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## TECHNOLOGICAL PROBLEMS AND EXPERIMENTAL INVESTIGATION OF HYBRID: CLINCHED – ADHESIVELY BONDED JOINT

### ZAGADNIENIA TECHNOLOGICZNE I BADANIA EKSPERYMENTALNE W POŁĄCZENIACH HYBRYDOWYCH: KLINCZOWO-ADHEZYJNYCH

The choice of proper joining technology is an essential aspect of designing and manufacturing activity. New product designs enforce joining different materials in a new joining method. Clinching is a relatively new joining technology in which sheet metal parts are deformed locally without use of any additional element. Combining clinching with adhesive bonding seems to be interesting hybrid joining method with new potential applications in manufacturing industry.

The paper deals with discussion of technological aspects and experimental investigations of clinched lap joints of different metal strips combined with their adhesive bonding, which can be applied for different branches of engineering. The main purpose of using different types of sheet metals was to analyze their influences on the geometry and mechanical strength of the clinched joint. The experiments with application of Digital Image Correlation (DIC) system ARAMIS allowed for exact monitoring of the deformation process of considered hybrid joint.

The clinched joint test specimens were carried out with laboratory test-stand which consisted of a pair of tools (punch and die) attached to C-frame hydraulic press.

*Keywords:* clinching, hybrid clinched – adhesive joints, digital image correlation system

Wybór właściwej technologii łączenia stanowi istotny aspekt projektowania i wytwarzania. Projektowanie nowych produktów wymusza łączenie różnych materiałów za pomocą nowych technologii. Łączenie przetłaczaniem (klinczowanie) jest relatywnie nową technologią, w której różne części metalowe łączone są poprzez lokalną deformację bez zastosowania dodatkowych elementów. Równoczesne zastosowanie klinczowania i klejenia łączonych elementów jest interesującą propozycją hybrydowego połączenia z nowymi potencjalnymi możliwościami zastosowania w przemyśle wytwórczym.

W pracy przedyskutowano aspekty technologiczne i badania eksperymentalne klinczowych połączeń zakładkowych wykonanych z różnych materiałów w połączeniu z techniką klejenia, które mogą być zastosowane w różnych gałęziach inżynierii. Głównym celem pracy było zastosowanie różnych materiałów metalicznych, aby przeanalizować ich wpływ na geometrię i mechaniczną wytrzymałość połączeń hybrydowych. Badania wspomagane były przy pomocy cyfrowego systemu przetwarzania obrazów ARAMIS, który pozwala na dokładne monitorowanie całego procesu deformacji rozpatrywanego połączenia hybrydowego.

Złącza klinczowe na próbkach stosowanych w badaniach wykonywano na laboratoryjnym stanowisku badawczym wyposażonym w prasę ramową typu C z zamontowanym zestawem narzędzi (stemplem i matrycą).

### 1. Introduction

Clinching (mechanical interlock) is a method of joining different metal parts (mainly sheets) by a process of local deformation without use of any additional joining elements with the application of a punch and a die [e.g. 1-3]. The mechanical interlock with application the clinching technique is shown schematically in Fig. 1. During clinching, a punch presses the joined sheets inside a die cavity forming a shape that locks the sheets

together. The clinching technique is known from the end of the nineteenth century but it was not used on an industrial scale until the eighties of the twenties century. Nowadays, clinching is used in the automobile, furniture and computer industries. The most known examples of clinching technology are joints in certain parts of an automobile body (Mercedes-Benz S-class), different kind household appliances, ventilation and air-conditioning products and plenty of others in sheet product manufacturing.

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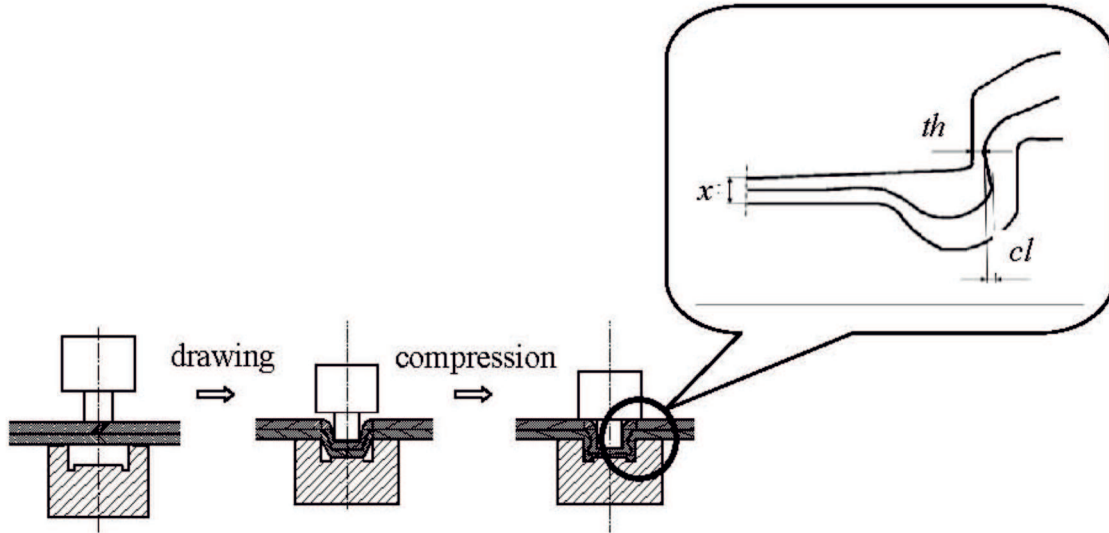


Fig. 1. Stages of clinch joining process and main geometrical parameters of a clinched joint:  $th$  – the thinning of the upper sheet (the neck thickness),  $cl$  – the clinch lock (undercut),  $x$  – the axial thickness of the sheets (thickness of the indentation bottom)

The required tooling set consist of: a punch, a die and a blank holder. The mechanical joining of two or more blanks (e.g. metal sheets) is based on only the accurate movement of the punch into the die; the sheet metals are deformed locally without the use of any additional elements. The joint strength is due to: force locking, material locking and “S” shape locking (Fig. 2). The quality of the clinching process strongly depends on precisely selected tools. The proper description of this process should include: the tool geometries, parameter optimisation and FEA simulation of the process [4-9].

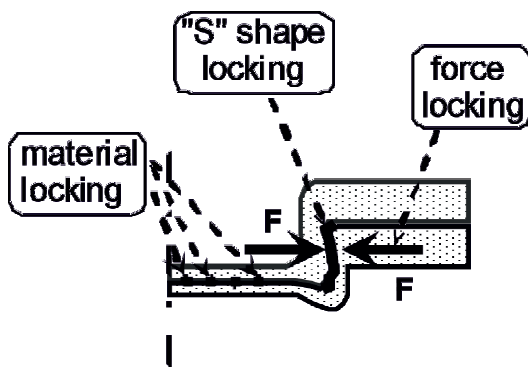


Fig. 2. The mechanisms of locking of joining parts during clinching process

The static strength of clinched joints is lower than that of other joints (e.g. self-pierce riveting and spot welding), but the fatigue strength of clinched joints is comparable to that of the other joints. Nowadays, many researches are looking for appropriate combination of clinching tools to obtain the maximum load under shear test of the clinched joint [e. g. 5, 6, 10-12].

Shortages of this cold-formed mechanical fastening can be also removed by hybrid joining, involving clinching and adhesion techniques. It is a modern and innovative technology allowing connection of different types of materials to create durable and reliable light constructions. However, its practical implementation is still very limited. The application of clinching together with adhesive bonding leads to an improvement (in comparison to a simple joint): the quality, rigidity and the load capacity, dumping of noise and vibration, pressure tightness and corrosion protection. This entails a significant increase of:

- long-term static strength
- the amplitude of force under fatigue test
- the energy required to the rupture of the hybrid joint under static, dynamic and impact loading.

The clinch-adhesive technique may be useful mainly in the automotive industry. However, wider application in aerospace and aeronautical industries should be investigated after an elaboration of the proper technology and an experimental verification of numerical models. Each application of the clinch-adhesive technique leads to a formulation of the specific requirements to guarantee a proper design of the joint, and further a manufacture of safe and durable fastening. The basic technological problem is the optimisation of the clinching process – cold forming operations – by the application of the suitable shape of the tools. The proper shape of the manufacturing process leads to improvements of joint strength under different types of loading: mechanical, temperature and environmental or aggressive effects.

## 2. Experimental work

The range of experimental investigations included shear tests of single lap joints and visualisation of the deformation process by the application of the DIC system ARAMIS. Single lap joints were manufactured and tested as clinched, adhesive bonded and hybrid joints.

Clinch lap joints were manufactured by a die and a punch arranged in an adopted stamping attachment set on 120 kN in a C-frame hydraulic press. The maximal press load was reduced by the overflow valve of the hydraulic system to about 90 kN. The tools were designed for joining of two sheets with 1 mm thickness. The position of the round indentation was symmetrical with respect to the specimen axis. The nominal diameter of the clinch bulging measured on the side of the die was  $\varnothing 10$  mm. The configuration of tools geometry was established to obtain good steel – steel joint.

Three sheet materials were used in the study: ETP-cooper, CuZn37 brass and low-carbon steel (deep-drawing steel). Thickness of all sheets was about 1 mm. Mechanical properties of sheet materials were determined in uniaxial tensile tests. Because of sheet material anisotropy, the tests were performed in three directions in the sheet plane:  $0^\circ$ ,  $45^\circ$  and  $90^\circ$  according to the rolling direction. The results are shown in Table 1.

TABLE 1

Averaged values of mechanical properties of materials used in the tests (averaging formula  $x_{av}=(x_0+2x_{45}+x_{90})/4$ )

Type of material	CuZn37 brass	ETP-copper	deep-drawing steel
Yield stress $R_{0.2}$ [MPa]	251	242	203
Ultimate tensile stress $R_m$ [MPa]	389	273	325
Elongation to failure A [%]	39	20	29
Lankford's parameter $r$	0,81	0,98	1,93

The lap shearing tests were performed on mechanical 100 kN screw testing machine. During the tests force and ram displacement were recorded by the HBM amplifier SPIDER and CATMAN software with the ram displacement rate equal 8 mm/min. The test specimens were composed of two strips with three different metals ( $\sim 132 \times 35 \times 1$  mm) with an overlap of the length 35 mm (Fig. 3.). It was assumed in the description that first material in specimen's denotation (A) is deformed by a

punch, the second (B) is deformed by a die (i.e. A – B clinch joint).

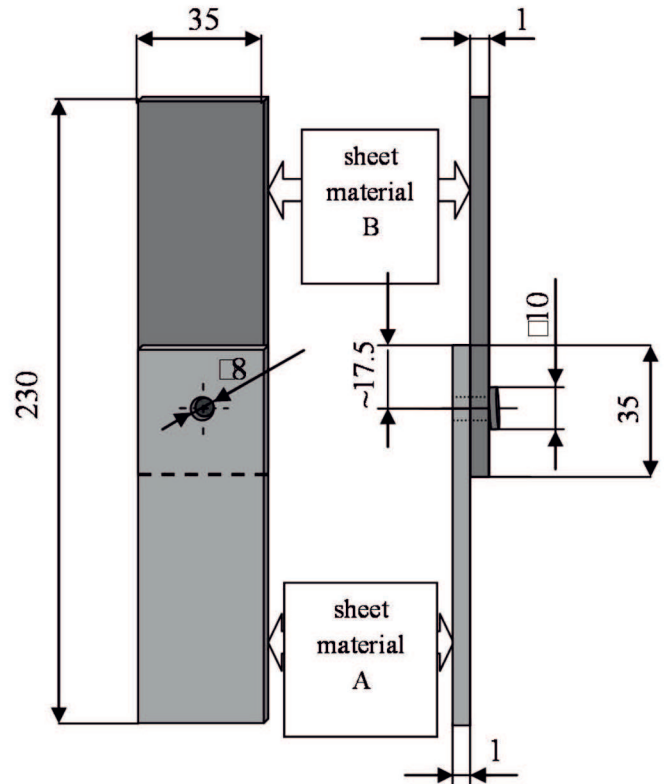


Fig. 3. Geometry of overlap joint specimen (A – B clinch joint)

The adhesive used in the tests was Dragon® (product of Chemical Factory DRAGON, Krakow, Poland), a two-component epoxy destined for metal joining. The curing cycle of the adhesive is 4 hours at  $20^\circ\text{C}$  and it can be accelerated by warming. The full strength of the joint is obtained after 24 hours. The adhesive is assigned to joining, in different combination, such materials as: steel, cast iron, aluminium, metal alloys, ceramics, plastics. Adhesive bonding joints were manufactured as overlap joint shown in Fig. 4a and 4b. The lap surfaces of sheets were cleaned and roughened with abrasive paper and then degreased with acetone. The adhesive, after mixing components, was spread on both joined surfaces and parts were pressed with constant load and were left for curing for 24 hours at room temperature. The average value of adhesive layer was about 0,15 mm. The hybrid joint was created by the third stage of technological process (Fig. 4c) – after curing of the adhesive layer, clinching took place.

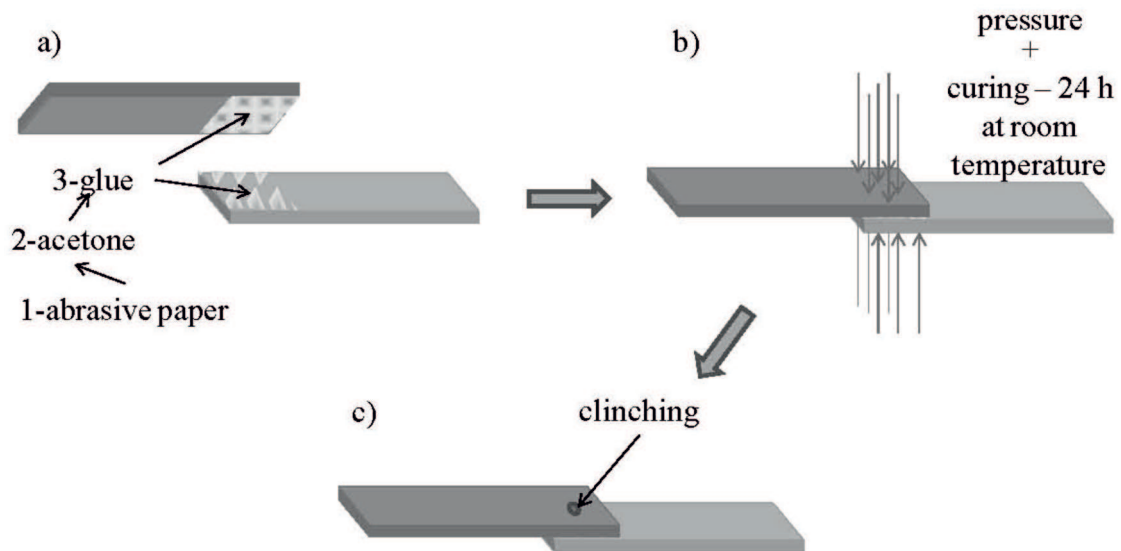


Fig. 4. Methodology of adhesive bonded and hybrid specimens preparation: a) cleaning of the lap surfaces, b) adhesive bonding, c) clinching process

### 3. Results and discussion

The experimental results concerning the pure clinched joints for three considered materials were presented in Fig. 5. One can notice, that the maximum value of the shear force was obtained for steel-steel sheets joint. The minimum value of the loading force was observed for brass – brass sheets joint, whereas medium one for copper – copper samples.

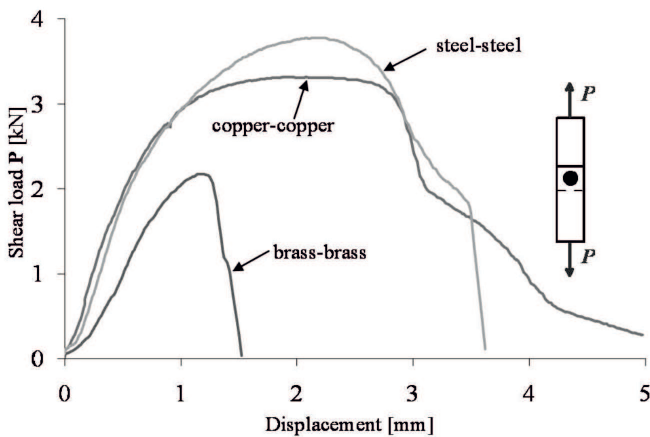


Fig. 5. Experimental load-displacement curves obtained for clinched joints of tested materials

The example strength characteristics of hybrid joints compared with the single joining techniques by pure clinching and pure adhesive bonding are shown in Fig. 6 and 7. In case of different types of brass-brass joints (Fig. 6) one can observe that the hybrid joint and the pure adhesive joint have almost similar load-displacements curves. At the maximum shear load both types of joints

suddenly undergo failure, like in brittle materials. The energy absorption to the final failure of the sample is almost the same. Comparison of the pure clinched and hybrid joints lead to the conclusion, that the load capacity increases approximately 6 times.

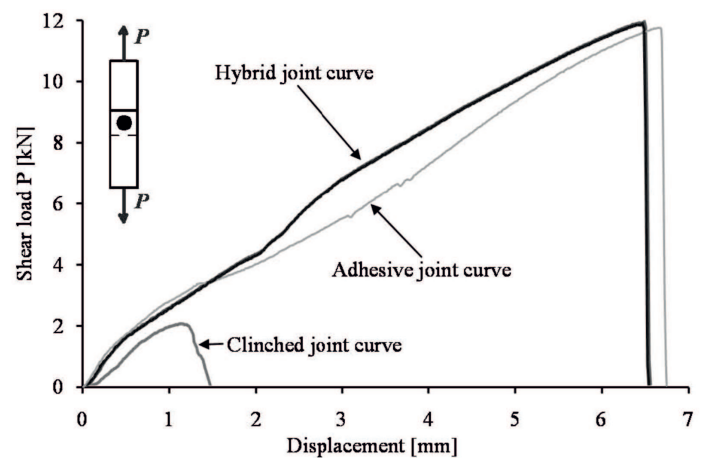


Fig. 6. Experimental load-displacement curves (for clinched, adhesive and hybrid joints) obtained for brass – brass joints

Materials that create strong clinched joint, i.e. steel – copper, don't create hybrid joint with high response to shear force (Fig. 7). But strength characteristics of these materials have a special feature – when adhesively bonded joint fails, the clinched joint still keeps the materials connected what results in long way of joint separation and high energy absorption. Comparison of the clinched and hybrid joints leads to the conclusion, that the hybrid joint is 3 times stronger. It is also visible, that the pure adhesive joints have 33% higher energy absorption to the final failure. The lower value of this energy in case

of the hybrid joint is due to local damage introduced by clinching.

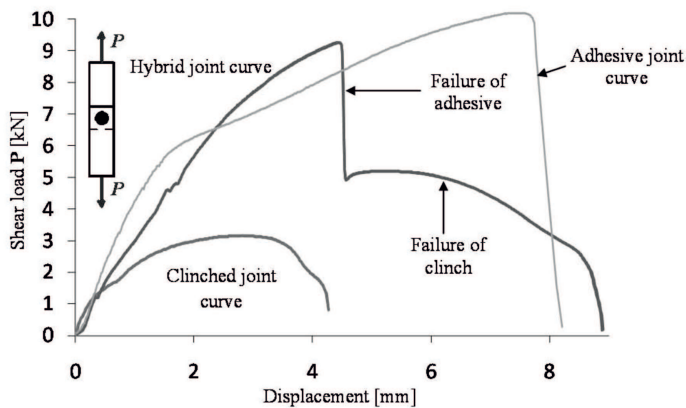


Fig. 7. Experimental load-displacement curves (for clinched, adhesive and hybrid joints) obtained for steel – copper joints

The longitudinal cross sections of hybrid joints are shown in Fig. 8. Differences between the clinch joint and the hybrid joint are visible in the bottom corner of the joint cavity as a fold (particularly in Fig. 8a and 8c). This is due to fact, that the adhesive causes a buckling of lower material in the die groove. There is no difference in the shape of the upper material deformed by the punch in both cases: the pure clinched and the hybrid joints. The influence of the above buckling effect on the final strength of the hybrid joints should be investigated in details in further experiments.

Table 2 presents the estimation of the energy absorption (EA) of all tested types of the joints. Application of the adhesive causes the increase of the EA about 3-4 times in relation to pure clinching of hybrid joints manufactured from the steel or steel-copper. In case of the copper-copper, brass-copper and brass-brass joints almost the whole energy accumulation capacity takes place up to the maximum force  $P$ . The addition of the Dragon adhesive to the copper-copper clinched joint is the most effective as for EA increase. The pure clinch joints made of brass and brass-copper are very weak as for capability of EA accumulation. Introduction of the adhesive bonding to clinched joints diametrically changes mechanical performance of these joints. It is particularly visible in case of the brass-brass joint, where EA of the hybrid joint is approximately equal to 20 times of the one of the clinched joint and is almost the same like EA of the adhesively bonded joint.

TABLE 2  
Energy absorption of the clinched and the hybrid lap joints

types of joined materials	energy absorption [J]		
	clinch joint	adhesive joint	hybrid joint
steel - copper	10,4	58,78 J	44,2
steel - steel	9,6	-	42,1
copper - copper	9,9	-	50,6
brass - copper	3,7	-	30,8
brass - brass	1,9	42,86 J	44,5

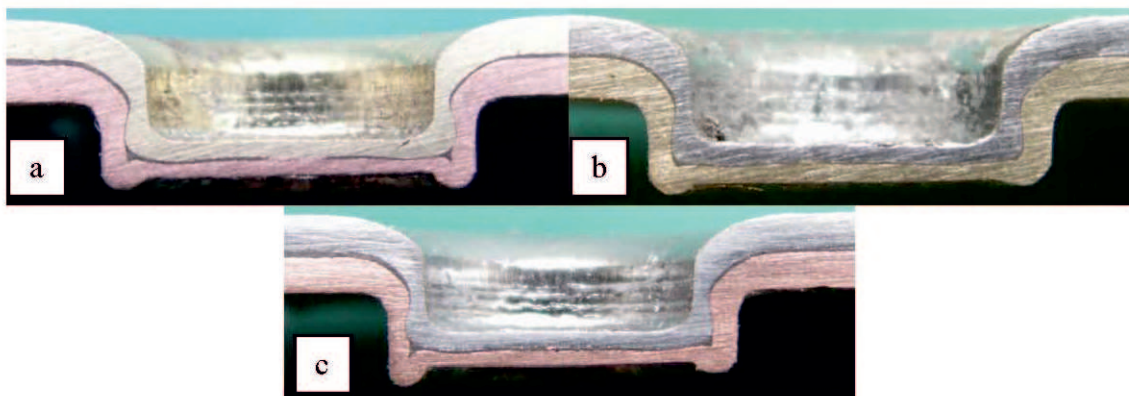


Fig. 8. The longitudinal section of hybrid clinched - bonded joint: a) brass – copper joint, b) steel – brass joint, c) steel – copper joint

The experimental load-displacement hybrid curve of copper - steel joint, illustrated by specimen pictures obtained in ARAMIS test, is shown in Figs 9 and 10. Fig. 9 presents all stages of the deformation process (the vertical strain  $\epsilon_y$  and the shear force  $P$ ) related to the time  $t$ . In order to monitor the whole deformation process three vertical sections: “0”, “1” and “2” were specified along the specimen axis. The most important is the section “1”, which contains clinched part of the joint. The

vertical strain  $\epsilon_y$  distributions in sections “0” and “2” are almost homogeneous during the whole loading process. A quite different distribution takes place along section “1”, where the very strong strain concentrations are visible in the die groove.

The hybrid joint failure starts (Fig. 10), as the shear damage of adhesive layer from the lap edge of the punch side material spreads to the clinch impression (this is visible on the strength curve top as the small step). Then, clinch joint undergoes small deformation.

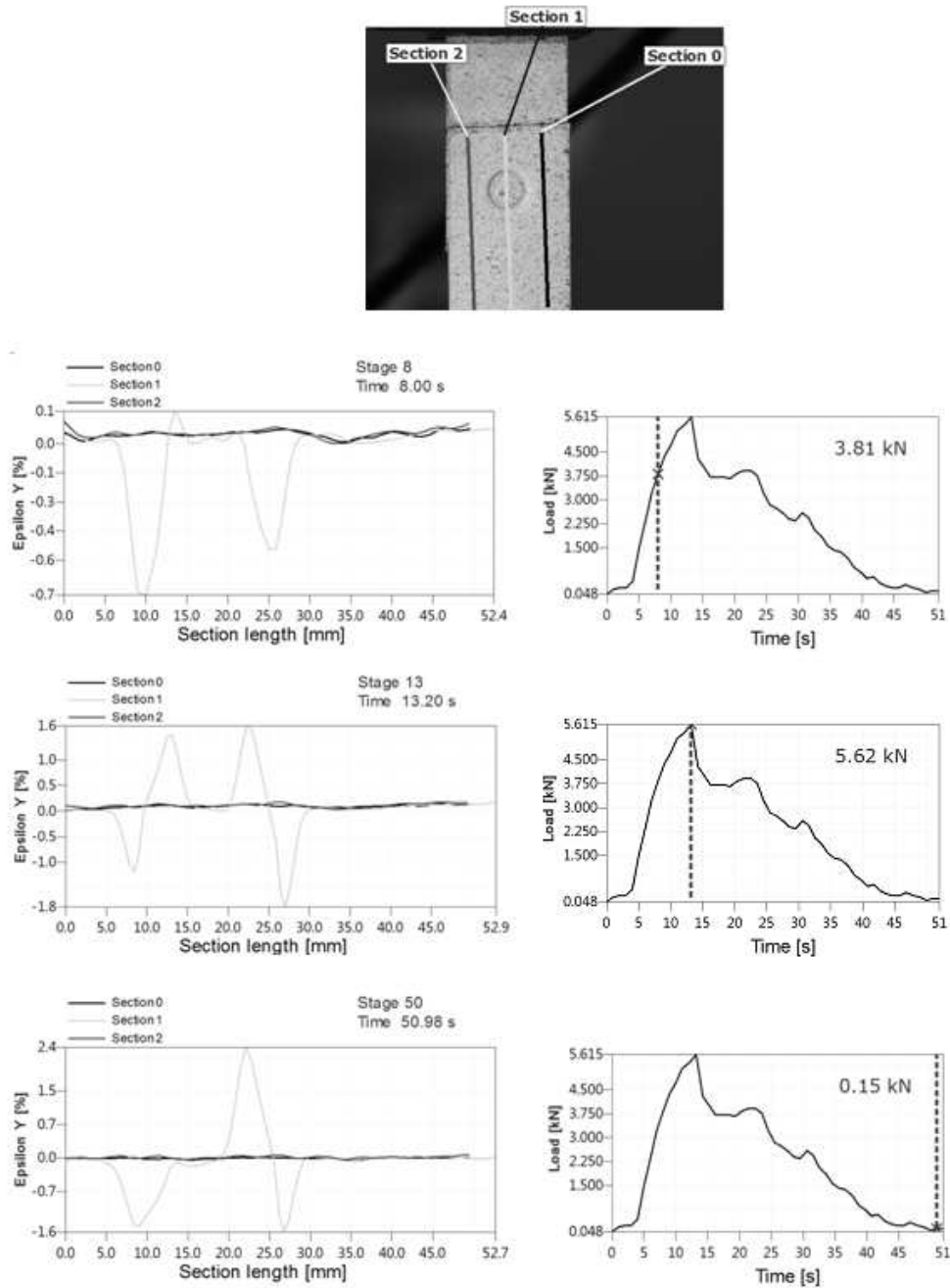


Fig. 9. The results of ARAMIS test obtained for copper – steel joint

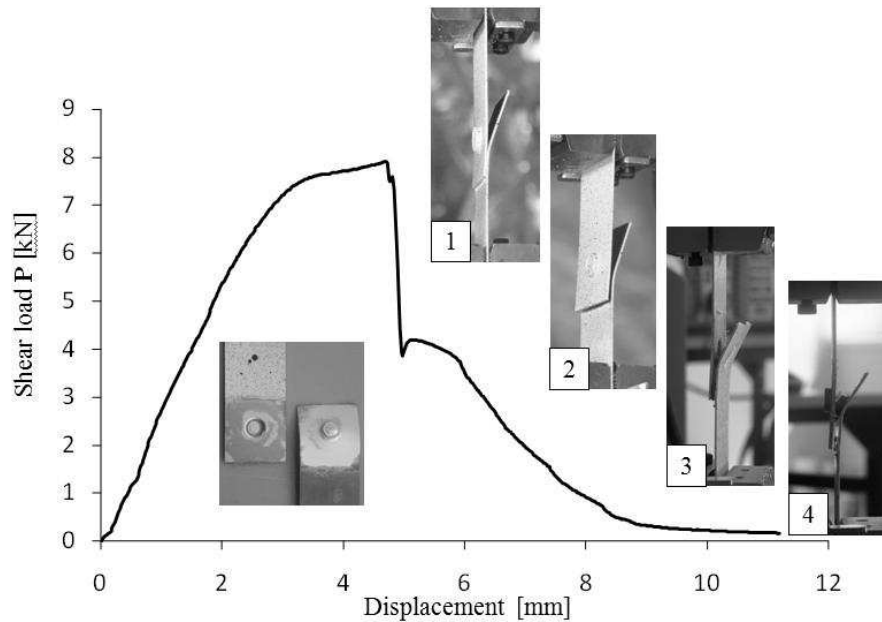


Fig. 10. Experimental load-displacement hybrid clinch – adhesive curve (copper – steel joint) illustrated by specimen pictures

and the shear damage of the rest of the adhesive layer underneath the clinch impression proceeds (the long vertical segment of the curve, picture 1). The last steps develop when a gradual clinch joint failure occurs (pictures 2, 3, 4) and this involves the local shearing force maximum. The path of the clinch joint failure is long as well as the corresponding segment of the curve. The shape of this segment depends on the clinch joint quality and features described above.

#### 4. Conclusions

The mechanical strength of the hybrid clinched – adhesively bonded joints strongly depends on adhesive and adherents properties. When joined materials undergo the plastic deformation, the adhesive properties should match these condition. In the experiments the brittle and stiff adhesive Dragon was used. Therefore the adhesive layer did not sustain the plastic deformation during clinching process and the adhesive failure occurred around clinching indentation. This additionally demonstrates the influence of the processing technology, when the clinching process introduces the initial microdamage into the adhesive interface. Local microdamage causes the decreasing of the shear strength of tested hybrid joints. Therefore the proper production of the hybrid joints is the crucial point for the further engineering applications.

Introduction of the adhesive into the clinched joint essentially changes the mechanical strength of the joint. Taking into account the wide range of commercial ad-

hesives for professional usage (from stiff and strong to flexible and ductile) the adhesive choice should be carefully balanced. The choice criterion of adhesive for the hybrid clinched – adhesive joint seems to be similar to mixed adhesive joint. The clinch joint is like a strong adhesive in the middle of the overlap and a flexible adhesive should be used in the neighbourhood. The future investigations should focused on determination of such joint composition, likes a clinch – flexible adhesive.

The hybrid clinched – adhesively bonded joining is very new assembly technology and there is lack of its practical usage for nowadays. Technology is intensively investigated because of expected advantages concerning low costs, flexibility and its environmental compatibility. The low mechanical strength of simple clinched joints (resistance to shear or tensile loading) compared to equivalent spot welds, forces to looking for a new joining solutions. The clinched – adhesively bonded joining seems to be very good combination which can enhance advantages of these both methods.

#### Acknowledgements

Financial support of Structural Funds in the Operational Programme – Innovative Economy (IE OP) financed from the European Regional Development Fund – Project "Modern material technologies in aerospace industry", No POIG.0101.02-00-015/08 is gratefully acknowledged.

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