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Experimental study on DP600 clinched joints

Badanie eksperymentalne łączeń klinczowanych DP600

Abstract

Clinching is an effective joining technique for lightweight sheet materials that are difficult or impossible to weld. Clinching is a relatively new technology in which two to three sheet metal parts are joined together by a process of local plastic deformation without the use of any additional components with the application of a special tool. In this study, an experimental investigation of clinch joints was performed. A non-standardized technique was used to determine the optimal joint geometry for further experiments. The used material type was DP600 (dual-phase, advanced high strength steel).

Keywords: clinching, clinching method, DP600

Streszczenie

Klinczowanie jest skuteczną metodą łączenia stosowaną przy lekkich materiałach arkuszowych, w przypadku których spawanie jest niemożliwe. Klinczowanie jest relatywnie nową metodą, w której 2–3 arkusze blachy są łączone w wyniku miejscowego odkształcenia plastycznego dokonywanego bez użycia żadnych dodatkowych komponentów, za pomocą specjalistycznego narzędzia. W tym badaniu dokonano eksperymentalnej analizy łączeń klinczowych. Do ustalenia optymalnej geometrii łączeń w dalszych eksperymentach użyto niestandardowej techniki. W badaniu został użyty materiał DP600 (dwufazowa wysokowytrzymałościowa stal).

Słowa kluczowe: klinczowanie, metoda klinczingu, DP600

1. Introduction

These joints are used mostly in the automotive, computer, and aircraft industries; however, according to the standards, it is not allowed to be used in the food industry, for instance [1–3]. The clinch joints are quite new types of joints; the first patent was accepted in 1989. This joint can be done between two to three thin sheet plates. A cross section of a joint can be seen in Figure 1. This figure shows the main geometrical parameters

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of a joint (two sheets were joined). The undercut size (*C*) and the size of the neck thickness (t_N) greatly affect the strength of the joints. In an optimal case, both values are as high as possible.

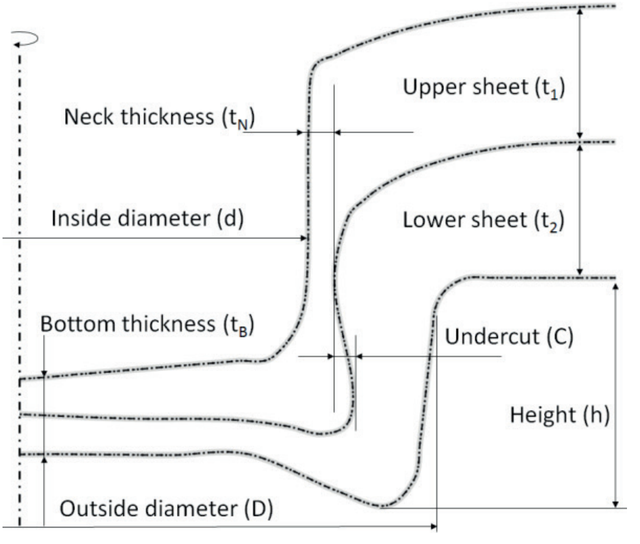

Fig. 1. Cross section of clinched joint and main geometrical sizes

The material of the plates can be ferrous or non-ferrous at the same time, so this joint can realize dissimilar joints without any added material (weld material or glue). The joint is made by metal plastic forming by a special tool. After the patent, the increasing industrial needs of this type of joint led the researchers to analyze the joint much more deeply. Several studies carried out the geometry optimization of the clinching tool to get better joints by different optimization methods [4, 5]. Other studies were carried out on the so-called hybrid joints. These joints have an adhesive layer between the sheets. These joints have higher strengths, but these joints need much more time because of the adhesive layer's drying is a time-consuming process [1, 6, 7].

2. Identification of material

The used material type is the DP600 type of steel. DP600 is an advanced high-strength steel that is a multiphase (ferrite and martensite) steel with an excellent combination of strength and formability. Dual-phase steel (DP) consists of a soft ferrite matrix with a disperse hard second phase in the form of islands. It possesses high strength, high work hardening rates, and high strain energy absorption properties [8].

Figure 2 shows the microstructure of the used steel. For preparation of the specimen, 100–200–600–1200-μm series of sandpaper, 3 μm of polish pasta, and 3% of Nital were used. The measurements were done with a Carl Zeiss microscope with an image recognition software module. The image analysis was carried out in ten places on two specimens. According to the measurements, this steel contains ~23% of martensite (with an average grain size of 5 μm). For the chemical composition, a piece of 60-μm sandpaper was used. The measurements were performed with an Oxford Instruments Foundry Master Pro spectroscopy device. The chemical composition can be seen in Table 1 (the average of 13 measurements).

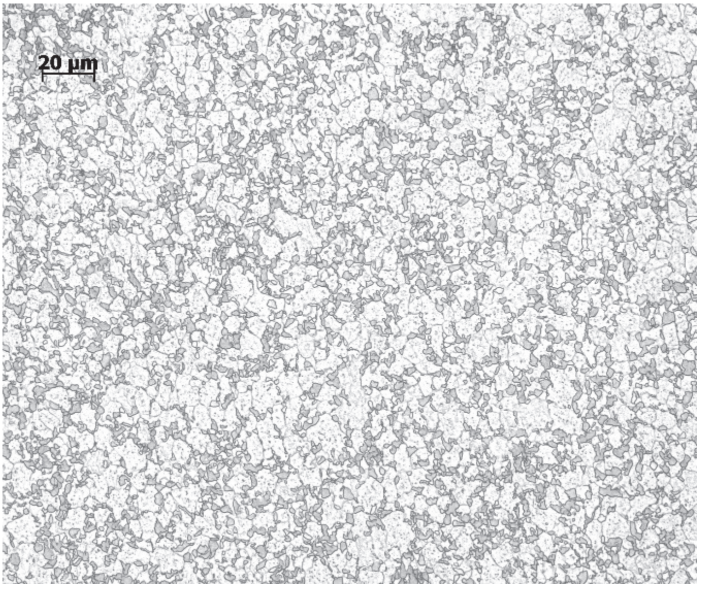

Fig. 2. Microstructure of DP600 (light – ferrite; grey – martensite)

Table 1. Chemical composition

	Fe	C	Si	Mn	P	S	Cr	Mo	Ni
wt.%	98.6	0.116	0.171	0.876	<0.005	<0.005	0.0262	0.0077	0.0362
	Al	**Co**	**Cu**	**Nb**	**Ti**	**V**	**W**	**Pb**	
wt.%	0.0553	0.0125	0.0074	0.0214	<0.005	0.0124	0.0103	0.0114	

Tensile tests were performed at the University of Miskolc in a previous research project [1] to determine the mechanical properties with an MTS electro-hydraulic testing machine. These results can be seen in Table 2.

Table 2. Mechanical properties

Parameter	Unit	Mean value	0°	45°	90°
Ultimate tensile strength, R_m	[N/mm^2]	680	669	679	691
Yield strength, $R_{p0.2}$	[N/mm^2]	451	448	451	454
Fracture elongation, A_{80}	[%]	19	19	20	18
Hardening exponent, n	[–]	0.14	0.14	0.14	0.14
Anisotropy, r	[–]	0.81	0.71	0.73	0.98

3. Clinching process

The TOX-produced clinching tool was set up in an MTS servo-hydraulic testing machine. The maximum load that the tool can survive is 50 kN. The setup can be seen in Figure 3. The first seven specimens were prepared for the Charpy test. The specimens were pre-drilled for this application. Two holes were drilled that, on the one hand, centralized the specimens and, on the other hand, prevented them from moving.

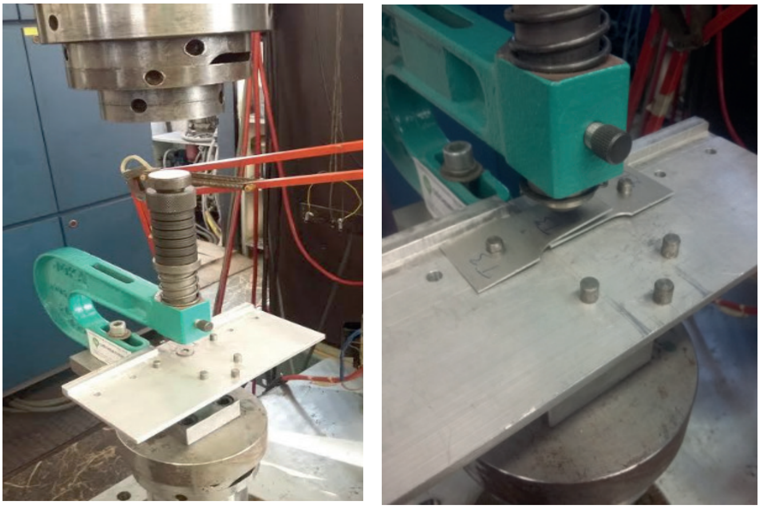

Fig. 3. Clinching test setup

The force-displacement curves (Fig. 4) were recorded in each case. According to [9], the measured curve can be divided into three main phases and five steps. In Phase I, the testing machine starts to work, the punching tool moves down, the holder moves downward to fix the sheets, the tool comes in contact with the upper sheet (punch side), and the joining process is started (Step I). The tool punches the sheets, and they move together (Steps I and II); this part of the process continues to the first bending point (Step II). The lower sheet (die side) reaches the die; this is why the slope of the curve changes after Phase I. In Phase II, the sheets start to flow around the punching tool and start to flow inside the free space of the die (Step III). The last part of the process needs more deformation force; the curve raises the highest slope. In Step IV, the punching tool reaches the end position. In this phase, the setting force also reaches the maximum point. After this, the tool begins to be removed from the joint with a certain slope (which is according to the stiffness of the machine). After Step V, the joint is released completely.

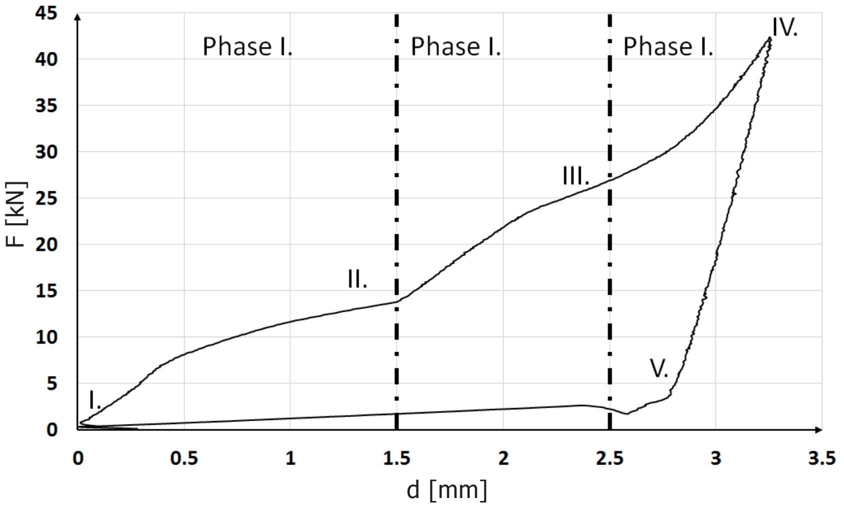

Fig. 4. Force-displacement (F-d) curve

3.1. Determination of optimal bottom thickness

To reduce the time necessary in finding the best joint with a given tool, impact tests were performed. The basic idea of using the impact tests was that the joint with the highest value of impact energy should be the best joint. Based on previous studies at the University of Miskolc [10–12], the best choice of thickness of the bottom layer was already quite well-known; only three thicknesses were tested. From these impact energy values, the highest was analyzed for further testing. For the tests, a standard Charpy impact tester was used (which was instrumented). The clamping device was developed for these types of tests. Figure 5 shows the testing machine, and Figure 6 shows the device with a specimen after clinching. This measurement is not a standard method; however, it can be used for comparison. To analyze the joint, the specimens were tested on both sides. The two layouts can be seen in Figure 7.

Fig. 5. Charpy test machine

Fig. 6. Clamping device

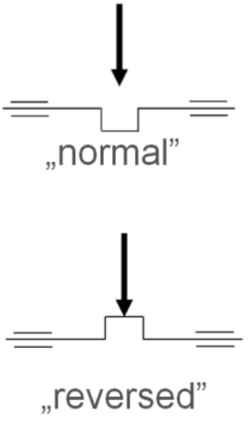

Fig. 7. Test lay-outs

Figures 8–10 show the test joints' cross sections with different bottom thicknesses. According to the tests, the optimal bottom thickness for DP600 steel with the used clinching tool is 0.55 mm (Fig. 9).

Fig. 8. High forming force; tB = 0.46 mm

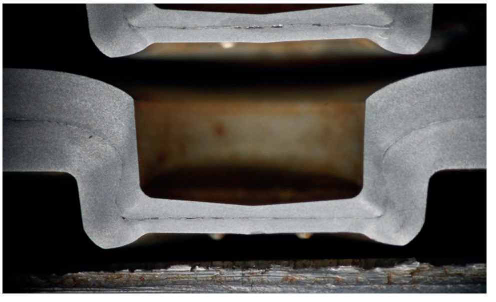

Fig. 9. Optimal bottom thickness; tB = 0.55 mm

Fig. 10. Small undercut; tB = 0.65 mm

To prove the strength, six specimens were tested in "normal" mode. The scatter is low (less than 1 J). The results (Fig. 11 – dark grey bar) show that the reversed specimen layout has a higher ability to absorb the impact energy (the median of the six normal specimen + 4 J). The explanation of this high energy absorption is due to the fact of the upsetting of the joint, which means the convex side of the joint pushed through the sheets before the bending of the sheets. This phenomenon needs more energy compare to the normal layout joints because of the extra forming phase during the impact. This observation can be useful for design considerations.

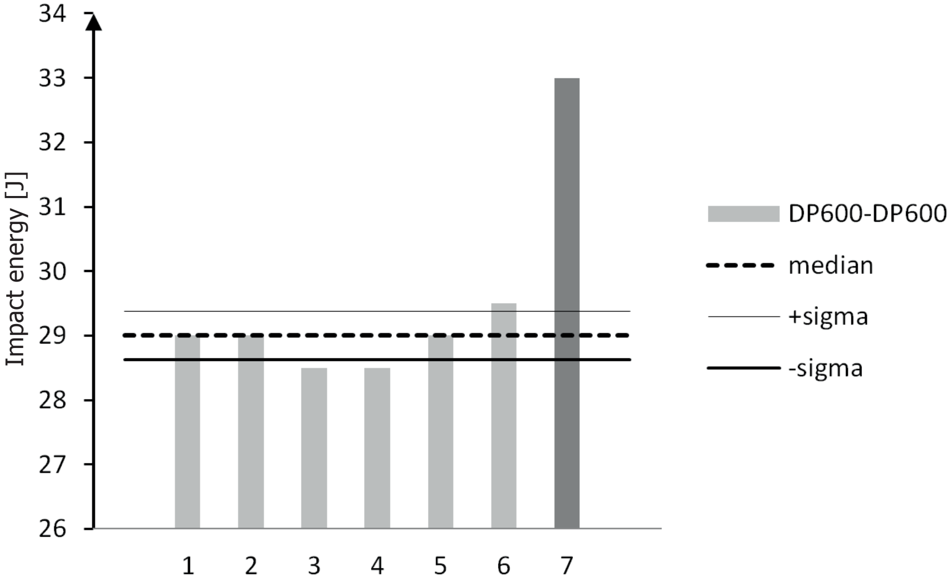

Fig. 11. Impact energies of specimens (seventh specimen is with reversed layout)

3.2. Determination of joint strength

Three types of tests were performed with the optimal bottom thickness to determine the static strength of the joints. Each test was performed with three specimens with the same MTS testing machine. The dimensions of the sheets were $100 \times 30 \times 1$ mm^3 in each case. The test setups can be seen in Figures 12–15. The testing methods are similar to standard spot-weld testing methods. The joints have four types of common failure modes due to the mechanical stress: full shear, half shear, unbuttoning with cracking, and full unbuttoning [5]. In this study, the failure mode was in full unbuttoning mode except for the pull tests. In the case of the pull tests, the full shear mode was the dominant failure mode (as can be seen in Figure 15).

The testing speed was 1 mm/s in the cases of the peel and box tests and 0.2 mm/s in the case of the pull tests. The lower test speed in the case of the pull test is needed because of the small displacements before the failure [1]. The specimens for the peel tests and box tests were bent after clinching with a special tool.

The results of the tests can be seen in Table 3. These values are less than the spot-welded joints between the same materials [4]; typically, the strength is just 70% of the spot-welded joints [2].

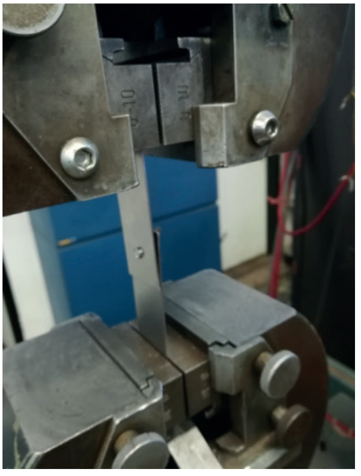

Fig. 12. Pull test setup

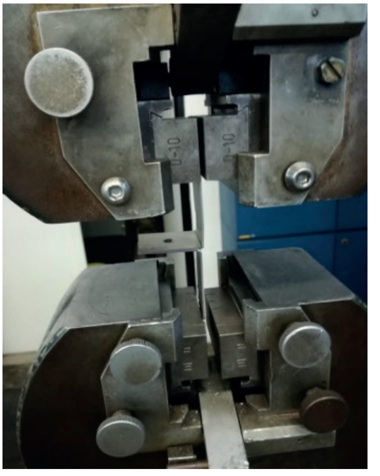

Fig. 13. Peel test setup

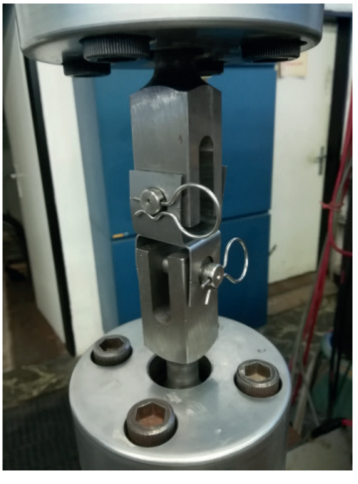

Fig. 14. Box test setup

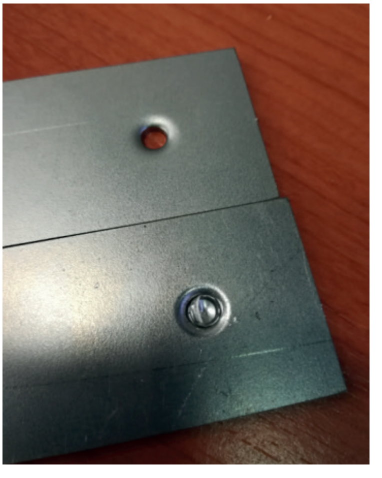

Fig. 15. After test – full shear mode

Table 3. Test results

Specimen No.	Pull test	Peel test	Box test
1	2899 N	750 N	1596 N
2	2877 N	733 N	1545 N
3	2770 N	690 N	1727 N
Mean	**2849 N**	**724 N**	**1623 N**

4. Summary

In this study, DP600 steel was used to perform clinched joints. A non-standard approach was presented that can be useful for fast decision-making. The observation of the "reversed" joint can be useful for designers in the automotive industry, for example. The mechanical behavior of the joints was tested, and the results were presented. The highest values were measured in the cases of the pull tests, and the lowest values were measured in the cases of the peel tests. In the viewpoint of design, this is useful knowledge because the designer can consider the highest loaded directions.

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