EVALUATION OF PROPERTIES OF JOINTS MADE BY CLINCHING AND SELF-PIERCING RIVETING METHODS

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Abstract
Various materials are used in car body production. Numerous issues arise not only in their formation but also in joining. It is not always possible to use conventional joining methods such as resistance spot welding, therefore clinching and self-piercing riveting methods seem to be possible alternatives. The paper evaluates the properties of joints made by clinching and self-piercing riveting methods. The following materials utilized in automotive industry in car body production were used in the joining process: microalloyed steel H220PD (thickness of 0.8 mm), extra deep-drawing grade steel DC06 (0.7 mm) and drawing grade steel DX51D+Z (0.9 mm). In order to evaluate the properties of the clinched joints, the following tests were performed: tensile test – to determine the carrying capacities and the force-elongation diagrams; microhardness test – to determine the changes in the development of microhardnesses mainly in the critical areas of the joint; and a metallographical analysis observing the joints' structures. Clinching and self-piercing riveting proved to be suitable methods for joining the tested materials.

Keywords: joining, tension test, metallography, microhardness test

1 Introduction
The automotive industry is currently working to accommodate the conflicting requirements of both environmental legislation and customer demands for greater performance and more features luxury and safety, by developing a light-weight and therefore essentially, energy-efficient vehicle [1]. One of the possibilities of decreasing the car weight and consequently lowering the fuel consumption is using various combinations of materials, such as a combination of conventional deep-drawn steel sheet and high-strength steel sheet. Assembly and joining techniques must also be redesigned when adopting alternative materials [2,3]. Low carbon steels are produced for automotive applications. These steels have a low yield strength and weldability [4-6]. Thanks to its versatility and low cost, low carbon steel is an effective material for most automotive applications, including crashsensitive parts because they perform better with respect to crash energy management as well as wear resistance [7-9].
Microalloyed steels have developed during the past 40 years into an important class of highstrength structural materials. A project involving an ultra-light-steel auto body (ULSAB) concluded that high-strength-steels are the materials of choice for the automotive industry. This project showed that replacing cheaper carbon steels with high-strength steels allowed automakers to reduce the weight of an auto body at the same or at potentially lower costs. The strengthening effects of vanadium make microalloyed steels particularly suited for highstrength-

steel applications [10,11]. The increasing use of coated, lightweight and high-strength materials has led the automotive industry to re-examine the traditional methods of component assembly. For example, direct welding of dissimilar sheet metals has proven to be difficult or impossible; thus, alternative joining techniques, such as mechanical fastening systems, have attracted increasing interest and applications in recent years [12]. Mechanical fastening encompasses a broad range of methods, from threaded fasteners to different forms of rivets and mechanical interlocking methods [13,14].

One of these methods is clinching, which has not attracted much attention from researchers yet, so it has not been studied deliberately so far. Clinching does not use any kind of appending joining components (such as screws, bolts) [15]. The second of the useful mechanical fastening methods is self-piercing riveting (SPR), which is a quick, cheap and single-step technique, using a semi-tubular rivet to fix the sheet components into a mechanical joint. No pre-drilled hole is needed; the rivets are pushed directly into the sheets clamped together between a blank holder and a die in a press tool [16]. With the increased use of high strength steel and aluminium sheets in automobile parts in order to reduce the car weight, a lot of research has been carried out to extend the application domain of the SPR process [17-19].

The clinching process is a combination of drawing and forming that locks together steel sheets. Only a die and a punch are used to press the sheet components to finish the whole joining process. The blanks are plastically deformed and the shape of the tools remains theoretically unchanged during the clinching processes. The punch is movable, whereas the fixture and the die are fixed during the process. The punch force needed for the joining process depends on the thickness and the strength of the materials to be joined, the size of the tools and friction coefficient usually varies from 10 to 100kN [20,21].

2 Experimental materials and methods

Clinching is a joining method in which sheet metal parts are deformed locally without the use of any additional elements [2] as shown in **Fig. 1**. The technology allows joining of two or more metal sheets (made of the same or different materials and up to a total joint thickness of about 5–6 mm) regardless of surface condition (painted, lubricated, coated or oxidised) and without any edge preparation [21]. After the joint has been made, there is no need for repainting the sheets or performing stress relieving treatments [9].

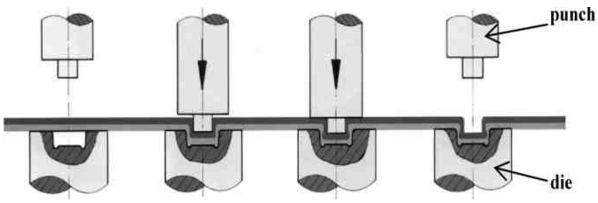

Fig. 1 Clinching process

Self-piercing riveting is a high-speed joining process that does not require pre-existing holes, therefore eradicating the need to align the joining materials. The materials to be joined are stacked, with a punch above the stack and a die underneath it [22]. The punch impacts the rivet, piercing the top sheet, and partially piercing the bottom one. The die on the underside of the materials causes the rivet to flare under the force, creating a mechanical interlock [23,24]. This process therefore requires access to both sides of the joint. The entire process of piercing and forming the joint is carried out in a single operation [7] as shown in **Fig. 2**.

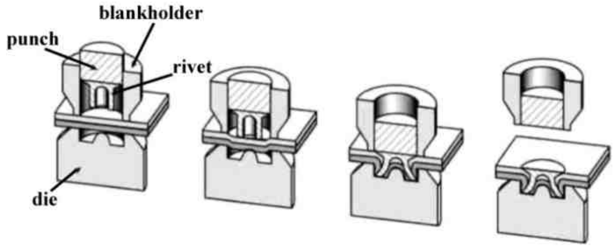

Fig. 2 Self-piercing riveting process

The following steel sheets were used for experimets: microalloyed steel HSLA H220PD with the thickness of 0.8 mm, extra deep-drawing grade steel DC06 with the thickness of 0.7 mm and DX51D+Z with the thickness of 0.9 mm.
Their basic mechanical properties and chemical composition are shown in **Table 1** and **Table 2**. Mechanical properties of DX51D and DC06 steels were specified by producer as follows:

Table 1 Basic mechanical properties of materials

Material	**$Rp_{0.2}$[MPa]**	**Rm [MPa]**	**A_{80} [%]**
H220PD	238	382	36
DC06	170	270-330	41
DX51D+Z	≥ 140	270-500	23

Table 2 Chemical composition (in [%] of wt) of materials

Material	C	Mn	Si	P	S	Al	Cu	Ni
H220PD	0.012	0.435	0.119	0.057	0.002	0.041	0.040	0.013
DC06	0.020	0.071	0.010	0.017	0.002	0.055	0.038	0.011
DX51D	0.064	0.178	0.007	0.016	0.002	0.120	0.041	0.002
Material	Cr	Ti	V	Nb	Mo	Co		
H220PD	0.046	0.033	0.012	0.052	0.009	0.047		
DC06	0.022	0.062	0.008	0.023	0.009	0.035		
DX51D	0.023	0.002	0.005	0.015	0.004	0.019		

The following samples of the same material combinations were used for joining:
- ***Samples A***: H220PD (a0 = 0.8 mm)
- ***Samples B***: DC06 (a0 = 0.7 mm)
- ***Samples C***: DX51D (a0 = 0.9 mm)

In order to evaluate the properties of the joints, the following tests were performed: tension test, microhardnesses test and a metallographical analysis.
The samples with dimensions of 40 x 90 mm and 30 mm lapping according to STN 05 1122 standard were used for the experiments (**Fig. 3**). Six samples were prepared for every combination of sheets. It was not necessary to clean the surfaces of the samples before clinching. The self-piercing riveting method was carried out with the aluminium rivets (**Fig. 4**).

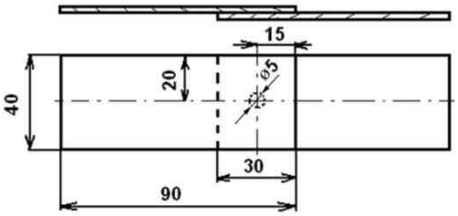

Fig. 3 Dimension of samples for the tension test

Fig. 4 Aluminium rivets for self-piercing riveting method

The carrying capacities of the clinched joints were evaluated according to standard STN 05 1122 – Tension test of spot welded joints. This test was used for measuring the maximum carrying capacities Fmax of the joints. The test was carried out on the metal strength testing machine TIRAtest 2300 produced by VEB TIW Rauenstein, with the loading speed of 8 mm/min.
Further tests for the quality evaluation of clinched joints included the metallographical analysis and microhardnesses analysis according to STN EN ISO 6507-1 standard. Microhardness method is frequently used for determination of hardness of small items or thin layers, and identification of individual phases in metallography. The principle of measurement is identical to Vickers hardness test, except for considerably smaller loads [25]. In this experiment, the applied load was 980 mN in the range of 10-15 s.

3 Results and discussion

The measured values of carrying capacities of clinched joints (CJ) and joints made by self-piercing riveting (SPR) are shown in **Table 3**.

Table 3 Measured values of carrying capacities Fmax[N] (SPR – self-piercing riveting)

Samples A (H220PD)		**Samples B (DC06)**		**Samples C (DX51D)**	
Clinching	***SPR***	***Clinching***	***SPR***	***Clinching***	***SPR***
1038	4952	870	3673	1451	5054
980	4820	805	3929	1485	5020
997	4703	850	3901	1455	4695
1036	4763	884	3893	1478	4667
1051	4725	858	3889	1469	4554

The tensile tests were executed under displacement control conditions on both specimen configurations (clinching and self-piercing riveting) in order to characterise the static behaviour of the joints and to estimate the ultimate tensile strength. The maximum shearing load was the most significant value obtained from the ‘‘load-displacement’’ curves as shown in **Fig. 5**.
The form of the curves indicates the behaviour of the joints under load. The shearing load is higher for SPR joints than for clinched joints in all observed combinations of joined materials.
All observed samples of SPR joints had higher values of carrying capacities in comparison to clinched joints. On average, the clinched joints reached 21% (samples A), 22% (samples B) and 30% (samples C) of carrying capacities of SPR joints.

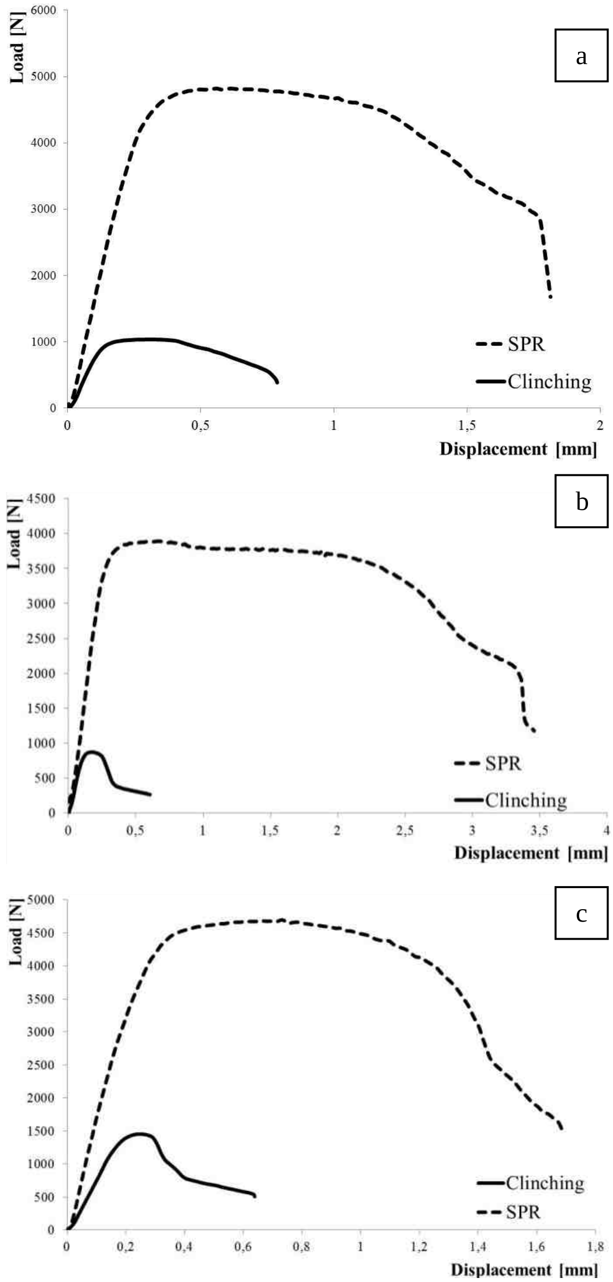

Fig. 5 Load-displacement curves and deformation of the CJ and SPR joints after tension test: a) samples with H220PD materials, b) samples with DC06 materials and c) samples with DX51D materials

The deformation capacity of a clinched joint was considerably lower than the deformation capacity of anSPR joint. In this case, the average maximum shearing load was: for sample Aapprox. 4800 N with the corresponding displacement of about 0.4 mm, for sample B approx.3800 N with the corresponding displacement of about 0.5 mm and for sample C approx. 4800 N with the corresponding displacement of about 0.4 mm. During the riveting process, the rivet and the riveted sheets undergo massive deformation in order to form the mechanical interlock. This energy is stored within the interlock, leading to higher energy absorption than that of clinched joint.

Joints made by self-piercing riveting method failed in the manner of a press-stud in combination with a failure of one edge of the joint– **Fig. 6**. Joints made by clinching failed at the neck of the joint – **Fig. 7**. Both modes result in loosening of the joint after quite small displacements. In the press-stud mode, insufficient deformation produces minor interlocking of the sheets and will lead to failure. In the second mode, there is insufficient material in the neck of the joint and loading will result in failure in the neck; excessive elongation in the region of the joint neck, causing crack formation.

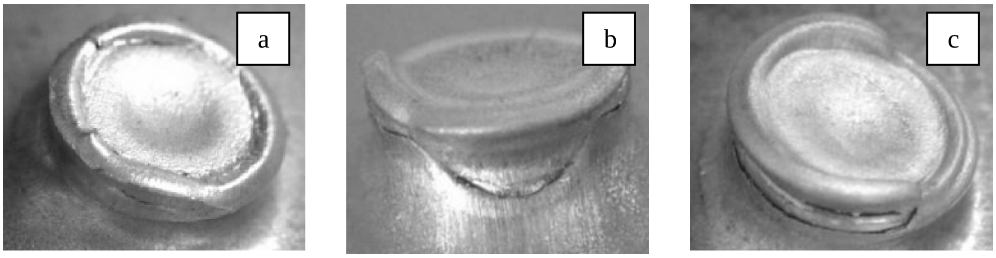

Fig. 6 Failures of SPR joints: a) samples with H220PD materials, b) samples with DC06 materials and c) samples with DX51D materials

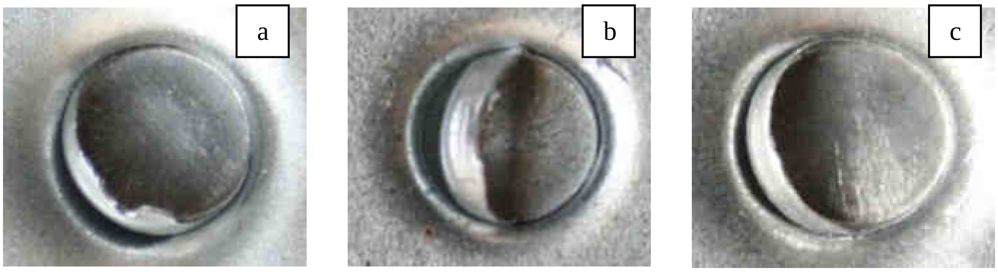

Fig. 7 Failures of CJ: a) samples with H220PD materials, b) samples with DC06 materials and c) samples with DX51D materials

Both types of failures occurred in the critical area of CJ joints as well as SPR joints. The critical area of both types of joints is the place of the most significant thinning of the joined materials in the area of neck joints, as shown in **Fig. 8**. When using SPR joints, this area is strengthened with rivets. However, significant thinning or failures were observed in these joints on their bottom parts – in the place of the transition from the bottom of the joint into the bulge on the bottom's edges.

Samples with marked areas of microhardness measurements on samples of SPR joints and clinched joints are shown in **Fig. 9**. The measured values of samples A with H220PD materials are presented in **Fig. 10**, samples B with DC6 materials are in **Fig. 11**, and finally samples C with DX51D materials are shown in **Fig. 12**. The measurements show the changes in the clinched joint and self-piercing riveted joint. The highest microhardness values were measured in the critical areas of both joints, i.e. in the areas of the most significant deformation and material hardening. When comparing the microhardness values of self-piercing riveted joints and clinched joints, higher values of microhardness were measured on all observed samples of self-piercing riveted joints, especially in the places marked as *4* and *9*. In these places, the rivet caused greater deformation and material hardening of the joined materials in comparison with the clinched joints.

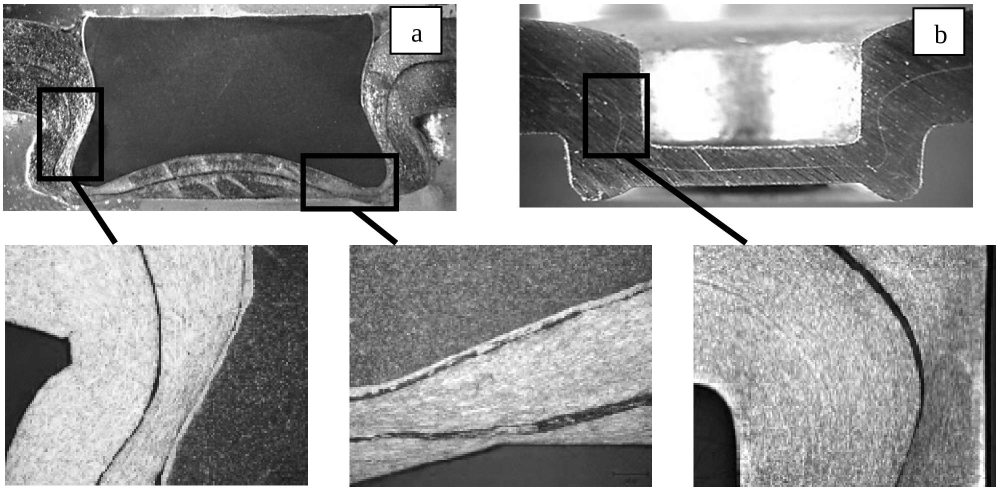

Fig. 8 Critical areas of the joints: a) self-piercing riveting joints;b) clinching

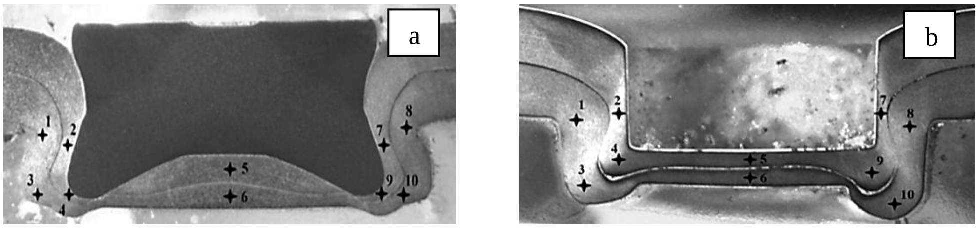

Fig. 9 Marked areas of intender penetration in the microhardness test: a) self-piercing riveted joint and b) clinched joint

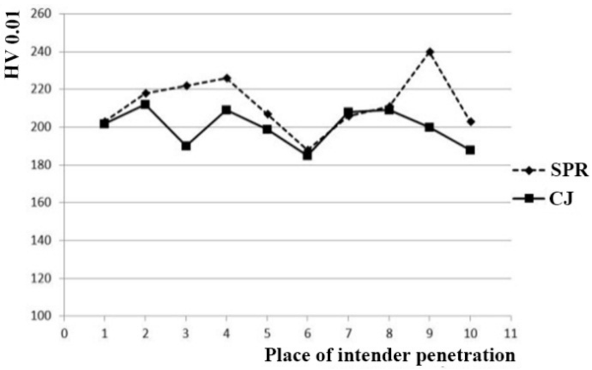

Fig. 10 Microhardness values of SPR and CJ joints of sample with H220PD materials

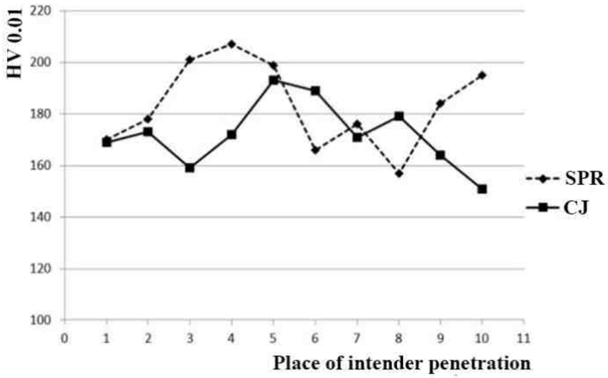

Fig. 11 Microhardness values of SPR and CJ joints of sample with DC06 materials

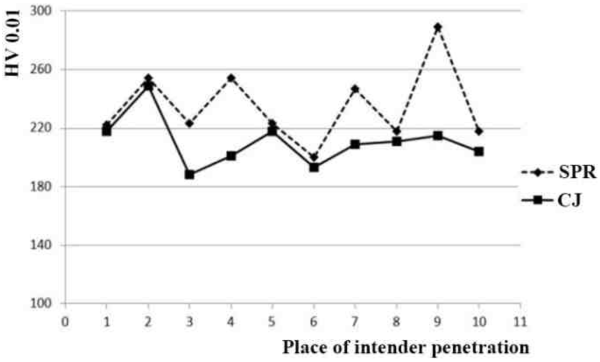

Fig. 12 Microhardness values of SPR and CJ joints of sample with DX51D materials

Conclusions

The methods of clinching and self-piercing riveting are suitable for joining the tested materials. All tested samples of self-piercing riveted joints reached higher values of carrying capacities in comparison with clinched joints. The maximum load values of clinched joints and self-piercing riveted joints were 1020 N and 4790 N for the samples of H220PD materials, 853 N and 3857 N for the samples of DC06 materials, and 1467 N and 4798 N for the samples of DX51D materials.

The carrying capacities of these samples were sufficient and the metallographical analysis confirmed no occurrence of cracks or failures in the area of joints during both joining processes.

Using the self-piercing riveting method led to significant hardening of the joint in the critical area in comparison to the classical clinching method. This result was evident from the values of carrying capacities of the joints.

The highest values of microhardness were measured in the areas with the most significant thinning of the joined materials as well as in the areas with the most significant hardening of joined materials in both types of joining.

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