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clinch joint, undercut, neck

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THE INFLUENCE OF ORIENTATION OF SEGMENTED DIE ON CLINCH JOINTS MECHANICAL PROPERTIES

This paper presents the results of joining of 1,5 mm thick high-strength steel grades including DP600 and TRIP. Joints were manufactured using C-type clinching machine. The diameter of the tools used in joining process was selected according to the thickness of sheet metal plates. Shearing tests of manufactured joints were conducted with the use of universal testing machine. Bottom thickness of clinches amounted to: 0.6mm, 0.8mm and 1.0mm. Afterwards the joints were cut through in three different planes: two orthogonal and one intermediate. The influence of orientation of die opening plane on the value of the thickness of the neck and the width of the undercut was analyzed. Those parameters are directly responsible for joints shear and transverse tensile strength. The distinct influence of the orientation of die opening plane on the investigated parameters were presented.

1. CLINCHING PROCESS

One of the key steps of designing process of new constructions of machines and equipment is the selection of materials and suitable elements joining technology. Second factor, although often considered as insignificant, plays very important role. Even the most modern materials without the development of efficient joining technology will not find commercial application. The widespread use of spot welding for connecting thin-walled components in the automotive industry favors metals and projects of some steel structures. A similar situation can be observed in the aerospace industry, where the use of advanced welding techniques contributed to the significant use of aluminum alloys in airplanes load-carrying structures. Modern passenger aircrafts consists of more than 65% aluminum by weight [1]. Joining technology is often factor that results in the increase of competitiveness of some materials and intensification of research focused on their property.

One of the most interesting materials joining technology is clinching. This method consist in plastic deformation of joined materials. It is a technique for creating inseparable joints, which means that they will be irreversible damaged during disassembly process. Clinching allows for mechanical joining of two or more thin walled sheets without using

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additional elements. Described technology consists in mechanical forcing of upper sheet by the stamp in the lower sheet placed on die. After the contact of sheet metal plates and abutting surface of the die, joining of materials starts. There are two important stages of this process: at the beginning sheet metal plates are deformed and then further radial flow of the material occurs. It results in thinning of the bottom of joint and clinch joint creation as a final result.

The most important advantages of the clinching technology are:

- low cost of production of the joints. It is related to the lack of additional elements, low cost of purchasing the necessary equipment and instrumentation, low joining forces, high durability of punches and dies used in the process and the high energy efficiency of the process itself,
- the absence of: harmful fumes, sparks, high-intensity of sound, bright light or high temperatures, which makes the process operator-friendly,
- the possibility of joining various thickness, dissimilar materials (such as steel and aluminum) without pre-treatment of the surface. It is also possible to join materials with protective coatings without their destruction,
- high aesthetics of produced joints and the possibility of selection of solution that ensures hermetic joints,
- high shearing strength of clinch joints (up to 70% of strength of the spot-weld joints of the same diameter) combined with definitely higher elongation at rupture (even 100% higher).

Described advantages of clinch joints result in wide use of this technology in the automotive industry, white goods industry and for joining less responsible thin-walled components.

The clinching has been known for many years. Recently increased industrial interest in this joining method was noticed. It is caused by successful replacement of other joining techniques, such as spot welding, by clinching. Varis [2] studied several different clinching methods. The conclusion from his study was that all clinching method could be used successfully for every kind of steel, excluding high-strength materials. The most significant result was that the round tool is appropriate for all of tested materials. Sawa et al. [3] studied aluminum/mild steel clinch joints with adherents between metal sheets subjected to tensile shear loading. Mucha et al. [4] analyzed the effect of material thickness, sheet type and die construction on the joint strength. In this extensive study the results of clinch joints shearing strength analysis was presented. Taguchi's [5] presented design of experiments method in order to investigate the effects of the neck thickness and clinch lock on the clinch joint strength with the use of ABAQUS/Explicit finite element method. S. Coppieters et al [6] presented an analytical approach to estimate the pull-out strength.

2. TESTED MATERIALS

Two different materials were selected for the tests. The first of them was DP600 (Dual Phase) steel grade. It has multi-phase microstructure (Fig. 1a). The matrix is a soft ferrite, whose presence is beneficial for plastic properties. This results in a relatively large elongation ranging from a few to several percent. The second phase is a hard, located between the grains of ferrite, martensite inclusion. This phase is responsible for a significant increase of the material strength and its strengthening during cold forming of products [7],[8]. Described structure allows to achieve Rm/Re ratio of 2.

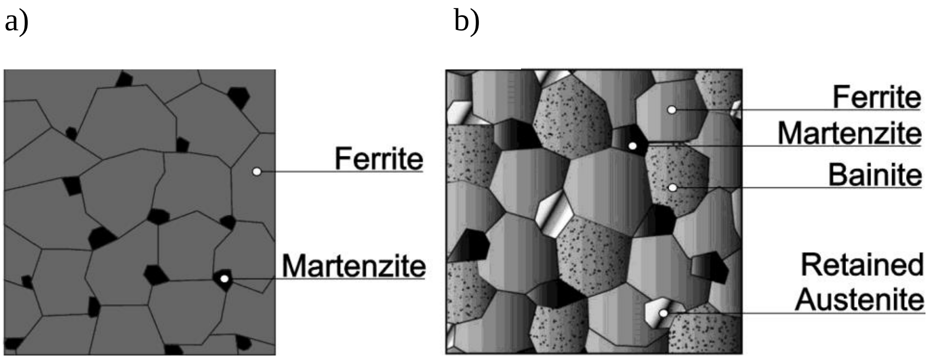

Fig. 1. The microstructure of the tested materials [9]: a) DP steel b) TRIP steel

The second material was TRIP (Transformation Induced Plasticity). It strengthens by phase transformations. It is a low-alloyed material, which combines high strength and good plastic properties. This steel grade has characteristic microstructure (Fig. 1b), obtained by hot rolling and multi-stage cooling. It consists of (5-15)% of retained austenite phase in a matrix of ferrite α (50-55)%, martensite (1-5)% and bainite (30-35)% [10]. Hard phases allow to obtain high strength, which is additionally enhanced by residual austenite islands. During deformation retained austenite phase is transformed into martensite, thereby changing the percentage composition of the individual phases. In contrast to other DP steel grades, described behavior allows to achieve definitely higher levels of ultimate tensile stress and strain.

3. PREPARATION OF SAMPLES

Most authors investigating clinching technology emphasizes that the shear strength of the joints is determined by the thickness of the neck. They also emphasize that the width of undercut is directly connected with transverse tensile strength. This statements are also emphasized in paper "Ensuring the integrity in clinching process" of one of the first researcher of clinching technology – Varis. Moreover, in many studies it is assumed that the joints prepared by round tool have constant dimensions along circumference. In order to verify these assumptions authors planned to test joints geometry in different cross-sections. The joints were manufactured by the C-type DFG 500/150 DW Eckold clinching machine (Fig. 2).

Strips were cut out with the use of numerical guillotine. Specimens were made of 50mm long and 25mm wide strips of steel. R-DF tools were used in order to prepare round connections.

a) b)

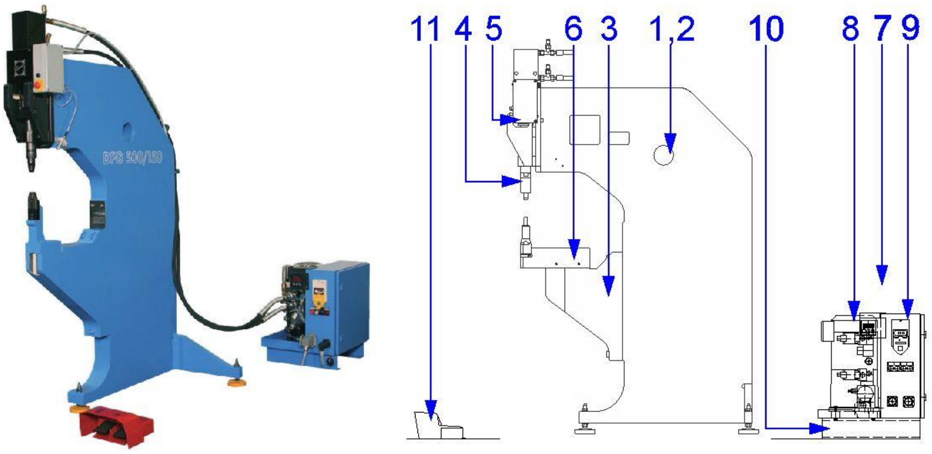

Fig. 2. C-type DFG 500/150 DW Eckold clinching machine [11]: a) general view, b) machine diagram
1 – c-frame column, 2 – stand, 3 – table, 4 – tool carriers, 5 – drive unit, 6 – shackle, 7 – hydraulic unit, 8 – hydraulic equipment, 9 – electrical equipment, 10 – mechanical equipment, 11 – footswitch

Joints were realized by plastic deformation, without the ruptures of the joined sheet metal plates.

a) b)

Fig. 3. The tools used for joining
a) tools installed in the machine DFG 500/150, b) the shape of the tools

The diameter and shape of the tools have been selected from the commercial catalog based on the thickness and type of combined materials. Tools (Fig. 3) used for realization of joints allowed to create joint characterized by 5mm internal diameter and 8mm external diameter (die-side diameter). Final form of joints used in destructive tests is depicted in Fig. 4.

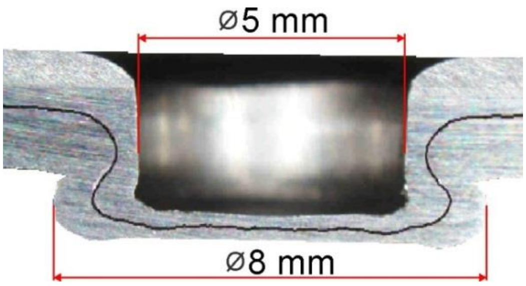

Fig. 4. The cross-section of the clinch joints

Three different samples were made. The bottom thickness of samples amounted to: 0.6mm, 0.8mm and 1.0mm. The thickness of the bottom was controlled by the piston displacement limiter (Fig. 5). In order to increase path length of the punch, limiter should be turned counterclockwise (+). This reduces the thickness of the bottom. Turning to the limiter clockwise (-) results in reduction of the path length and consequently increase the thickness of the joints bottom.

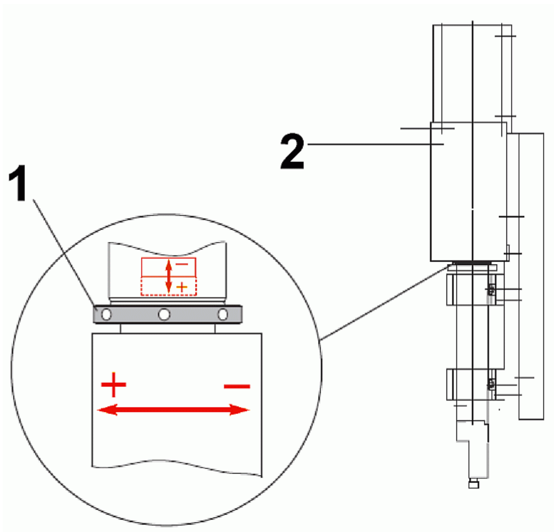

Fig. 5. The control system of punch displacement [11]
1 – piston displacement limiter, 2 – drive unit

For the purpose of study TRIP and DP600 clinch joints were made. The thickness of both steel sheets amounted to 1.5mm. In order to investigate geometric parameters 77 samples were made. Such a wide range resulted from the testing of various materials, different bottom thickness and different joints orientation in respect to the direction of shear force. A detailed list of the samples is shown in Table. 1. Each series consisted of a 4 samples minimum.

In order to conduct shear tests of clinch joints additional samples were made. They have been prepared according to the spot joints shear testing resistance standard (EN ISO 14273:2001).

Table 1. List of specimens

Material	Direction [°]	Bottom thickness [mm]
DP	0°	0.6; 0.8; 1.0
	45°	0.6; 0.8; 1.0
	90°	0.6; 0.8; 1.0
TRIP	0°	0.6; 0.8; 1.0
	45°	0.6; 0.8; 1.0
	90°	0.6; 0.8; 1.0

Specimens were made of 100mm long and 45mm wide strips of steel. Strips were cut out with the use of numerical guillotine (simple shear with control equipment) and clinched with 35mm overlap (Fig. 6).

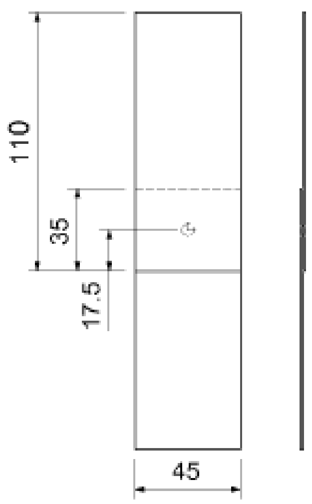

Fig. 6. Dimensions of the specimens

4. EXPERIMENT

The conducted research was mainly focused on the analysis of basic geometric parameters determining ultimate strength of the clinch joints. The most important amongst investigated parameters were: undercut „z" resulting from the radial flow of the material and neck thickness „p" occurring in upper sheet (on the side of punch). The repeatability of specified dimensions in different cross-sections of the joints was also analyzed.

Connections were cross-cut with the use of precise Struers Secotom-50 cut-off machine (Fig. 8a). Selected joints were fixed in the chucks in the directions depicted in Fig. 9. Samples were cut through with the use of 1mm thick disk-type grinding wheel at a speed of 3300rev/min.

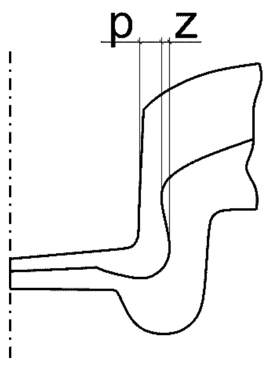

Fig. 7. The most important parameters of clinch joints [7a]: p – neck thickness; z – undercut

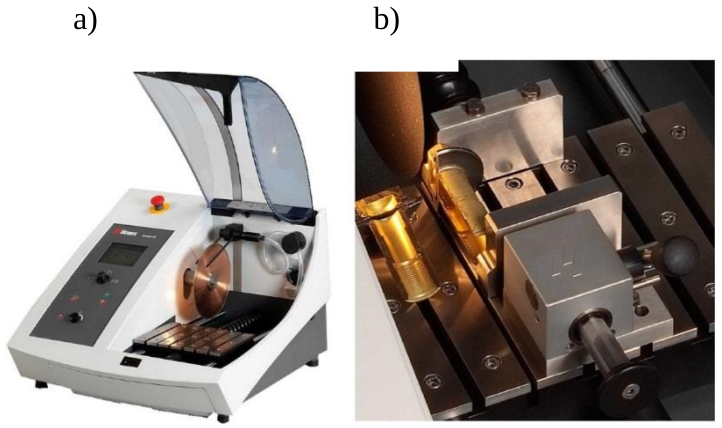

Fig. 8. Struers Secotom-50 cut-off macine [12]: a) general view; b) operating part

The measurements were carried out in three different sections (Fig. 9):

- „0°" – parallel to the direction of the die opening,
- „45°" – intermediate section,
- „90°" – perpendicular to the direction of the die opening.

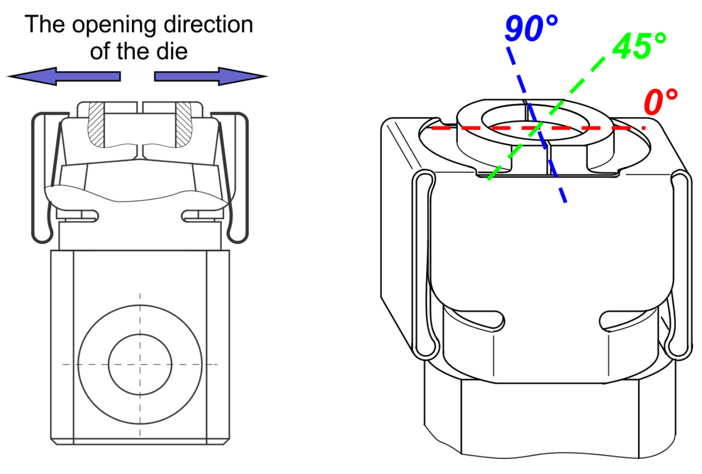

Fig. 9. The cutting directions of the samples [11]

The influence of the clinch joints orientation on their maximum shearing force was also examined. Shearing tests were performed with the use of Instron 3369 two-column, universal testing machine (Fig. 10). It was equipped with a load cell with a measuring range of 0–50kN.

Fig. 10. The test stand for the quasi-static tensile experiments [13]

The tests were performed for the cross-beam constant speed: 0.48mm/min. The frequency of data recording was adjusted to the duration of the measurement and amounted to 1Hz. During measurement the force as a function of the sample holder displacement was recorded on a PC and then the maximum value of the force was determined. Shear tests were conducted only for the bottom thickness of specimen equal to 0.8mm (according to the directions depicted in Fig. 11). The study was performed for two materials: DP600 and TRIP.

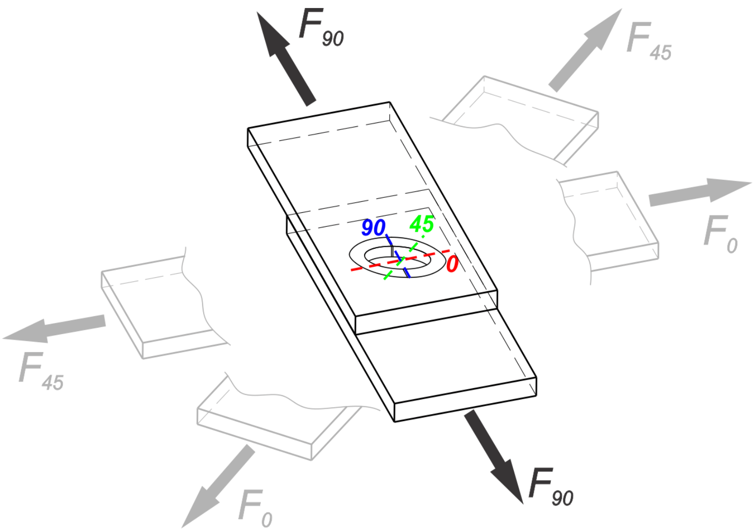

Fig. 11. The main loading directions of clinch joints

5. RESULTS AND DISCUSSION

The influence of the orientation of the clinch joints on the value of analyzed parameters was studied. Significant impact of examined cross-section orientation on the value of undercut was observed (Fig. 12a). In case of section 90° undercut width was lower than in other sections. The differences reached up to 200µm (e.g. 0.6 mm DP600 joints: directions 45° and 90°). The reason for this phenomenon is greater resistance of die in the direction of 90°, than in the direction of die opening 0° – particularly in the first moments of clinching.

Further analysis have been conducted, in particular the variance. Confidence intervals for parent population were determined using Gaussian distribution for the level of significance α = 0.05 (95% confidence level). The standard deviation was calculated using the "n-1" method. It was noticed that, regardless of the steel grade and the thickness of the bottom, in all series undercut confidence interval in the direction of 90° was significantly lower than for other directions (Fig. 12b). This clearly demonstrates the stability of the undercut width in the cross-section perpendicular to the direction of opening of the die. The authors states that this fact, as well as lower values of the undercut in the direction of 90°, results from characteristic construction of the die. Large scatter of results in the direction of 0° is also caused by the variation of material to die friction.

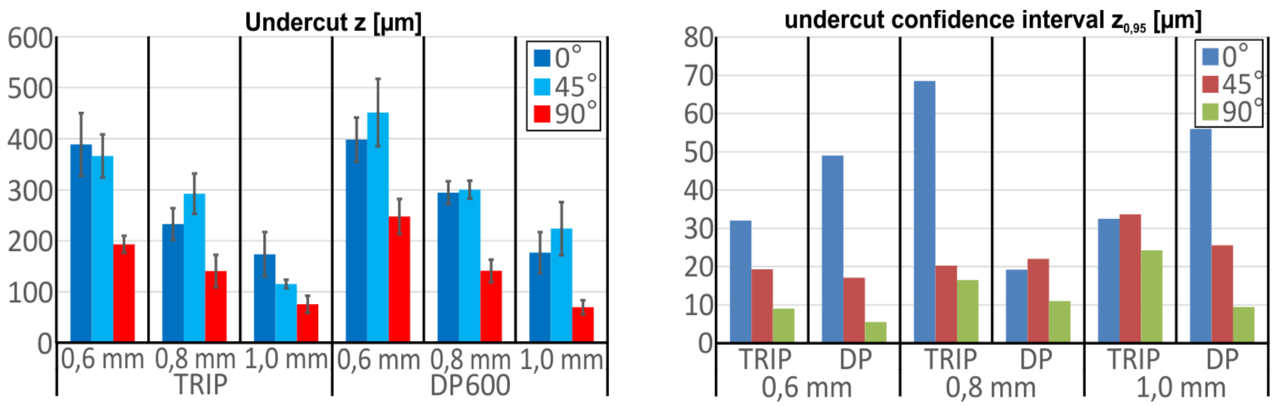

Fig. 12. The influence of orientation on size and confidence interval of undercut

According to the theory, the joint characterized by greater thickness of the neck should transmit greater force. Conducted research confirms this assumption. However, it should be noticed that the thickness of the neck, as well as undercut width changes depending on the cross-section. In case of DP600 steel highest tensile force occurred in the direction of 0° and amounted to 5592N (Fig. 13). The greatest neck thickness amounting to 520µm was recorded in the direction of 90°. A similar dependence was observed for both types of steel in the directions of 90° and 0°. Conducted studies allows to conclude that the greatest impact on the maximum value of the shear force has the thickness of the neck in the cross-section perpendicular to the force direction, not general neck thickness.

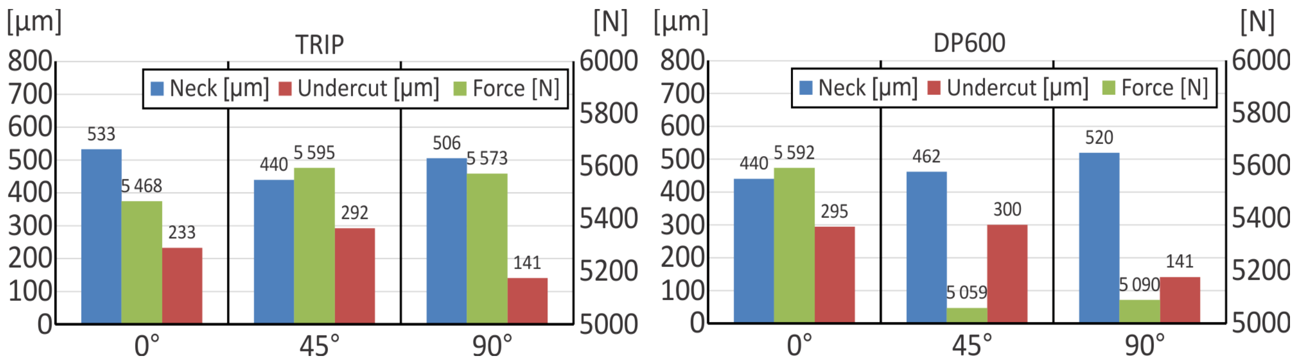

Fig. 13. The influence of neck thickness and undercut width on shear force

Additionally, in case of DP600 steel grade the largest thickness of the neck occurs always in the direction of 90°, which is perpendicular to the direction of opening of the die (Fig. 14). In case of this steel grade it is recommended to perform clinches so as to maintain the consistence of following directions: die opening and shear force. In case of TRIP steel it is not clear what orientation of the joint is the most advantageous. Joining of this material requires additional tests to determine the direction in which the thickness of the neck is the highest every time the thickness of the bottom changes.

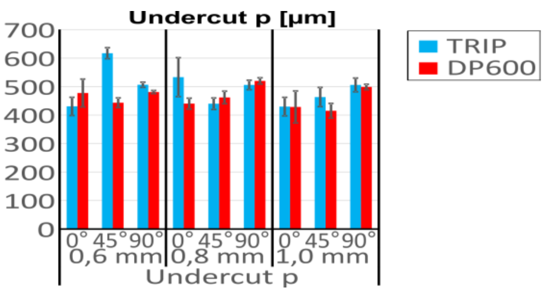

Fig. 14. The influence of clinch orientation and bottom thickness on the neck

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