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Investigation of clinch joints made of similar and dissimilar materials

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Abstract. Clinching is a mechanical cold forming method to join two or more overlapping sheets without using of rivet. This technology is already in use for production of aluminum and steel sheet car body panels. This process is carried out without heat effect on the material structure, thus the clinching is one of the technologies which may replace traditional processes as resistance spot welding or friction stir welding. The clinching technology has been well known for many years, but only during the last decades become more and more widely applied particularly in the automotive industry. This paper presents the results of experimental research work in the field of clinching of different strength sheets developed for automotive application.
Keywords: clinching, joining processes

1 Introductions

The variety of sheet materials applied in the vehicle industry is very versatile and the manufacturers can choose the most suitable ones for the given application according to their needs. It often happens that they apply dissimilar materials within one structural unit: it may mean different sheet thicknesses of the same material grade, but it may also mean the application of dissimilar material grades – e.g. aluminium and steel – with different material properties. However, they often have to join these sheets to assemble the suitable final product. There are various methods suitable for joining sheet metal parts. Among the many processes several groups of welding may be regarded as the most widely applied joining techniques, e.g. resistance spot welding, soldering, and besides them adhesive bonding, as well as various mechanical joining, or their combinations are also applied. The manufacturers choice is affected by many parameters, e.g. which process is more suitable for preparing the proper joint between the sheets, what is the cost for purchasing the right equipment, the raw material, and to what extent the given process can be mechanized, since all these can greatly affect the manufacturing time, the needed human resources quantity, and in this respect the final product price. These points of view altogether determine the process to be chosen. In this paper we will mainly focus on mechanical joining of similar and dissimilar sheet materials by clinching [1, 2].

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2 Mechanical joining by clinching

Clinching nowadays is a widely used joining process belonging to the group of mechanical joining. Clinching means pressing two or more sheets into each other with a punch and die pair with the help of a special or universal pressing machine.

2.1 Main types of clinching

Clinching is more and more often applied in the vehicle industry for joining coated or uncoated thin sheets of similar or dissimilar materials. Clinching of dissimilar materials either mean different material grades or different thicknesses. In clinching processes, two or up to three sheets are overlapped on each other and the sheets are joined by stamping. Clinching has several variants, and among them the round clinching is regarded as the most general one. In Figure 1, the round clinching process can be seen together with the main elements of a clinching tool.

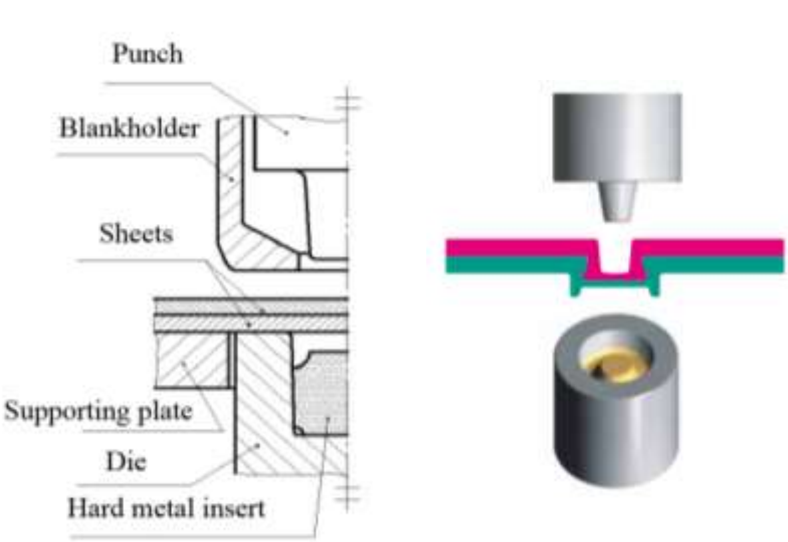

Figure 1. Main tool elements in a round clinching process.

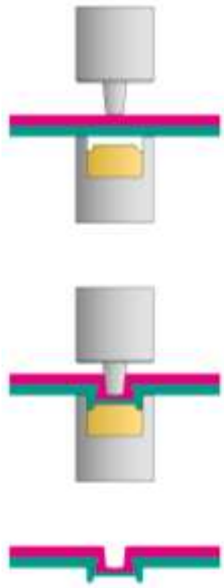

Figure 2. Process sequence in round joint clinching.

The process sequence and the material flow can be seen in Figure 2. The process sequence follows from up to down. As it can be seen in this Figure, a simple round punch presses the materials into the die cavity. As the force increases, the punch side material is forced to spread outwards within the die side material. The result is an aesthetically good looking round button at the end of this clinching process: the sheets are mechanically joined, clearly without any burrs or sharp edges.

Due to its versatility and its many advantages (summarised later) there are many different types of joints made by clinching. The TOX®-Twin Point [3] process provides two similar buttons with almost double strength of a single point. A special advantage of this process is that it prevents the rotation of two joined layers against each other. It may happen that the button normally formed by a round joint clinching is not acceptable: in this case flat joint clinching should be applied.

2.2 Characteristics, main advantages and disadvantages of clinched joints

As it was mentioned, round joint by clinching may be regarded as the most often used type of clinching processes. This is the simplest and the clearest mechanical joining of sheets. There is no need for preliminary works. The tools do not contain cutting or moving elements causing problem.

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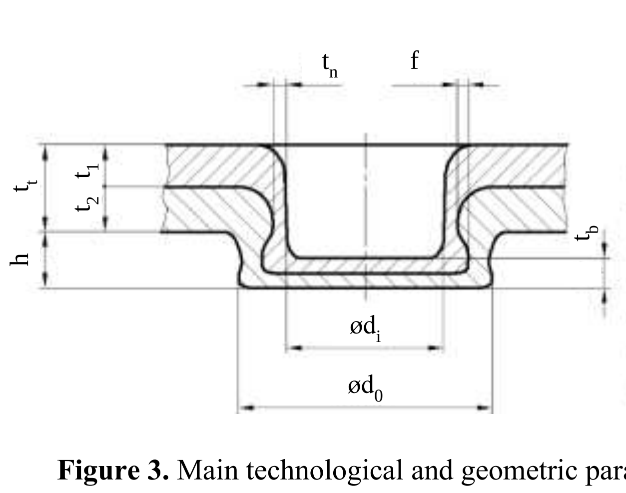
The most important advantages of clinching [3] may be listed as follows:

- 30 – 60% cost saving compared to resistance spot welding,
- the dynamic load resistance of clinched joints is usually better than in resistance spot welding,
- the necessary preparation for clinching can be well automated,
- simple, non-destructive quality inspection is possible by using a simple instrument to measure the remaining thickness at the bottom of the joint,
- during clinching there is no any heat generation thus no microstructural changes occur,
- there are no damages at different surface protecting layers (e.g. galvanised, pre-painted, etc.) since the layer flows with the base material together,
- parts joined by clinching have good electrical conductivity,
- since there is no temperature effect, clinching can be applied together with adhesive bonding,
- sheet thickness can vary in large interval (usual range between 0.3 mm and 6 mm),
- intermediate layers (e.g. paper or glue) can also be used,
- the process can be excellently monitored,
- joints made by clinching may have long life duration,
- since there is no contamination during the process, it does not require supplementary work,
- the process itself is extraordinarily environment friendly,
- clinching is significantly cheaper than laser welding.

Besides the many advantages, obviously there are some disadvantages, too. As one of the few disadvantages, we have to mention that the strength properties of joints made by clinching usually are weaker than that of made by resistance spot welding, however, in many cases it is even not always necessary. We could also mention that the strength parameters made by the new TOX technology already reach about 70% of the values of resistance spot welding. Furthermore, it is also worth mentioning that in spite of weaker mechanical properties, clinching is more and more often applied instead of resistance spot welding, since the clinching process often better fits into the manufacturing process route.

2.3 Quality factors of clinching

In a general round joint clinching process [4], the strength of the joints is determined by the neck thickness and the under cutting: both parameters are affected by the shape and parameters of tools as the diameter of the punch and the die, as well as the die deepness. The main geometric parameters of a round joint clinching tool are shown in Figure 3.



$ød_0$: outside diameter
$ød_i$: inside diameter
t_1: top sheet thickness
t_2: lower sheet thickness
t_t: total thickness
t_b: bottom thickness
t_n: neck thickness
h: point height
f: under cutting

Figure 3. Main technological and geometric parameters in clinching.

2.4 Investigation of clinched joints
To provide good quality clinched joints it is strongly advised to perform experimental investigations to define the appropriate process parameters and to choose the proper tool set for a given application. It is also desirable to perform mechanical tests applying static and dynamic loads.

The usually applied tests are the same as they are in case of spot welded joints, where the shearing and the pulling breakup tests are widely used as shown in Figure 4. During these tests, the neck width is also measured to investigate the effect of the geometric parameters on the strength of the joints.

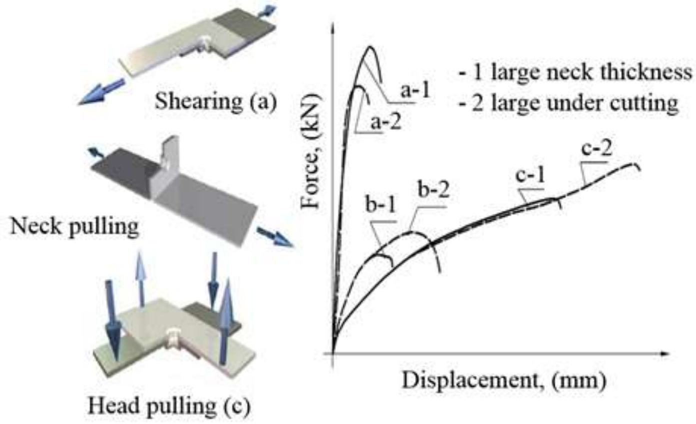


Figure 4. Illustration of shearing-, neck- and head pulling tests with the main types of failures [5].

2.5 Experimental investigations
During the experimental investigations a Round Tox tool was applied for testing clinched joints. The tool was specially designed for producing round joints. With this standard tool setup, it is possible to create mechanical joints between high strength sheets of 1 mm thickness. According to the tool manufacturer [3], the best properties of the joints can be reached when the bottom thickness is about 0.45–0.5 mm.

The tests were performed in the Material Testing Laboratory of the Institute of Materials Science and Technology. The testing machine was an MTS-801 type, electro-hydraulic, computer controlled, universal material testing equipment. The nominal force of this material testing system: F_{max} = 250 kN, The testing machine with a clinching tool mounted on it can be seen in Figure 5. On the right side of this Figure an enlarged view of the clinching tool is shown.

a) b)

Figure 5. The experimental setup; a) MTS-801 Testing System, b) the Clinching tool

In order to analyse the clinching process, first some preliminary clinching tests were performed with different punch displacements to produce different bottom thicknesses. After clinching, the parts are cut into two parts to create meridian sections as shown in Figure 6, for two different states (T0 and T6) of AA6082 material pairs. In the first case we analysed the joining in T6 (artificially aged) state then in T0 (solution heat treated) condition. From this figure it can be seen that successful joints could be made in solution heat treated condition, while in T6 condition cracks always appeared.

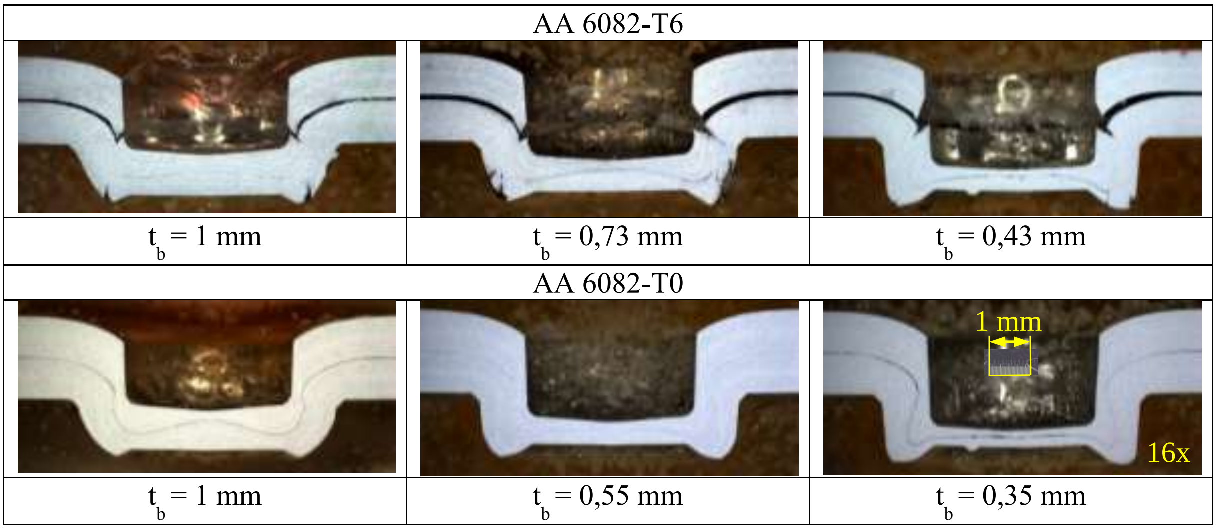


Figure 6. Sections of round joints made with different bottom thicknesses for AA6082 material grade in T6 and T0 condition (wall thickness 1mm).

On the microscopic samples micro-hardness measurements (HV 0.5) were also done. The micro-hardness values were measured in the meridian sections of the samples. Measurements started at the centre point of the joints, and the distance between the hardness measurement points was selected to 0.5 mm. The measured micro-hardness values of the specimen with 0.35 mm bottom thickness are shown

Then we investigated the effect of the bottom thickness (its optimum value is suggested by the tool manufacturer) on the strength properties of joints. The results of these investigations are shown in Table 1.

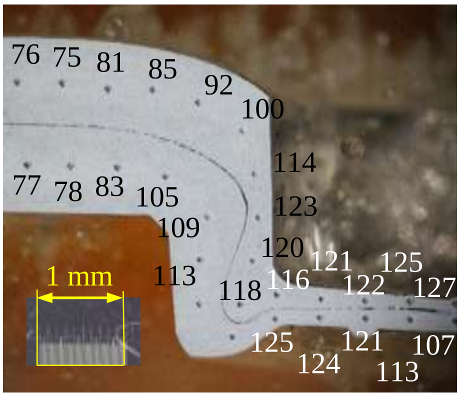


Figure 7. Results of HV 0.5 hardness measurement for 0.35 mm-bottom thickness on AA6082-T0 material quality (sheet thicknesses: 1 mm)

Besides the same AA6082 material quality clinched joints were made using dissimilar material grades with the same material thickness (t = 1 mm): in these tests AA5754 aluminium and DP600 steel materials were used. The optimum bottom thickness was also determined for these materials pairs, too. Those bottom thickness values were regarded as optimum when the highest tensile and neck pulling forces were measured (these bottom thickness values are shown with shaded colour in Table 1). Three tests types of samples were prepared: 1. Shearing – tensile test, 2. Head pulling test, 3. Neck pulling test. The samples were prepared by laser cutting. The sample geometry and dimensions are shown in Figure 8. The samples used for different tests are shown in Figure 9.

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Table 1. Results of the determination of optimal bottom thickness

AA6082-T0 / AA6082-T0			AA6082-T0 / AA5754			AA5754 / AA6082-T0			AA6082-T0 / DP600			DP600 / AA6082 -T0		
t_b (mm)	Tensile test (kN)	Tensile test average (kN)	t_b (mm)	Tensile test (kN)	Tensile test average (kN)	t_b (mm)	Tensile test (kN)	Tensile test average (kN)	t_b (mm)	Tensile test (kN)	Tensile test average (kN)	t_b (mm)	Tensile test (kN)	Tensile test average (kN)
0,64	1,37	1,30	0,65	0,8	0,85	0,60	1,00	1,03	0,74	0,60	0,50	0,88	1,68	1,89
0,65	1,24		0,64	0,9		0,59	1,05		0,77	0,40		0,87	2,10	
0,55	1,40	1,29	0,59	1	1,03	0,55	1,48	1,24	0,67	0,58	0,42	0,75	2,40	2,38
0,55	1,17		0,6	1,05		0,55	1,00		0,68	0,25		0,77	2,35	
0,47	1,31	1,47	0,52	1,20	1,06	0,50	0,92	1,21	0,55	0,68	0,69	0,62	-	-
0,47	1,63		0,52	0,92		0,50	1,50		0,56	0,70		0,72	-	
0,43	1,60	1,38	0,48	1,70	1,50	0,47	1,46	1,53	0,47	0,72	0,72	0,55	-	-
0,43	1,16		0,47	1,30		0,46	1,60		0,46	0,72		0,56	-	
0,36	1,35	1,24	0,41	0,90	1,09	0,42	1,58	1,45	0,40	0,50	0,56	0,45	-	-
0,36	1,13		0,42	1,28		0,43	1,32		0,41	0,61		0,47	-	

The upper part of Figure 8, shows the original sample geometry and dimensions, while its lower part indicates the overlapping position of joined parts. The results of the tensile tests are summarised in Table ***2***.

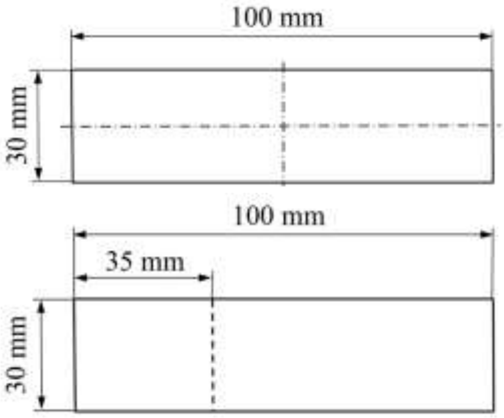

Figure 8. Geometry of test samples.

Figure 9. The samples used for tensile, head pulling and neck pulling tests.

Table 2. The results of the tensile, head and neck pulling tests for T6 and T0 condition of AA6082

AA6082-T0 t_b = 0,47mm T = 525°C, t = 30 min				AA6082-T6 t_b = 0,47mm T = 525°C, 30 min + T = 190°C, t = 8 h		
No. of samples	Tensile test (N)	Head pulling test (N)	Neck pulling test (N)	Tensile test (N)	Head pulling test (N)	Neck pulling test (N)
1	1 171	709	254	1 755	803	307
2	1 662	737	279	1 738	816	295
3	1 506	692	310	1 751	872	290
4	1 329	737	277	1 717	883	304
average	1 417	719	280	1 740	843	299

Based on these results, it can be stated that the aluminium AA6082 alloy in T6 condition practically cannot be clinched successfully. After solution heat treatment at T=525°, with t=30 min holding time, the clinching can be done successfully. The best joints were obtained by using 0.45 and 0.5 mm bottom thicknesses. After ageing at T=190°C, t=8 h, the strength properties were significantly improved for all three types of tests.

As it was already mentioned, we also investigated clinched joints with dissimilar materials. The tested material pairs (thickness: 1 mm) were: AA6082-T0/AA5754, AA5754/AA6082-T0, AA6082-T0/DP600, DP600/AA6082-T0. In Figure 10, the clinched joints of AA6082 and AA5754 are shown. For clinched joints formed with Al 6082 / Al 5754 pairs, perfect joints were created (see Figure 10).

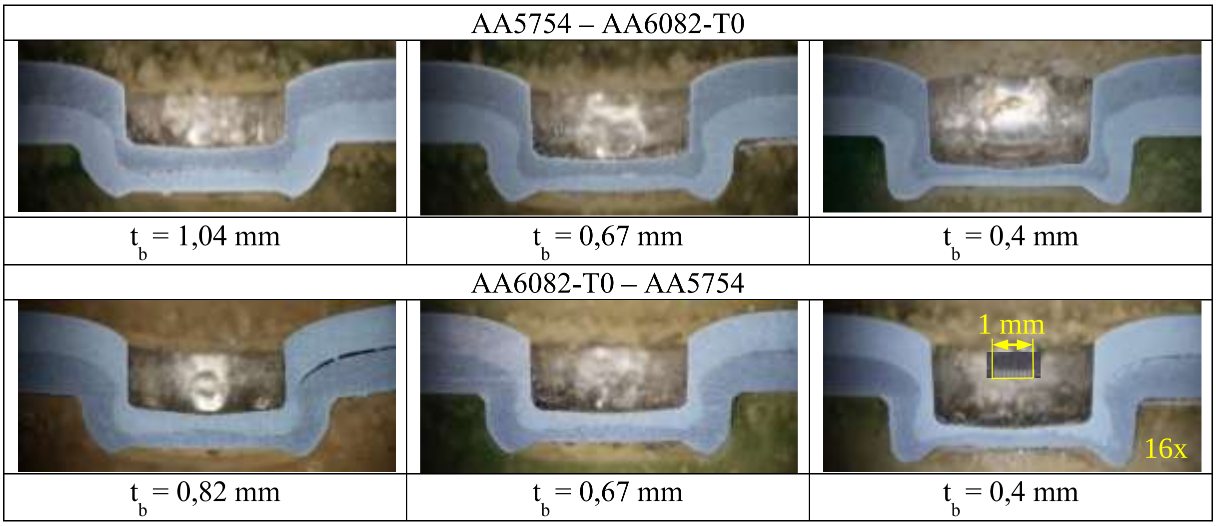

Figure 10. The process of clinching using AA6082-T0 and AA5754 (thickness t =1 mm).

In Figure 11, clinching of AA6082 and DP 600 material qualities are shown. In these experiments, we applied different joining configurations, i.e. punch side and the die side was differently applied to the materials joined.

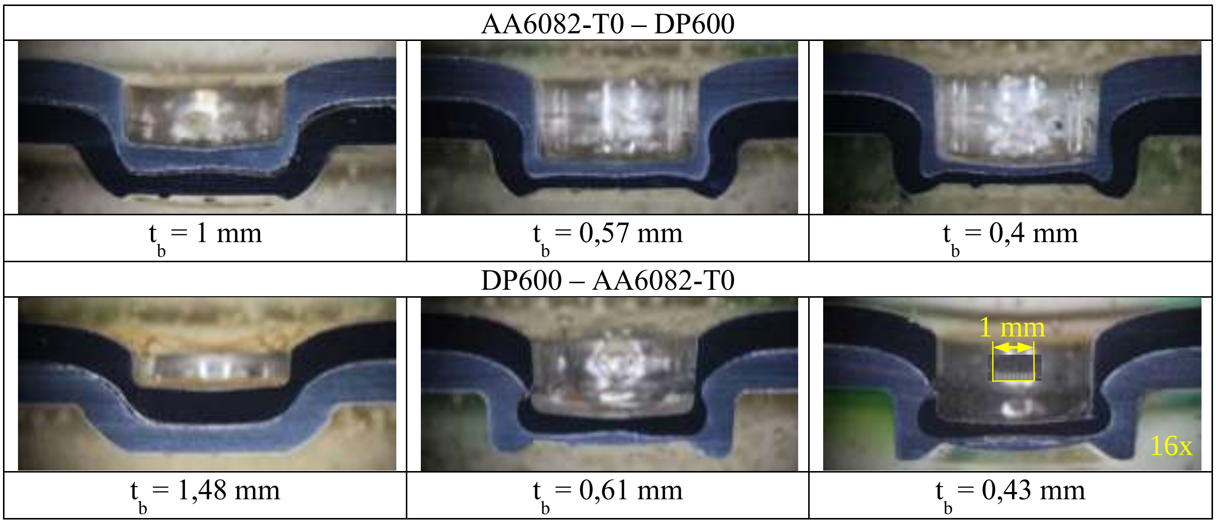

Figure 11. The process of clinching AA6082-T0 and DP600 material qualities (thickness t =1 mm).

For joints made with AA6082 / DP600 material qualities, it was not always possible to successfully create joints at different bottom thicknesses when the higher strength material, i.e. DP600 was on the punch side. The results of the tensile tests for dissimilar materials are summarised in Table 3.

Table 3. The results of the tensile tests for dissimilar materials

	AA6082-T0 / AA6082-T0		AA6082-T0 / AA5754		AA5754 / AA6082-T0		AA6082-T0 / DP600		DP600 / AA6082 -T0	
	T0 - (T = 525°C, t = 30 min)									
speciment	Tensile test (kN)	Head pulling test (kN)	Tensile test (kN)	Head pulling test (kN)	Tensile test (kN)	Head pulling test (kN)	Tensile test (kN)	Head pulling test (kN)	Tensile test (kN)	Head pulling test (kN)
1	1,17	0,71	1,35	0,70	1,25	0,55	0,85	0,58	1,15	0,30
2	1,66	0,74	1,30	0,65	0,92	0,60	0,30	0,40	2,50	0,55
3	1,51	0,69	1,38	0,66	1,40	0,62	0,45	0,43	0,70	0,37
4	1,33	0,74	1,30	0,62	1,20	0,53	0,50	0,52	1,40	0,51
average	**1,42**	**0,72**	**1,33**	**0,66**	**1,19**	**0,58**	**0,53**	**0,48**	**1,44**	**0,43**
	AA6082-T6 / AA6082-T6		AA6082-T6 / AA5754		AA5754 / AA6082-T6		AA6082-T6 / DP600		DP600 / AA6082 -T6	
	T6 - (T = 525°C, t = 30 min + T = 190°C, t = 8 h)									
speciment	Tensile test (kN)	Head pulling test (kN)	Tensile test (kN)	Head pulling test (kN)	Tensile test (kN)	Head pulling test (kN)	Tensile test (kN)	Head pulling test (kN)	Tensile test (kN)	Head pulling test (kN)
1	1,75	0,80	1,55	0,72	1,10	0,70	0,75	0,40	2,95	0,88
2	1,74	0,82	1,51	0,75	1,40	0,70	0,75	0,55	2,80	0,89
3	1,75	0,87	1,42	0,80	1,38	0,70	0,85	0,55	3,00	0,80
4	1,71	0,88	1,40	0,72	1,30	0,65	0,65	0,60	3,20	0,90
average	**1,74**	**0,84**	**1,47**	**0,75**	**1,30**	**0,69**	**0,75**	**0,53**	**2,99**	**0,87**

Based on these results, it can be stated that AA6082 solution heat-treated aluminium sheets can be successfully clinched with similar strengths material grade AA5754, while with other high strength sheets (DP600) cannot always be joined successfully.

3 Summary

In this paper, the mechanical joining of similar and dissimilar materials was analysed. Similar clinched joints were made from the same the material grades (e.g. AA6082) with the same sheet thicknesses. Then dissimilar clinched joints can be made either applying different material qualities (e.g. AA5754/AA6082, or AA6082/DP600) or different material thicknesses. The clinched joints were tested using tensile, head pulling or neck pulling tests. Several clinching parameters were also tested, e.g. the effect of bottom thickness and the heat treatment on the mechanical properties of joints. According to the results, it can be stated that the use of heat treatment allows to avoid fractures, improves the flow of material and consequently improves the mechanical behaviour of the joints.

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