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THE APPLICATION OF CLINCHING TECHNIQUES TO JOIN IMPACT ENERGY ABSORBING THIN-WALLED ALUMINIUM SECTIONS

ZASTOSOWANIE METODY PRZETŁACZANIA DO ŁĄCZENIA ALUMINIOWYCH PROFILI CIENKOŚCIENNYCH ABSORBUJĄCYCH ENERGIE ZDERZENIA

Energy absorption by thin-walled aluminium elements joined by clinching with round tools (R-PJ) and that by such elements joined by spot welding (SW) are compared. Owing to their advantageous strength-to-specific gravity ratio (whereby fuel consumption can be re-duced by reducing vehicle weight) aluminium alloys are increasingly used in the production of modern cars. But the alloys are poorly weldable and so other techniques of joining aluminium alloy constructions are sought. An example of such a technique is clinching (forcing through). Dynamic deformation tests carried out on thin-walled sections joined by clinching and by welding showed that the clinching technique can be used to join controlled crushing zone elements in cars.

Keywords: clinching, spot welding, aluminium, energy absorbing

W pracy przedstawiono porównanie pochłaniania energii poprzez aluminiowe elementy cienkościenne łączone metodą przetłaczania narzędziami okrągłymi (R-PJ) oraz zgrzewania punktowego (SW). Stopy aluminium ze względu na korzystny parametr konstrukcyjny wytrzymałości do ciężaru właściwego są coraz częściej stosowane w budowie nowoczesnych samochodów, jest to związane z dążeniem do zmniejszenia zużycia paliwa poprzez zmniejszenie masy pojazdów. Z drugiej strony natomiast stopy aluminium należą do materiałów, które są trudno zgrzewalne, dlatego poszukiwanie są innych metod do łączenia takich konstrukcji, przykładem takiej metody jest łączenie poprzez przetłaczanie. Przeprowadzone w pracy badania dynamicznego odkształcania profili cienkościennych łączonych przetłaczaniem i zgrzewaniem wykazały, że metodę przetłaczania również można stosować do łączenia elementów przeznaczonych na strefy kontrolowanego zgniotu w samochodach.

1. Introduction

Investigations into the kinetic energy absorbing capacity of various sections used in the controlled car body crushing zones are the subject of many experimental and theoretical researches [1-3]. The sections differ in their cross-sectional shape (circular, square, polygonal), the material they are made of (steel, aluminium, composites) and the mechanisms triggering the formation of regular buckling folds. The first notable research in this field was done by Alexander who showed that the compressive force waveforms for tubular specimens are oscillatory and closely connected with the formation of the successive folds as the specimen is being compressed [4].

The modern car's load-bearing structure consists of numerous thin-walled components made from mainly three-dimensional elements formed from metal sheets and joined. The structural elements of the car are most often joined by spot welding or laser-beam fusion welding. Besides their many merits, the techniques have their drawbacks which are mainly due to structural changes within the weld, resulting in considerable hardening of the material in this area and a reduction of its deformability. In the course of the dynamic deformation of the thin-walled sections the material often cracks at low deformation values in the heat-affected zone (HAZ), whereby the amount of energy absorbed by the element being de-formed is considerably reduced.

Today, new materials such as: aluminium alloys, magnesium-based alloys, new-generation steel and composites, are increasingly used in the car industry [5-7]. The use of such materials brings notable benefits resulting from their high strength and a reduction in vehicle weight, but also creates problems with, for example, joining them.

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In recent years mechanical techniques based on the principal plastic working operations, e.g. clinching, have been introduced to join car elements. Clinching can be used to join elements of the same or different thickness and made of different materials. There can be an intermediate layer (foil, paint, seals, etc.) between the elements to be joined and the quality of the joint will not suffer. Clinching consists in local forcing one metal sheet into another in order to block the bottom of the forced-in sheet relative to the press-formed sheet. The quality of such joints depends on the plasticity of the elements being joined, the process parameters, the dimensions and shapes of the tools and the magnitude of the pressures appropriate for the materials being joined [8-10] (Fig. 1).

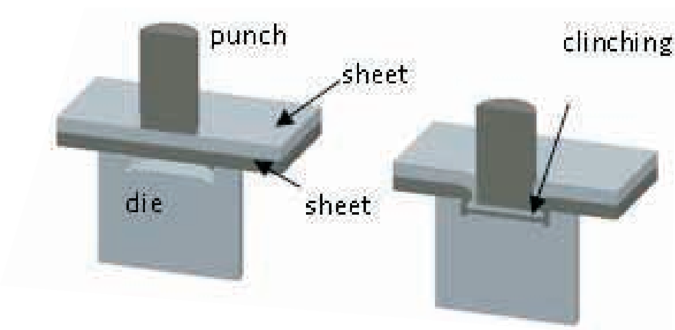


Fig. 1. Schematic of joining by clinching

The cross section of a clinch joint of the R-PJ type, with marked characteristic dimensions, is shown in fig. 2. Tests showed that neck thickness and undercut are the main parameters determining the force at which the joint fails.

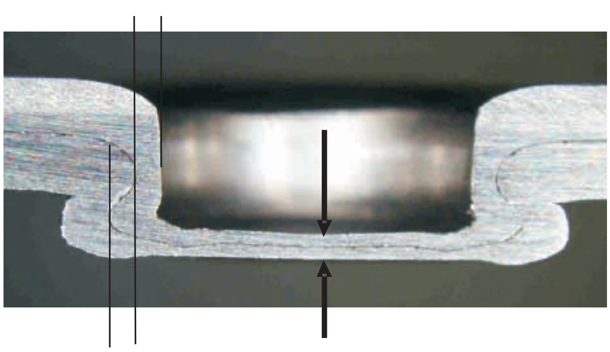


Fig. 2. Cross section of clinch joint R-PJ with marked characteristic dimensions

The main advantages of clinching are: no thermal effects in the joining zone, different materials can be joined, no need to use additional materials such as: solder, welding wire or adhesive, or auxiliary connectors (e.g. rivets), no emitting of toxic gases or vapours and low costs [10-12].

Clinching was applied to join thin-walled structures in car making quite recently. This means that it is a new technique which has not been fully understood and mastered. Consequently, there is some reluctance to use it to join critical elements such as collision energy absorbing thin-walled elements. There is no information about any research dealing with energy absorption by clinch-joined thin-wall constructions.

The aim of the present research was to compare the energy consumption and the deformation mode of clinch-joined and spot-welded thinwalled aluminium sections.

2. Test methods

A drop hammer, described in detail in [13], was used to investigate the absorption of collision energy by thin-walled elements subjected to dynamic deformation. A ram weighing 227 kg, striking the specimen with a velocity of 7.27m/s^2 (an energy of 6kJ) was used in the tests. The recorded signal from an acceleration sensor was used to plot force-ram displacement diagrams.

The way in which the thin-walled elements folded and the absorption of energy by them were studied. The following coefficients were used in the analysis of energy absorption by the thin-walled elements:

- P_{max} – the maximum load. It is the force required to initiate deformation and energy absorption. This load should be within the tolerance limits for the vehicle user.
- the average impact force, which is an indicator of the energy absorption capacity of an element and is determined as a ratio of absorbed energy E to total specimen displacement d from this formula

$$P_m = \frac{E}{d} \tag{1}$$

- deformability coefficient γ, defined as section shortening δ to overall section length l

$$\gamma = \frac{\delta}{l}, \tag{2}$$

Thin-walled sections (their dimensions are shown in fig. 3) made of (2mm thick) aluminium alloy AW 5754 O (whose chemical composition is shown in table 1) were tested. Sections with such geometric dimensions are often used in dynamic deformation tests [5,6].

TABLE 1
Chemical composition of sheet made of aluminium alloy AW 5754 O

Mg	Mn	Cu	Fe	Si	Zn	Cr	Ti	Al
3.1	0.5	0.1	0.4	0.4	0.2	0.25	0.2	rest

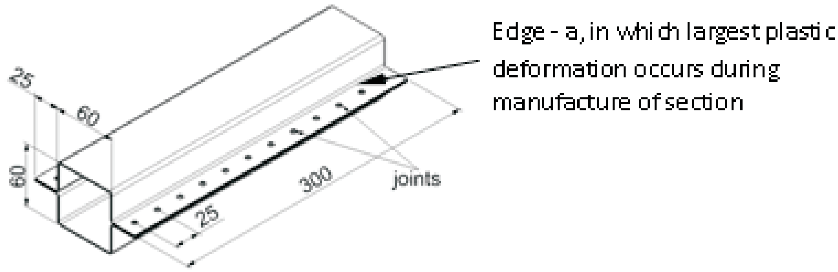


Fig. 3. Dimensions of specimens

Spot welding (a weld nugget of ca. 7 mm) was used to join the collision energy ab-sorbing thin-walled constructions. The welded joints were made in the Institute of Welding Technology in Gliwice. The clinch joints were made using round tools with two die diameters, made by Eckold GmbH & Co. KG (Germany). The clinch joints are marked respectively R-PJ8 and R-PJ10 (fig. 4).

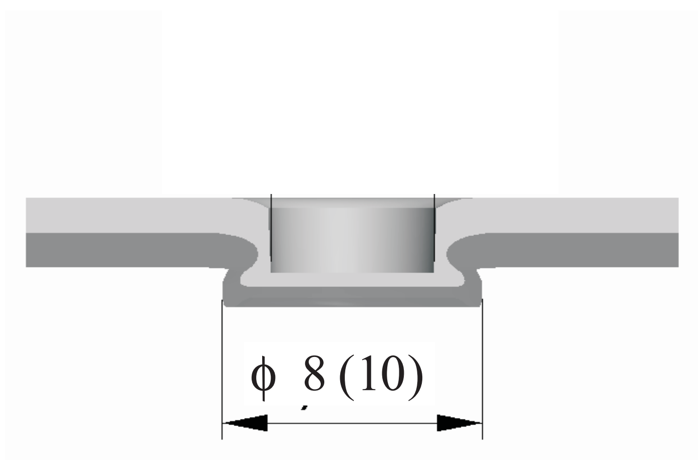


Fig. 4. Dimensions of clinches R-PJ8 and R-PJ10

3. Strength tests of joints

Specimens shown in fig. 5 were used in shear tests and to determine the normal force. The tests were carried out using an Instron 3369 testing machine equipped with a max. 50 kN tensometric head. The change of the force versus to the total elongation of the specimen was recorded during the tests.

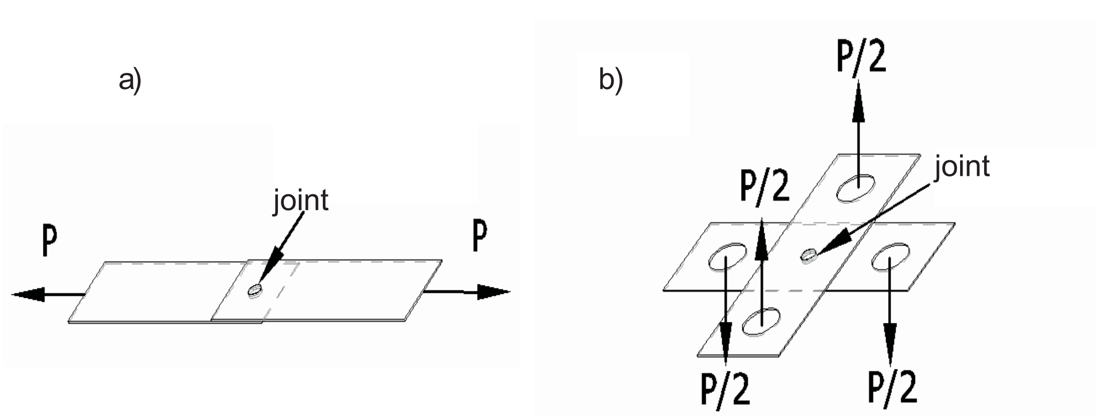


Fig. 5. Scheme of strength tests on welded and clinch joints: a) shear tests and b) cross tests for determining normal forces

4. Test results

The results of the strength tests carried out on the welded joints made of aluminium alloy AW 5754 O are shown in fig. 6. The force in the shearing test increases proportionally to the displacement of the holders, amounting to about 0.8 mm, and when ca. 5 kN is exceeded, the shearing force increases much less than the displacement until a maximum is reached and once the latter is exceeded, the welded joint is sheared with no cracking of the sheet around the weld. In the cross test the specimen bends and then the sheet thickness in the weld region decreases. Two types of joint failure would occur: the weld would break off in the weld nugget centre and the joint around the weld would be pulled out (whereby a hole would appear in one of the sheets). The maximum force of the joint amounts to about 6 kN in the shearing test and to about 3 kN in the pull-out test.

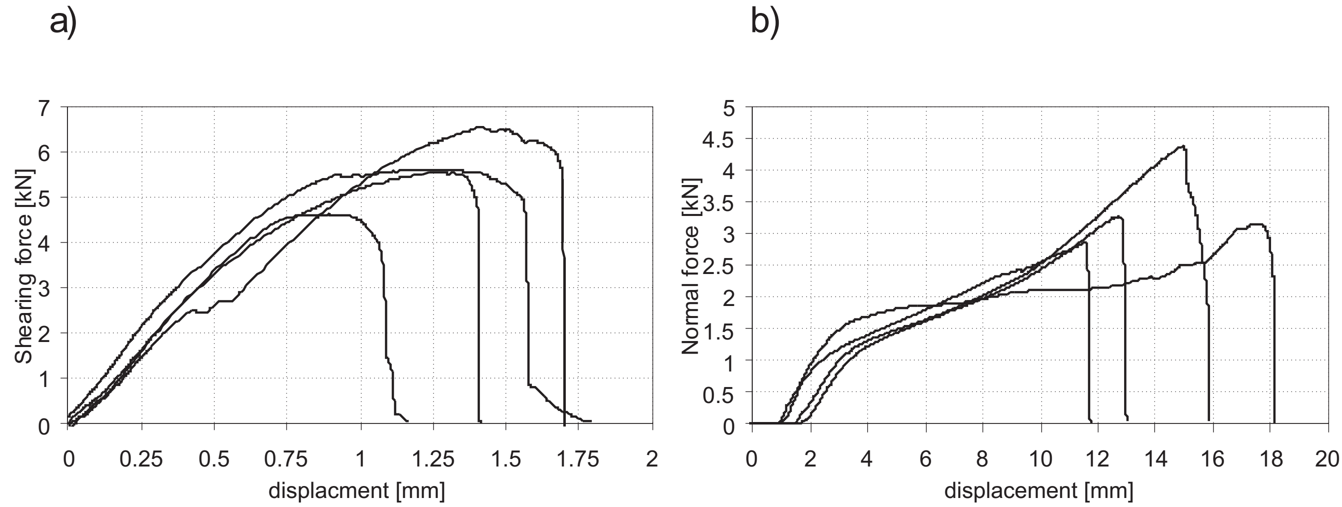


Fig. 6. Force diagrams from strength tests of welded joints: a) shearing test, b) cross test for determining normal forces for four samples

Metal spurts occur in the joint between the sheets (Fig. 7), which is typical of joining aluminium sheets due to the difficulties in welding them. Moreover, the results are spread widely, which indicates great difficulties in making welds with reproducible properties.

Fig. 7. Metal spurt between welded aluminium alloy sheets

The results of the strength tests of the R-PJ8 and RPJ10 clinch joints are shown in fig. 8. The force in the shearing test increases proportionally up to about 2.6 kN for R-PJ10 and up to about 1.5 for R-PJ8, and then non-linearly increases to the maximum value. Once the latter is exceeded, the joint deforms and starts cracking in the region of the smallest neck thickness (Fig. 2). Owing to the larger force-bearing cross section, the shearing forces were greater in the R-PJ10 joints than in the R-PJ8 joints. The way in which the joints deformed is shown in Fig. 9.

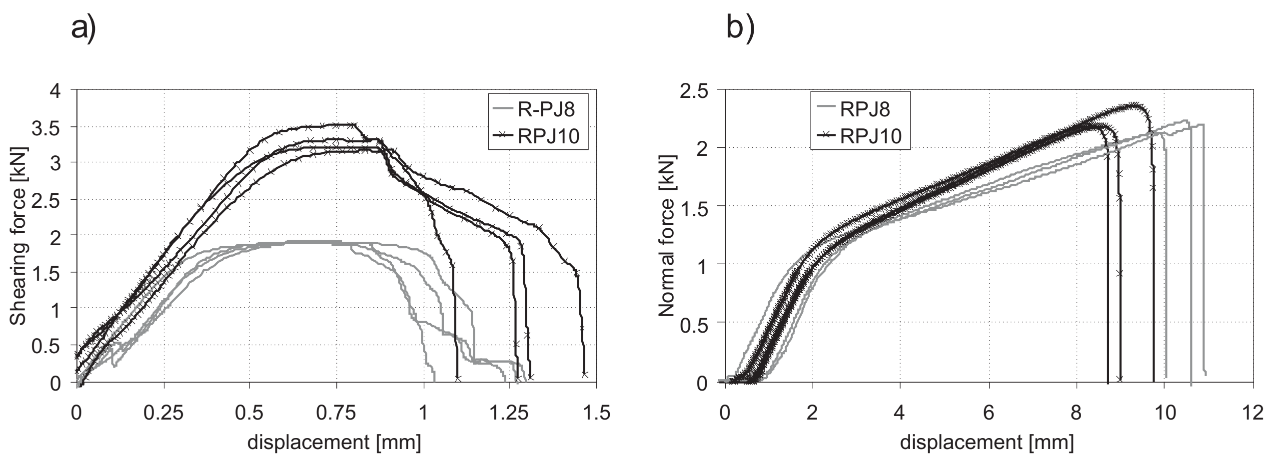


Fig. 8. Force diagrams for strength tests of clinch joints: a) shearing test and b) cross test for determining normal forces

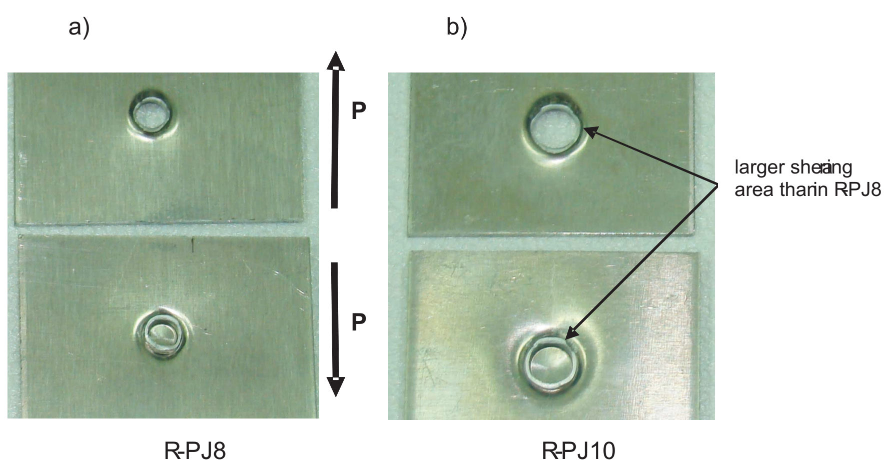


Fig. 9. Clinch joint failure in shearing test: a) R-PJ8 and b) R-PJ10

In the cross test the specimen bends but less than the welded joint and the force which the joint can carry depends on the magnitude of the applied force. According to the diagram, the R-PJ8 joint has a strength of about 2.2 kN and the R-PJ10 joint has a strength of about 2.3 kN. Since the undercut width was very similar in both cases the difference is slight. The joint fails as a result of material deformation and when the limit force is exceeded, the sheets separate with no cracking of the material in the region of the joint.

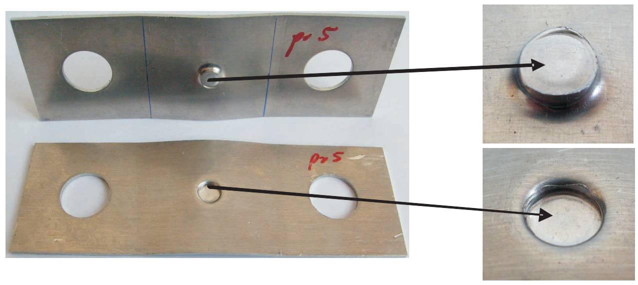


Fig. 10. R-PJ joint after pull-out test: a) bottom sheet, b) top sheet

The strength tests of the welded joints and the joints clinched with circular tools for aluminium alloy AW 5754 showed that the welded joints had greater strength. The R-PJ10 clinch joint under shearing and normal load shows strength amounting to 60-80% of the strength of the welded joint under shearing and normal load.

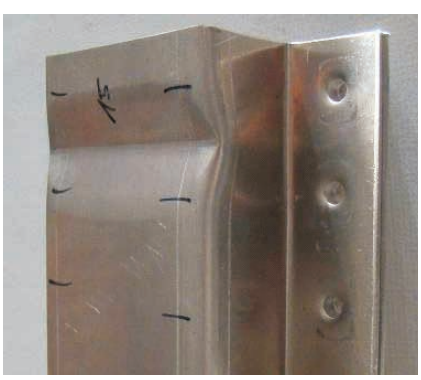
The strength of clinch joints could be increased, for example, by increasing the clinching diameter, but in the case of energy absorbing thin-walled specimens the strength of the joints is not as important as proper progressive deformation ensuring high energy absorption. Such deformation could be obtained by combining different properties, but this is difficult to determine by means of simple (pull-out and tensile) tests. It is also hard to predict the behaviour of clinch joints in energy absorbing thin-walled specimens because the stress state in such specimens during dynamic deformation is more complex than in the above simple tests. As opposed to spot welding, clinch joining by introducing material inhomogeneity may improve the way in which the specimen deforms. The above observations and the advantages of mechanical clinching mentioned in the introduction, provide encouragement to carry out dynamic crushing tests on thin-walled specimens joined by clinching.

It is particularly noteworthy that strength reproducibility is higher for clinch joints than for welded joints.

5. Dynamic deformation of aluminium sections

Preliminary dynamic deformation tests carried out on thin-walled sections made of aluminium alloy AW 5754 O, joined by spot welding and clinching, showed that during deformation the sections undergo either global deformation or the joints fail and the construction "rips" (several neighbouring joints are destroyed).

Since the sections would undergo uncontrolled deformation, initiators of the formation of the first buckling fold, i.e. "imperfections", were introduced into the specimens (Fig. 11).



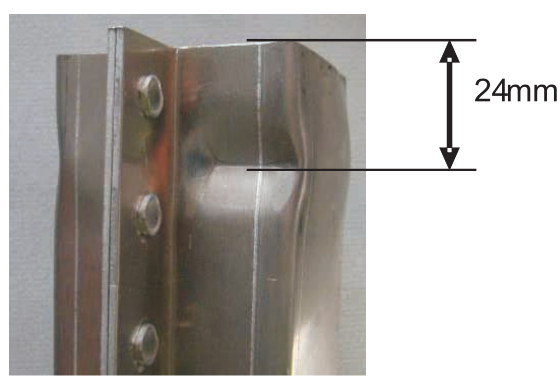


Fig. 11. Prestamping of thin-walled section on ram side (introduction of imperfections)

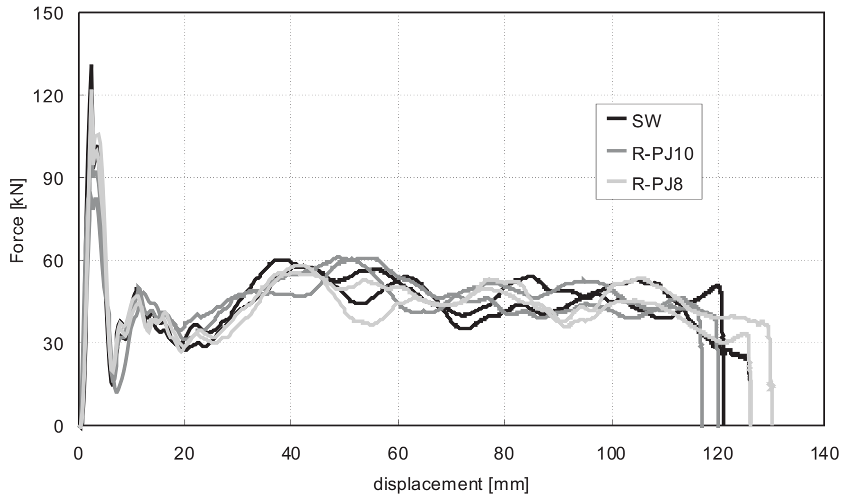


Fig. 12. Force versus specimen shortening for aluminium alloy AW 5754 O under dynamic crushing with energy of 6kJ; spot-welded specimens SW, clinch-joined specimens R-PJ8 and R-PJ10

According to the force-specimen shortening curves shown in Fig. 12, the introduction of imperfections resulted in repeated characteristic oscillations, irrespective of the joining method. This is confirmed by the regular way in which the specimens deformed (Fig. 13). Slight disturbances in the formation of buckling folds were observed on the specimen's flange. In the initial stage of deformation the force sharply increases, reaching a maximum of ca. 120 kN (depending on the joining technique used). This is caused by the formation of the first buckling fold. Then the force decreases to about 20 kN. The next folds form at a force below 60 kN. When analyzing the curves for a specimen shortening of 0-40 mm one notices the high reproducibility of the results, regardless of the joining technique. This is owing to the introduction of an imperfection into the specimen, which forced the formation of the first fold. For a section shortening of 40-120 mm the force values are very close to the average of 50 kN and the differences in the force waveforms do not have a significant effect on the final shortening of the sections. A larger specimen shortening was obtained in the case of the R-PJ8 joints, which was due to the lower strength of this type of joint in comparison with the other tested joints.

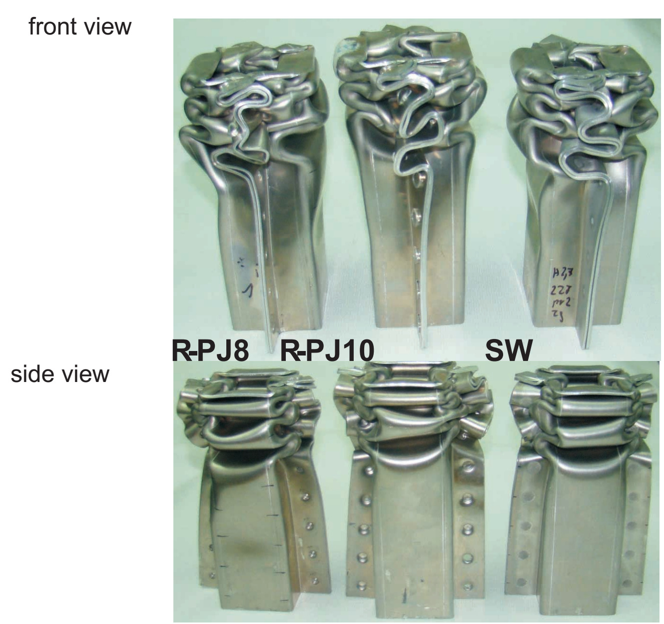


Fig. 13. Deformation of sections (with introduced imperfections) made of aluminium AW 5754 O, joined by clinching – R-PJ8 and R-PJ10 and by spot welding – SW

In the places where during the making of the sections the largest plastic deformations were obtained (edge – a in Fig. 3) sheet material cracking was observed, irrespective of the joining technique (Fig. 14).

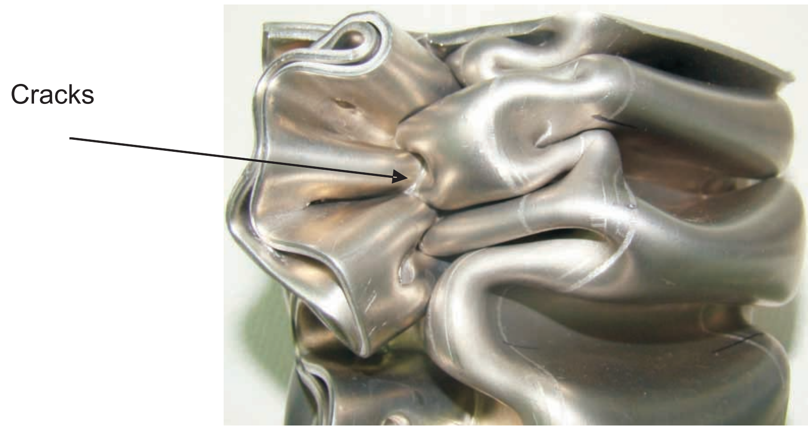


Fig. 14. Sheet material cracking in places of largest plastic deformations for sections made of alloy AW 5754 O

Clinch joining is better as regards maximum load P_{max} which is smaller than for spot welding. This means that clinching ensures a lower car user overload (Fig. 12).

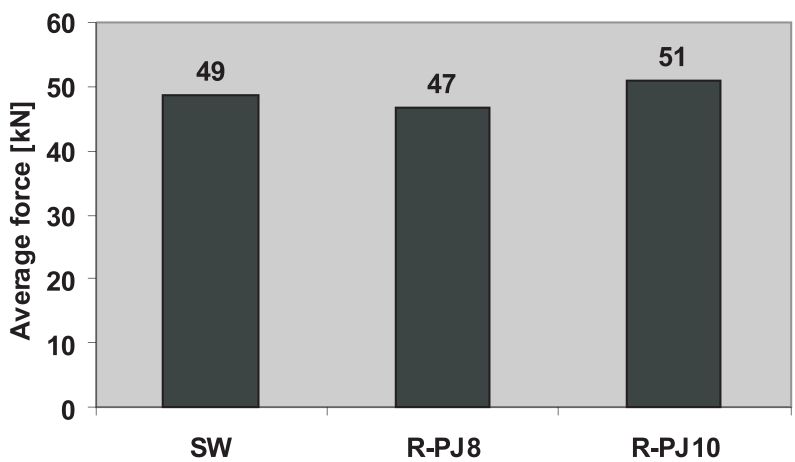


Fig. 15. Average impact force in dynamic test for different types of joints in thin-walled profiles made of aluminium alloy AW 5754 O

The tests carried out for the aluminium alloy showed that the average impact force, defined as a ratio of absorbed energy E to total specimen shortening δ, is the best indicator of the capacity to absorb kinetic energy by a given section. According to figure 15, the highest average force value was recorded for clinch-joined sections R-PJ10. The average is even higher than for the spot-welded sections. In the case of the R-PJ8 joints, larger specimen shortening was recorded γ = 0,428 whereas for SW γ = 0,406 and R-PJ10 γ = 0,393. This was due to the lower strength of this type of joint in comparison with the other tested joints. Therefore clinches with their diameter equal to or larger than 10 mm should be used for clinching.

6. Conclusion

The absorption of energy by thin-walled elements joined by spot welding and that by such elements joined by clinching with round tools were compared. As the strength diagrams show, clinch joints have lower strength than spot-welded joints, which is due to their structure. But the higher strength of the joint has no significant effect on energy absorption by the thin-walled sections. A comparison of energy absorption by the thin-walled sections joined by clinching with circular tools (R-PJ10) and that by the spot-welded sections showed no significant differences in the process of deformation. The values of the parameters describing energy absorption by the thin-walled sections for the two kinds of joints were very similar.

A lower energy absorption was recorded in the case of the R-PJ8 joints because of their too low strength.

Clinch joining is better as regards maximum load P_{max} which is smaller than for spot welding. This means that clinching ensures a lower car user overload.

The results show that clinching could replace the joining by welding of energy absorb-ing thin-walled specimens, but then suitable clinching techniques should be selected.

Acknowledgements

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