THE ABILITY TO CLINCHING AS A FUNCTION OF MATERIAL HARDENING BEHAVIOR

Tadeusz Balawender[1)]
[1)] *Rzeszow University of Technology, Faculty of Mechanical Engineering and Aeronautics, Rzeszów, Poland*

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**Corresponding author: e-mail: tbalaw@prz.edu.pl, Tel.: +48 17 865 1667, Department of Materials Forming and Processing, Faculty of Mechanical Engineering and Aeronautics, Rzeszow University of Technology, al. Powstańców Warszawy 8, 35-959 Rzeszów, Poland*

Abstract

Mechanical clinching can be used to joining different metallic materials. The only restriction is their plastic properties. However, some plastic materials, with good ductility, do not conform strong clinch joint, e.g. materials, featured by high strain hardening phenomena are difficult to clinching and do not create durable clinch joint. In case of others materials with limited ductility clinch forming generates the process-induced defects such as cracks. So, there are material's features which are very important for the clinch forming process and among them the strain hardening properties seem to be in special importance. The clinch joints of different materials with diversified plastic and strength properties were tested. A single overlap clinch joints with one clinch bulge were realized in the tests. The joints were tested in the pull test. The obtained results showed the relation of the clinch joinability to the materials' strain hardening exponent. The good quality and good strength joints, were obtained for materials with low value of strain hardening exponent below n = 0,22.

Keywords: clinching, strain hardening, strain hardening exponent, aluminium alloys, copper alloys, high strength steels

1 Introduction

The clinch joint forming process consists in localized cold forming of joined metallic materials with a punch and a die. The result is an interlocking friction joint between two or more sheet materials [1-4]. This joining technology is applied in manufacturing of thin-walled structures. The force necessary to separate the sheets depends mainly on the joint geometrical parameters and the friction conditions in the sheets' interface. During the clinching process, the sheets are forced in the die impression by a punch and mainly two operations take place: deep drawing and compression. The deep drawing results in sheets' two-dimensional stretching when a local hollow cavity is formed and it causes the reduction of sheets' thickness [5, 6]. The next stage proceeds when joined sheets reach the bottom of the die impression and further compression action between die and punch causes radial movement and additional reduction of sheets' thickness. During this stage, filling of the die cavity, i.e. the die groove placed in the bottom of impression and forming of the joint interlock proceed. The total thickness of joined sheets is reduced to a fraction of their initial thickness in the joint bottom, with typical reductions of the order of 60% [3].

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A good drawability of joined materials is a favourable for clinching; the only restriction of applying of this method is material's deformability. However some plastic materials, with good ductility, do not form durable clinch joint. Low shear strength of clinched joints was obtained in experimental investigations [e.g. 7, 8] for such material like CuZn37 brass. High-alloy chrome-nickel stainless steel X5CrNi18–10 did not create a durable clinch joint at all; there was no clinching effect in the deformation area. These both materials are featured by high work hardening phenomena during plastic deformation. The dependence of the flow stress on the strain is significant for materials characterized by high values of strain hardening exponent 'n'. Because clinching process is commonly realized at room temperature, the work hardening phenomena play a main role on the plastic deformation during clinching. So, the work hardening properties of materials should be taken into account when they are subjected to clinching.

The wide range review of publications made in the work [3] shows that the susceptibility of different materials to clinching is assessed by considering the mechanical properties of materials, such as elongation at failure A80 and 0.2% proof stress and the following limiting values have been established: A80 >10% and 0.2% proof stress equal 550 MPa. Another clinchability criterion based on experimental work is that materials able to be bent on 180 degrees with zero radius can be clinched. A lot of publications emphasise directly that low yield stress and high ductility of joined materials are favourable to clinching [9÷20].

2 Experimental materials and methods

The studies of strain hardening phenomena on the clinch ability were realized on such materials like: pure aluminium 1070, 2024 aluminium alloy, ETP-copper, CuZn37 brass, low-carbon steel DC04, non-alloy quality steel C45, structural alloyed —chrome–vanadium spring steel 50CrV4, structural alloyed—heat-treated chrome–manganese–silicon steel 30CrMnSi and steel X5CrNi18–10. Three grades of structural steel, i.e. C45, 30CrMnSi and 50CrV4 were used, because these steel grades have wide range of applications in manufacturing industry, e.g. 30CrMnSi - construction alloy steel – for hardening and tempering, is used in the construction of heavy machinery and medium to heavy duty parts, which work under great load at temperatures up to 150-200°C, and is used for the riveted part of a structure, the seamless pipes applied in aviation and for all kinds of components. Clinching of these all materials was preceded by uniaxial tensile tests of base materials to determine their work-hardening behaviour. All materials were used in the as-commercial mechanical state, one-off aluminium alloy 2024, which was subjected to solution heat treatment before clinching and after that to one-week aging at room temperature before shear-tensile testing the joint.

Thickness of all materials used in the tests was equal 1 mm. The tensile tests were performed on Zwick/Roell 100 kN screw testing machine according to ASTM E 8. During the tests a tensile load and an extensometer gage length (initial length Lo=50 mm) were recorded.

The Swift's hardening law [21] was used to fit the experimental true stress – true plastic strain curves up to maximum uniform strain and the equation parameters were found:

$$\sigma = K(\varepsilon_0 + \varepsilon)^n \tag{1.}$$

where: K - strength index,
n - strain hardening exponent,
ε_o - prior plastic strain,
ε - equivalent plastic strain.

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Clinched joints were manufactured by a die and a punch arranged in an adopted stamping attachment set on C-frame hydraulic press with a capacity of 90 kN (this maximal press load was used during sheet clinching for each sheet material). The clinch round indentations (8 mm diameter of the clinch joint cavity and 10 mm diameter of the clinch joint bulge) were made in two strips, dimensions ~100 x 35 x 1mm, put together in a single lap joint. The position of the clinch point was symmetrical with respect to the overlap dimensions.

The tensile-shear tests of clinched joints were performed on Zwick/Roell 100 kN screw testing machine in the same manner and with the same parameters as in tensile tests of sheet materials (**Fig. 1**). Using of extensometer to measure the displacement let to confine a recorded deformation of the joint sample almost to the lap area range.

As it was shown in [8, 9] very important are friction conditions between working surfaces of tools and sheets. Low value of friction coefficient is favourable for plastic deformation, especially in the compression stage of clinching process, when thickness of the clinch joint bottom and interlock are formed. In all realized tests materials were clinched without any surface preparation.

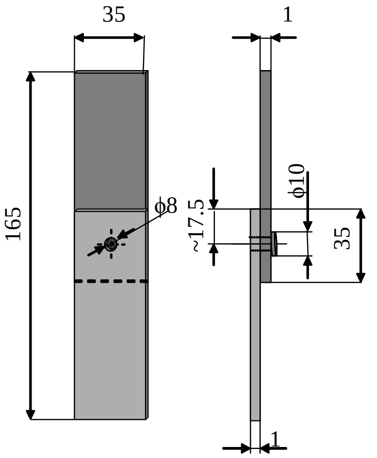

Fig. 1 Overlap clinch joint sample dimensions

3 Results and discussion

The mechanical characteristics of tested materials were described by Swift's equation and the Swift's law parameters were determined. As it can be seen in **Table 1**, where the test materials are aligned vertically for the sake of the strain hardening exponent n, there are great differences between materials regarding to strength index K and strain hardening exponent n, i.e. between very soft aluminium 1070 and brass CuZn37. In case of stainless steel X5CrNi18–10 sheets, forming the clinch joint was not possible.

The results of shear- tensile tests (pull tests) of clinch joints of tested materials are shown in **Table 1**, too. As it can be seen the strongest clinch joint (regarding to maximal load and energy absorption of the joints) was obtained for constructional steels (30CrMnSi, 50CrV4 and C45) and the weakest one for pure aluminium (1070). Steel grade DC04 showed mean shear load of clinched joint but the shear curve was very "long". It means that this joint is characterized by the highest energy absorbed during shear when compared to other tested materials (**Fig. 2**). As it was mentioned above stainless steel X5CrNi18–10 and CuZn37 brass distinguish high value of strain hardening exponent and they are not clinchabele materials; the joint of CuZn37 brass sheets was very weak (low maximal shear load and low energy absorbed during shear-tensile test). On the other hand, materials that create a high strength clinch joint, i.e. 30CrMnSi, 50CrV4, C45, DC04 and ETP-copper, reveal low value of n exponent (below n=0.22). The average n value for these materials is equal n = 0.15, as it is shown in **Fig. 3** as the "region of strong" clinch joint. Exception to this rule seems to be pure aluminium 1070 (low n value and low clinch joint strength). But when compare the maximal shear load of clinch joint with material tensile strength load (the last column in Table 1), aluminium 1070 and C45 steel have comparable clinch joint relative strength (maximal shear load of clinch joint F_{max} divided by maximal tensile load of material F_m). Additionally, taking in to account relatively high EA of this material, it seems that aluminium 1070 can be included to materials with good clinchability (as it was done in **Fig. 3**).

Another result was obtained for aluminium alloy 2024. Commercial 2024-T351 aluminium did not create a good quality clinch joint. After clinching cracks were observed in the bottom sheet of the clinched joint (**Fig. 4**) and low shear strength was obtained. This result could be the effect of low material's deformability what caused cracks in the joint area during plastic forming. To increase material's deformability solution heat treatment was realized before clinching. These clinch joint were shear-tensile tested after one-week natural aging what caused essential changes in material microstructure and mechanical properties but the joint mechanical parameters were not still satisfactory. So, it was decided that clinching of this aluminium alloy needs further scrutinises including age hardening process.

Table 1 Flow curve parameters and strength properties of clinched joints of tested materials

Material	**Strength coefficient *K* [MPa]**	**Strain hardening exponent *n***	**Prior plastic strain ε_o**	**Maximal shear load of clinch joint F_{max}[kN]**	**Energy absorption of clinch joint *EA* [J]**	**Relative shear load of clinch joint**
aluminium 1070	127	0.03	-0.0005	0.99	1.60	0.898
steel 50CrV4	902	0.14	-0.0085	4.46	3.26	0.738
steel 30CrMnSi	932	0.15	-0.0096	4.75	3.51	0.788
steel C45	804	0.17	0.0014	4.23	3.31	0.821
steel DC04	546	0.19	-0.0119	3.75	7.68	1.138
ETP-copper	395	0.22	0.0788	2.85	3.58	1.166
aluminium 2024 (solution heat treatment)	648	0.34	0.0050	2.7	0.453	0.614
brass CuZn37	816	0.64	0.0446	2.38	1.03	0.781
steel X5CrNi18–10	1671	0.75	0.1322	-	-	-

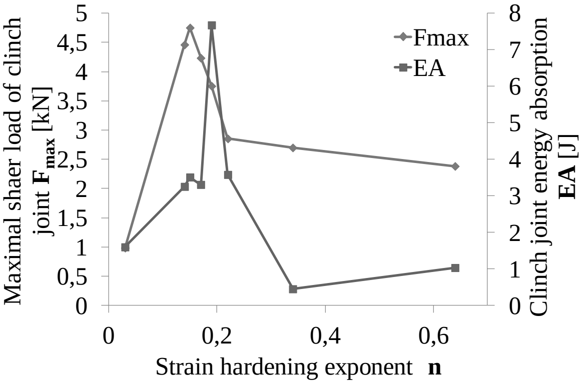

Fig. 2 Shear load (F_{max}) and energy absorption (EA) of clinched joint versus strain hardening exponent

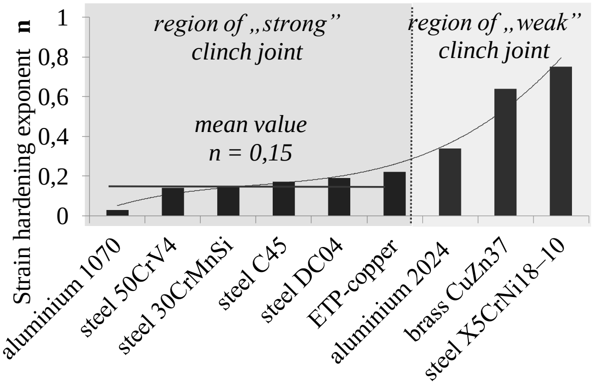

Fig. 3 Strain hardening exponent versus material type

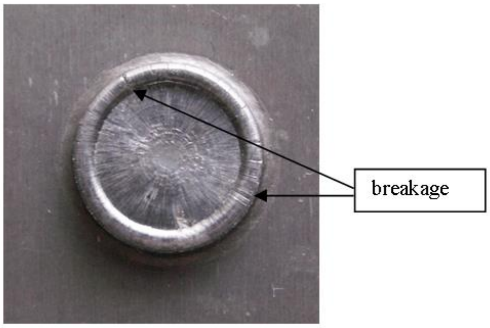

Fig. 4 Breakages observed on the die side of the clinch joint of 2024 aluminium sheets

Although the same tools were used to forming all clinch joints and the same forming load (i.e. 90 kN) was applied during forming process, tested materials were clinched in a different way. Reflection of the clinching is a failure mode which occurs during shear-tensile testing a clinch joint.

Failure mode observed during realized tests are shown in **Fig. 5**. When joined materials exhibit high ductility and low strength, the failure mode shown in **Fig. 5a** occurred and the sheets were folded in the punch side bottom. This is the result of a small thickness of the clinch joint bottom; it was obtained for aluminium 1070. When bending of sheets was observed, it means that a good quality clinch joint was made. This shear-tensile test results were obtained for low-carbon and structural steel sheets (**Fig. 5b**). When the neck of the joint was too thin the shear–tensile loading resulted in cracks of this region (**Fig. 5c**). The reasons for this type of failure could be a lot but this failure occurred for such ductile material like ETP-copper and it was caused by an excessive elongation in the region of the joint neck and a crack formation on the side wall of a sheet deformed by the punch. The failure mode shown in **Fig. 5d** occurred when the clinch joint was destroyed with small sheet bending and proceeded when small deformation of the sheets was realized during clinching. This failure was observed for CuZn37 brass and it was caused by material resistance to plastic deformation what resulted as an excessive bottom thickness and small interlocking of the sheets (small undercut). More complicated case is shown in **Fig. 5e** where aluminium alloy 2024 was clinched. The joined sheets were clinched tightly but sheet separation undergone by neck cracking without evident plastic deformation.

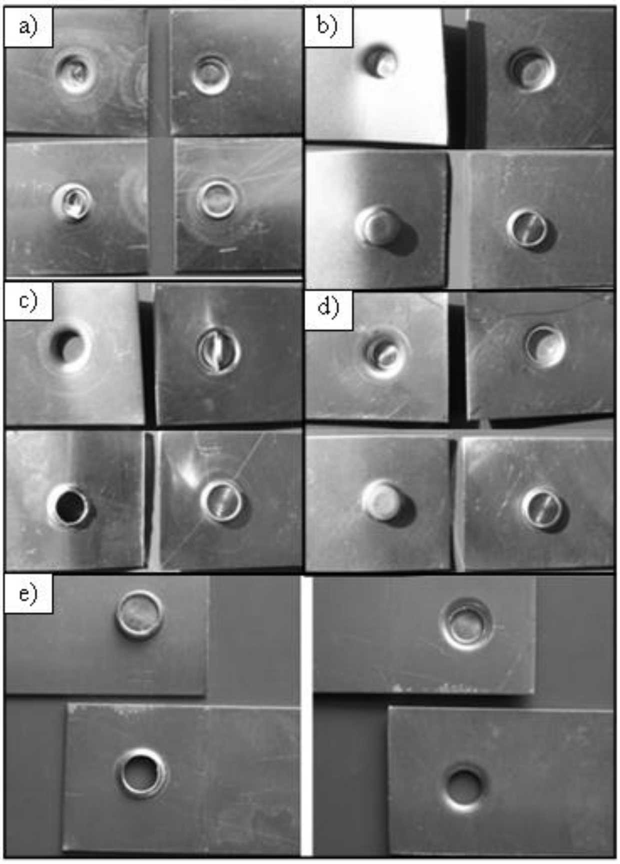

Fig. 5 Example samples after tensile test: a) joint of aluminium sheets, b) joint of low carbon steel sheets, c) joint of copper sheets, d) joint of brass sheets, e) joint of aluminium alloy 2024 sheets

4 Conclusions

The major conclusions resulting from experiments can be formulated as follows:

- clinching can be used for effective joining of wide range mechanical properties metallic materials, e.g. low carbon steel and constructional alloy steel, characterized by low and high mechanical properties,
- strain-hardening exponent ***n*** can be used as clinchability criterion; high value strain-hardening exponent ***n*** is not favourable for clinch joint forming; high strength clinch joint can be manufactured when low values strain-hardening exponent materials are clinched,
- clinching of metallic alloys, like aluminium 2024, can be combined with heat treatment to establish optimal clinch joint parameters, e.g. solution heat treatment before and aging after clinching.

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