszczeń połączeń klinczowanych. Pierwszy związany z niewystarczającą odkształcalnością materiału, natomiast drugi wynika ze zbyt wąskiej szyjki. Dla stali TRIP690 zaobserwowano tylko pierwszy rodzaj zniszczenia. Zbudowany model może być wykorzystany do określania optymalnego kształtu i wytrzymałości połączenia klinczowanego.

Received: November 11, 2014
Received in a revised form: December 10, 2014
Accepted: December 15, 2014