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RESEARCH PAPER

# ANALYSIS OF HYBRID JOINING OF MICROALLOYED STEEL SHEETS HX300LAD

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## ABSTRACT

Currently, the concepts of materials used for car bodies differ considerably, with the goal being to reduce the body's weight, thereby reducing fuel consumption and, on the other hand, increasing the passive safety of the crew. Various joining methods, including resistance spot welding, mechanical joining, adhesive bonding and others, combine this range of materials. However, current modern car body concepts require the use of a combination of joining techniques. The study evaluates the properties of the hybrid joints made by mechanical joining and adhesive bonding. Clinching and clinch-riveting were used as mechanical joining methods with a combination of TEROSON EP 5090 as a heat curing, solvent free, one-component adhesive, based on toughened epoxy resins. Double-sided hot-dip galvanized micro-alloyed steel sheets HX300LAD+Z with a thickness of 0.7 mm were used to join with hybrid joining techniques. The hybrid joints' properties were compared to the pure clinched and clinch-riveted joints. Applying the tested adhesive TEROSON EP 5090 in mechanical joints increased their load-bearing capacity by more than 8 times in clinched joints and more than 3 times in clinch-riveted joints.

Keywords: clinch-bonding; clinch-rivet-bonding; tensile test; metallography

## INTRODUCTION

Mechanical engineering, particularly in the automotive industry, is characterized by utilizing diverse materials with varying mechanical properties, thicknesses, and combinations [1,2]. The dominant joining method in the production of car bodies has been spot resistance welding (RSW) for many years. Its efficiency, speed, and automation compatibility make it the go-to method for mass production [3]. Automobile producers are seeking to partially or fully replace RSW. This reason is driven by the need to join various ferrous and non-ferrous materials [4,5]. Reducing environmental impact is an essential part of the automotive industry's focus. For this reason, energy efficiency in joining is also necessary [6].
Techniques such as mechanical joining are commonly employed to meet these requirements. A range of mechanical joining methods such as thread fastening, riveting, and clinching are utilized in automotive manufacturing. Additionally, some car producers employ advanced methods like clinch-riveting, self-piercing riveting, punch-riveting, flow-drill screwing, and friction-element welding as well [7,8].
Clinching is a modern mechanical method of joining materials that allow for the creation of strong joints without the use of heat or additional materials such as screws, rivets, or welds [9,10]. This process consists of mechanically pressing the materials to be joined using a specially designed tool, creating a permanent joint. The clinching process combines drawing and forming to lock steel sheets together [11,12] mechanically. The sheets undergo plastic deformation during the process, while the tool shapes remain theoretically unchanged. The punch moves to operate, while the fixture and die remain stationary [13,14]. The clinching process is carried out without damage to the surface of the materials, which reduces the risk of corrosion and eliminates the need for additional surface treatments [15].
Clinch-riveting is a fastening technique that involves creating a permanent joint by pressing or deforming a rivet to secure two or more sheets of material. It combines clinching and riveting, offering a strong and reliable mechanical bond. This method is widely used in manufacturing industries, especially applications requiring robust and lightweight connections [16,17].
In certain scenarios, combining multiple joining methods becomes necessary. Hybrid joining combines two or more joining techniques to create joints with improved properties than those obtained from their basic techniques. It is used in various applications, including many industries, from automotive to aerospace, marine, construction, and mechanical engineering [18].
Hybrid joining has become the preferred method for assembling modern lightweight structures in cars and commercial vehicles. One reason for this development has been the increased demand for mixed material designs (for example, combinations of steel and aluminum parts), which cannot be realized with traditional joining technologies such as welding. In addition, combining different joining technologies in hybrid joining can build on their strengths and advantages and balance specific weaknesses. For example, such hybrid joining technologies are currently used in the automotive industry to produce BIW (Body in White) bodywork consisting mainly of sheet metal parts [19,20].
Research combining mechanical joining and adhesive bonding has primarily explored using epoxy resin adhesives and low-odor acrylic adhesives in combination with clinching. The adhesive layer thickness usually ranged from 0.1 to 0.2 mm. A key advantage of combining mechanical joining and adhesive bonding is its compatibility with various adhesive forms, including liquids, pastes, foils, and tapes. Studies have demonstrated that, compared to standalone clinching, hybrid fastening introduces an additional strengthening mechanism. The adhesive not only reinforces the clinched area but also enhances the overlap region of the hybrid joint, significantly boosting the joint's load-bearing capacity and energy absorption during failure [21,22]. Mechanical joints should be supplemented with adhesive joints to reduce stresses, achieve smoother load transfer, increase load capacity, increase fatigue life, reduce vibrations, increase joint tightness, and increase corrosion resistance [23,24].
Micro-alloyed steel sheets, often high-strength low-alloy (HSLA) steel, are advanced materials designed to offer high strength, good formability, and enhanced toughness. These properties make them ideal for various applications, including automotive structures, construction, and industrial machinery. The unique properties of micro-alloyed steels are achieved by adding small amounts of alloying elements such as vanadium, niobium, and titanium, which refine grain size and precipitate hardening during thermo-mechanical processing [25-31].
The paper evaluates the properties of hybrid joints created by clinching and clinch-riveting, both with the combination of adhesive bonding. A heat-curing, solvent-free, one-component adhesive based on toughened epoxy resins was used.

## MATERIAL AND METHODS

### Material for joining

Double-sided hot-dip galvanized micro-alloyed steel sheets HX300LAD+Z, with a thickness of 0.7 mm, were used to join with hybrid joining techniques. Micro-alloyed grade steels are characterized by a fine structure and improved cold formability. The sheets are used for dynamically stressed vehicle parts. The basic mechanical properties and chemical composition are shown in **Table 1** and **Table 2**.

**Table 1** Basic mechanical properties of HX300LAD+Z

| Material | $Rp_{0.2}$ [MPa] | $R_m$ [MPa] | $A_{80}$ [%] |
|---|---|---|---|
| HX300LAD+Z | 340 | 460 | 23 |

**Table 2** Chemical composition (in [%] of wt) of HX300LAD+Z

| C | Si | Mn | P | Nb | Ni | Al | V | Ti |
|---|---|---|---|---|---|---|---|---|
| 0.062 | 0.148 | 0.780 | 0.012 | 0.031 | 0.011 | 0.032 | 0.007 | 0.002 |

### Adhesive

The adhesive with the technical designation TEROSON EP 5090 was used for experiments. TEROSON EP 5090 is a heat-curing, solvent-free, one-component adhesive based on toughened Epoxy resins. It has been specially developed to provide high peel and impact peel resistance over a wide temperature range. The product's high viscosity makes it wash-off resistant in all automotive pre-treatment lines. Due to its nanoparticles and toughened epoxy resins, TEROSON EP 5090 performs well in typical torsional and crash forces.

TEROSON EP 5090 is used in the automotive body shop for structural and hem flange bonding. It is specially designed for steel, zinc-coated surfaces, zinc/magnesium surfaces, and aluminum alloys used in the automotive industry, where high strength and corrosion protection properties are required. TEROSON EP 5090 is also used for adhesive bonds in combination with other joining techniques, such as spot welding, which require higher shear strength and, especially, impact peel (crash) resistance.

Technical data of TEROSON EP 5090:

| | |
|---|---|
| Cured | 25 min, at 175°C |
| E-modulus | 2 GPa |
| Tensile strength | 35 MPa |
| Elongation at break | 10% |
| Poisson rate | 0.4 |
| Shear strength (DIN EN 1465) | >30 MPa |
| Layer thickness | 0.2 mm |

### Joining process

A fixation method was used to prepare the samples - the samples were first bonded with adhesive, then joined by mechanical joining (clinching or clinch-riveting), and finally the adhesive was cured in an oven at 175°C for 25 minutes.

To achieve a thickness of adhesive layers of 0.2 mm, distance pads with a thickness of 0.2 mm were used, applied on each side of the glued part of the sample (**Fig. 1**).

**Fig. 1** Sample for the experiments (hybrid joints)

The samples were prepared according to ISO 12996:2013: Mechanical joining - Destructive testing of joints - Specimen dimensions and test procedure for tensile shear testing of single joints. The surfaces of the steels sheets were cleaned before joining.

Two types of hybrid joints combining adhesive bonding and mechanical joining were prepared:

1. samples joined by adhesive bonding and clinching (AB+CL),
2. samples joined by adhesive bonding and clinch-riveting (AB+CR).

For the clinching method, a punch with a diameter of ø 5 mm and a die with a diameter of ø 8 mm were used, which is recommended for this thickness of materials. For the clinch-riveting method, rivets with a diameter of ø 5 mm were used (**Fig. 2**), which is also recommended for these thicknesses of the joined materials.

**Fig. 2** Rivets for the clinch-riveting method

The principles of clinching and clinch-riveting joining were described in [14]. The clinching process (**Fig. 3**) involves mechanically pressing the materials to be joined using a specially designed tool, resulting in a permanent joint. Clinching integrates drawing and forming techniques to lock steel sheets together mechanically. During the clinch-riveting process (**Fig. 4**), an additional deformable rivet indirectly creates the embossment and interlock. Once the lower sheet reaches the die bottom, the rivet material flows radially during the upsetting process. The blank holder and spring system apply pressure, driving the movable and fixed segments of the die into position.

**Fig. 3** Principle of clinching

**Fig. 4** Principle of clinch-riveting

The hybrid joints' properties were compared to the pure clinched and clinch-riveted joints.

### Tensile test

Tensile tests according to ISO 12996:2013 were performed on the samples under displacement-controlled conditions to evaluate the joints' static behaviour and determine their ultimate tensile strength. The maximum shearing load was the primary parameter obtained from the "load-displacement" curves recorded during testing.

Additionally, samples joined by the clinching and clinch-riveting method were prepared and tested to compare their load-bearing capacity with that of the clinch-bonded and clinch-rivet-bonded samples. The experiments utilized samples measuring 30 × 90 mm with a 30 mm overlap.

Testing was conducted on a TIRAtest 2300 metal strength testing machine, manufactured by VEB TIW Rauenstein, at a loading speed of 8 mm/min.

**Metallography**

Clinch-bonded and clinch-rivet-bonded joints were also assessed through metallographic observation to identify potential defects such as cracks, failures, or insufficient interlocking within the joints.
Sample preparation for metallographic observation involved creating cross-sections and grinding, polishing, and etching. Observations were conducted using KEYENCE VHX-5000 digital light optical microscope (**Fig. 5**).

**Fig. 5** Optical microscopes KEYENCE VHX-5000

**RESULTS AND DISCUSSION**

**Load-displacement curves**

The load-displacement curves obtained from the tensile test of the joints are shown in **Fig. 6** and **Fig. 7**. In hybrid joints (AB+CL and AB+CR), the load-displacement curves continue in the descending part with the load course of the clinched (CL) or clinch-riveted (CR) joint, respectively. The mechanical joints created by the clinching and clinch-riveting methods in hybrid joints increase the area under the loading curve and contribute to the totally absorbed deformation energy of the joint.

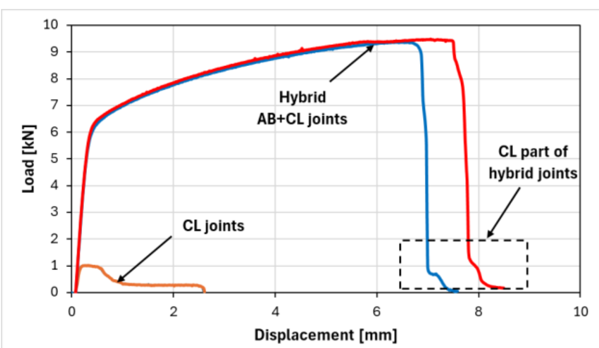


**Fig. 6** Load-displacement curves of clinched joints and hybrid clinch-bonded joint from tensile test (CL – clinching, AB – adhesive bonding)

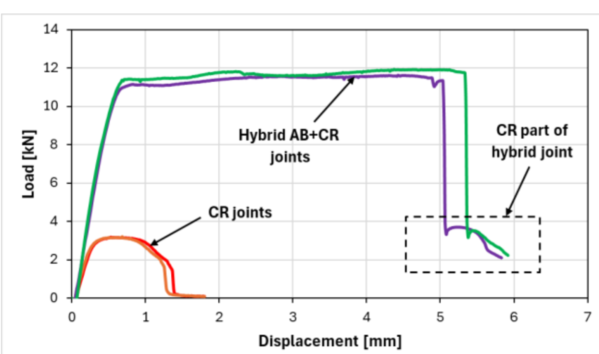


**Fig. 7** Load-displacement curves of clinch-riveted joints and hybrid clinch-rivet-bonded joint from tensile test (CR – clinch-riveting, AB – adhesive bonding)

The comparison of the load-displacement curves and the average values of the load capacities Fmax shown in Fig. 8 shows that higher values of the load capacities were measured for samples with hybrid joints. The highest values of the load capacities were measured for samples with a combination of adhesive bonding and the clinch-riveting method. The lowest values of the load capacities Fmax were measured for samples with simple clinching joints. Applying the tested adhesive TEROSON EP 5090 in the joints increased their load capacities more than 8-fold for clinched joints and more than 3-fold for clinch-riveted joints.

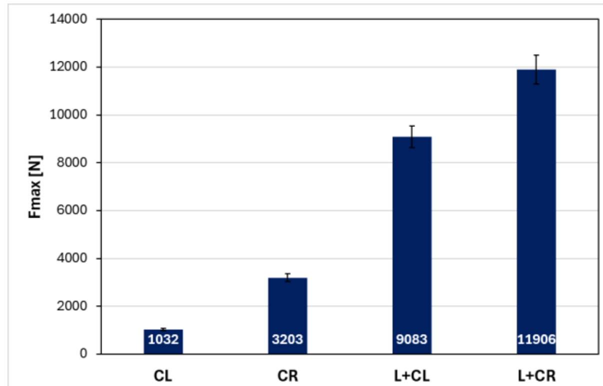


**Fig. 8** Average values of load-bearing capacity of investigated joints

**Fig. 9** shows hybrid joints and mechanical joints after tensile testing. A different failure mode was observed during tensile testing in hybrid clinch-bonded joints and simple clinched joints. In clinched joints, failure occurs by fracture in the joint neck area and with plastic deformation (**Fig. 9a**). Deformation of the joint part occurs at the beginning of the joint loading. Then, failure occurs in the joint neck area. In hybrid clinch-bonded joints, the failure mechanism of the joints was fractured in the joint neck area (**Fig. 9b**). This failure mechanism is characteristic of joints under shear stress. In this case, it was caused by the adhesively bonded part of the joint.
The same failure mode was observed for the simple clinch-riveted joint and the hybrid clinch-rivet-bonded joint, i.e. peeling of the joined sheets, with the rivet remaining wedged in the top sheet (**Fig. 9c,d**).

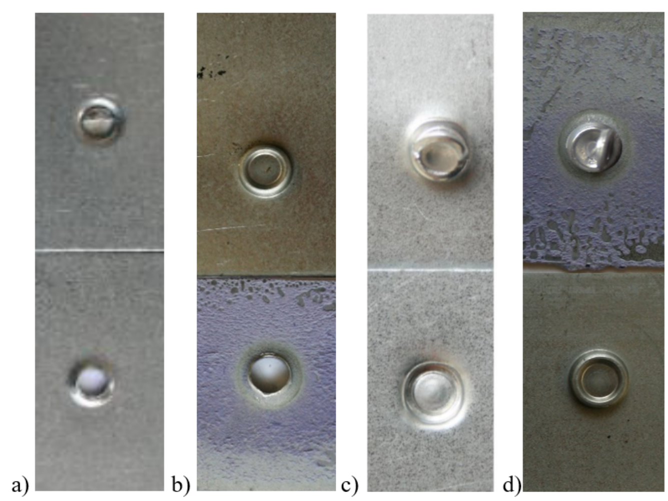


**Fig. 9** Specimens with joints after tensile test: a) CL joint, b) clinch-bonded joint, c) CR joint and d) clinch-rivet-bonded joints

**Metallographic observation**

Metallographic observation on cross sections of all types of joints examined confirmed that both mechanical joining methods clinching and clinch-riveting, as well as hybrid joining methods combining adhesive bonding and clinching and clinch-riveting, produced joints without internal defects, with characteristic mechanical interlock (**Fig. 10**). Well-formed parts of the bottom of clinched joints with typical shape of groove die are visible as well. In both types of hybrid joints, a layer of applied adhesive is visible, which did not hurt the formation of mechanical joints.

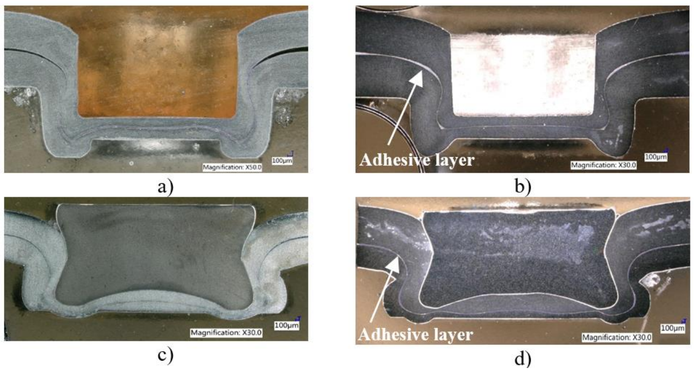


**Fig. 10** Macrostructure of joints: a) CL joint, b) hybrid joint AB+CL, c) CR joint, d) hybrid joint AB+CR

## CONCLUSION

Recently, increasing interest has been in developing hybrid joints that combine multiple joining techniques. Researchers are researching these combined joints because each of the joining techniques used has its own strengths and weaknesses, and by combining them, it is possible to create joints with better properties than those created using either joining technique alone.

Samples with hybrid joints exhibited higher load-bearing capacities. The maximum load-bearing capacities were observed in samples utilizing a combination of adhesive bonding and the clinch-riveting method. Conversely, the lowest load capacities (Fmax) were recorded for samples with simple clinching joints. Incorporating the tested adhesive, TEROSON EP 5090, significantly enhanced load-bearing capacities - by over 8 times for clinched joints and more than 3 times for clinch-riveted joints.

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## REFERENCES

1. L. Calabrese, G. Galtieri, C. Borsellino, G. Di Bella, E. Proverbio: The International Journal of Advanced Manufacturing Technology, 87, 2016, 3137–3147.
2. N. Haghshenas, H. Moshayedi: Experimental Techniques, 44, 2020, 99–112. https://doi.org/10.1007/s40799-019-00341-z
3. C. Chen, H. Zhang, H. Peng, X. Ran, Q. Pan: Metals, 10(1), 2020, 1-13. https://doi.org/10.3390/met10010097
4. J. Viňáš, Ľ. Kaščák, M. Greš: Open Engineering, 6(1), 2016, 504-510. https://doi.org/10.1515/eng-2016-0069
5. M. Szpunar, M. et al: Materials, 14(13), 2021, 1-20. https://doi.org/10.3390/ma14133634
6. H. Peng, C. Chen, X. Ren, X. Ran, X. Gao: Thin-Walled Structures, 169, 2021, 1-9. https://doi.org/10.1016/j.tws.2021.108289
7. Y. Abe, T. Maeda, D. Yoshioka, K. Mori: Materials, 13(21), 2020, 1-22. https://doi.org/10.3390/ma13214741
8. Ľ. Kaščák, D. Cmorej, J. Slota, E. Spišák, J. Varga: Acta Metallurgica Slovaca, 28(4), 2022, 219-223. https://doi.org/10.36547/ams.28.4.1657
9. H. Peng, C. Chen, X. Ren, X. Ran, X. Gao: Thin-Walled Structures, 169, 2021, 1-9. https://doi.org/10.1016/j.tws.2021.108289
10. M. Džupon, Ľ. Kaščák, D. Cmorej, L. Čiripová, J. Mucha, E. Spišák: Applied sciences, 13(13), 2023, 1-25.
11. C. Steinfelder, D. Rempel, A. Brosius: Journal of Advanced Joining Processes, 10, 2024, 1-8. https://doi.org/10.1016/j.jajp.2024.100263
12. M. Franka, N. Wróbel, M. Rejek, G. M. Królczyk, M. K. Gupta, J. B. Królczyk: Engineering Science and Technology, an International Journal, 51, 2024, 1-10. https://doi.org/10.1016/j.jestch.2024.101656
13. A. Kubit, M. Drabczyk, T. Trzepiecinski, W. Bochnowski, Ľ. Kaščák, J. Slota: Metals, 10(5), 2020, 1-18. https://doi.org/10.3390/met10050633
14. Ľ. Kaščák, E. Spišák, J. Mucha: Acta Metallurgica Slovaca, 18(4), 2012, 172-180.
15. Y. Abe, S. Nihsino, K. Mori, and T. Saito: Procedia Engineering, 81, 2014, 2056–2061. https://doi.org/10.1016/j.proeng.2014.10.285
16. C. Shi, H. Li, C. Chen, Y. Ouyang, D. Qin: Thin-Walled Structures, 171, 2022, 1-10. https://doi.org/10.1016/j.tws.2021.108612
17. K. Mori, Y. Abe, T. Kato: Journal of Materials Processing Technology, 212(9), 2012, 1900-1905. https://doi.org/10.1016/j.jmatprotec.2012.04.017
18. S. Maggiore, M.D. Banea, P. Stagnaro, G. Luciano: Polymers, 13, 2021, 1-18. https://doi.org/10.3390/polym13223961
19. F.M.D. Wit, J.A. Poulis: Joining technologies for automotive components, In: Advanced Materials in Automotive Engineering. 1st ed., Woodhead Publishing, 2012.
20. Y. Zhang, X. Zhang, J. Guo, S.M. Manladan, Z. Luo, Y. Li: Journal of Manufacturing Processes, 39, 2019, 93–101. https://doi.org/10.1016/j.jmapro.2019.02.018
21. T. Balawender, T. Sadowski, P. Golewski: Computational Materials Science, 64, 2012, 270–272. http://dx.doi.org/10.1016/j.commatsci.2012.05.014
22. Y. Ma et al.: Journal of Materials Processing Technology, 305, 2022, 1-15. https://doi.org/10.1016/j.jmatprotec.2022.117602
23. F. Moroni, A. Pirondi, F. Kleiner: International Journal of Adhesion & Adhesives, 30, 2010, 367–379. https://doi.org/10.1016/j.ijadhadh.2010.01.005
24. L. Lei, X. He, D. Zhao, Y. Zhang, F. Gu, A. Ball: Thin-Walled Structures, 131, 2018, 393–403. https://doi.org/10.1016/j.tws.2018.07.017
25. D. Lee, J.K. Kim, S. Lee, K. Lee, B. C. De Cooman: Materials Science and Engineering: A, 706, 2017, 1-14. https://doi.org/10.1016/j.msea.2017.08.110
26. S. K. Paul, A. Raj, P. Biswas, G. Manikandan, R.K. Verma: Materials & Design, 57, 2014, 211-217. https://doi.org/10.1016/j.matdes.2013.12.047
27. H. Yu, Y. Guo, X. Lai: Materials & Design, 30(7), 2009, 2501-2505. https://doi.org/10.1016/j.matdes.2008.10.001
28. P. Prislupčák, T. Kvačkaj, J. Bidulská, P. Záhumenský, V. Homolová, P. Zimovčák: Acta Metallurgica Slovaca. 27(4), 2021, 207–209. https://doi.org/10.36547/ams.27.4.1306
29. P. Prislupčák, T. Kvačkaj, J. Bidulská, S. Nemeth, M. Demcakova, R. Gburik, V. Kundracik: Acta Metallurgica Slovaca, 28(4), 2022, 212–218. https://doi.org/10.36547/ams.28.4.1653
30. P. Prislupčák et al.: Materials, 15(3), 2022, 922. https://doi.org/10.3390/ma15030922
31. T. Kvačkaj, J. Bidulská, R. Bidulský: Materials, 14(8), 2021, 1988. https://doi.org/10.3390/ma14081988