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EFFECTS OF SURFACE PREPARATION ON THE ADHESIVE BONDING OF ALUMINIUM ALLOY EN AW 5754 IN THE RAILWAY INDUSTRY

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Abstract *– In the railway industry, adhesive bonding is increasingly used as a reliable alternative to traditional mechanical fastening methods. This study investigates the effect of surface preparation methods on the bond strength of aluminium alloy EN AW 5754 using two different epoxy adhesives: SikaPower®-492 G and SikaPower®-880. To evaluate the performance of the bonded joints, single-lap shear tests were performed using surface preparation with Scotch-Brite abrasive pads and P180 sandpaper. The results showed that SikaPower®-492 G achieved higher bond strength with increased surface roughness, while SikaPower®-880 performed better on smoother surfaces, indicating that its formulation is optimised for better wetting and adhesion. These results provide valuable insights into the optimisation of adhesive performance as a function of surface conditions.*

Keywords – adhesive bonding, railway industry, aluminium alloy EN AW 5754, surface preparation, epoxy adhesives.

1. INTRODUCTION

Railways have advanced with three key objectives: high speed, safety, and mass transportation. Rolling stock, which refers to railcars in a broad sense, is the most energy-efficient mode of transport, using the least energy per person-distance compared to all other systems. In recent years, high speed, passenger comfort, safety, and environmental sustainability have become essential requirements for railway systems. These priorities emphasize the need for weight reduction, high strength, rigidity, noise insulation, vibration damping, thermal insulation, fire resistance, and recyclability [1,2]. Additionally, with the shorter service life and model-change intervals of railcars, cost reduction has also become a crucial factor. To address these diverse demands, the introduction of lightweight structures made from aluminium extrusions offers an effective solution. Adhesive bonding is considered the most promising method for joining these material structures in trains.

The use of adhesives for joining materials in modern rail vehicles is growing, particularly in applications like interior panels, floor plates, and coverings [2]. Adhesives offer several advantages over welding, including a high strength-to-weight ratio, better stress distribution, and greater design flexibility [3]. They also provide improved resistance to damage, fatigue, and crash impacts. Additionally, adhesives help prevent water from getting into the joints, reducing the risk of corrosion. Overall, adhesive bonding offers a more durable, versatile, and low-maintenance alternative to traditional welding [4].

Despite significant advancements in adhesive technology, several factors continue to limit the optimal design and reliability of adhesive joints. These include joint geometry, the type of adhesive used, and stresses caused by differences in thermal expansion between materials. A considerable amount of research has been conducted to analyze the performance of adhesive bonded joints, as reflected in numerous review papers [5-7].

One of the most important factors influencing the mechanical performance of bonded joints is surface

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preparation. When bonding aluminium it is essential to remove the oxide layer (Al_2O3), impurities and grease from the surface to ensure proper adhesion [8]. It is therefore important to carry out adequate surface preparation of the parts to be joined before bonding. The surface preparation of materials involves a series of steps to optimize the quality of the bonding surface in terms of adhesion and cleanliness. Depending on the material and the desired durability of the bond, various methods can be used. These methods include mechanical, chemical and electrochemical treatments, laser technologies and thermal techniques such as plasma or flame cleaning.

In the context of surface preparation to enhance bonding properties, numerous studies [9-11] have advocated for the use of mechanical removal techniques prior to bonding in order to eliminate contaminants and introduce geometric patterns on the bonding surfaces. Researchers such as Łyczkowska [12] and da Silva et al. [13] have specifically examined the preparation of aluminium alloys for adhesive bonding. Their findings indicate that sanding plays a critical role in the bonding process, as increasing surface roughness enhances the adhesive-to-substrate contact, thereby improving the joint's shear strength. Sanding with various grit sizes of sandpaper is a commonly used technique due to its cost-efficiency, minimal training requirements, and lower expense compared to other surface preparation methods, making it particularly advantageous in large-scale production environments.

Based on the review of the current state of the art, this study focuses on analysing how different surface preparation methods for aluminium alloy EN AW 5754 affect the strength of adhesive bonds. The contribution of this study is to evaluate the effect of two different adhesives and surface preparation methods on the shear strength of bonded joints, providing insights into optimising adhesive bonding performance by analysing variations in surface roughness.

2. EXPERIMENTAL WORK

Aluminium alloy EN AW 5754 was used for the study, which is known for its favourable strength-to-weight ratio, excellent ductility and machinability, and remarkable resistance to corrosion and thermal effects, making it suitable for industrial railway applications. Detailed mechanical properties of the aluminium alloy EN AW 5754 are provided in Table 1 [14].

Aluminium substrates, each 2 mm thick, were bonded using a standardised geometry and dimensions, including an overlap of 12.5 mm, as depicted in Figure 1, following the EN 1465 standard [15].

Tab. 1. Mechanical properties of EN AW 5754 [14]

Yield Strength (MPa)	Tensile Strength (MPa)	Elongation to Break (%)	Module of Elasticity (GPa)
180	236	16.5	70

The surface preparation involved a mechanical abrasive process, where the surfaces were hand sanded and then cleaned with SIKA Remover-208, a solvent-based cleaning agent recommended by Sika Ltd. The sanding was performed using green, fine-grained Scotch-Brite pads and 180-grit sandpaper. The adhesive layer was 0.3 mm thick, with the thickness controlled by the glass beads embedded within the adhesive.

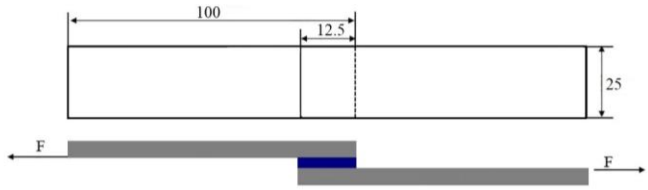

Fig.1. Dimensions of the aluminium substrates for the single-lap shear test [15]

This study considered the use of two different epoxy adhesives for investigation: the one-component (1C) epoxy hybrid adhesive SikaPower®-492 G [16] and the two-component (2C) epoxy adhesive SikaPower®-880 [17]. The main reasons for selecting these two adhesives were their availability and ease of use in the laboratory chosen for this study. They were also suitable candidates for this study due to their widespread use in the industry and their consistent performance.

The choice of surface preparation and adhesive bonding properties should aim to ensure that the weakest point in a bonded joint is within the adhesive layer itself, rather than at the interface between the bonded parts. Cohesive failure, which occurs within the adhesive layer, is the ideal failure mode as it best reflects the optimal performance of the bonded joints. The primary types of failure modes are illustrated in Fig. 2.

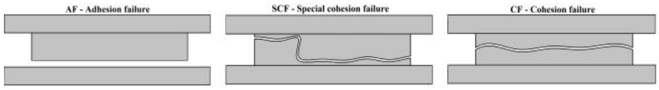

Fig.2. Failure modes of adhesive bonded joints: Adhesion Failure (AF), Special Cohesion Failure (SCF), Cohesion Failure (CF) [18]

All single-lap shear tests were performed using a 250 kN INSTRON 8802 universal testing machine at a crosshead speed of 1 mm/min, following the ISO 4587 standard [19]. To ensure repeatability, environmental temperature and humidity were strictly controlled, and three repeat samples were tested for each bonding scenario, with loads and extensions recorded by the machine.

The roughness of the aluminium alloy after both surface preparation methods was measured using a Mitutoyo SJ-301 profilometer, with the results reported as the average Ra and Rz values.

3. RESULTS AND DISCUSSION

The surface roughness of the samples prepared with Scotch-Brite abrasive pads and P180 sandpaper was measured longitudinally along 10 mm of the sample ends at a speed of 0.15 mm/s on all surfaces examined. The measurement results of two surface roughness parameters, Ra and Rz, in relation to the different surface preparations are shown in Fig. 3.

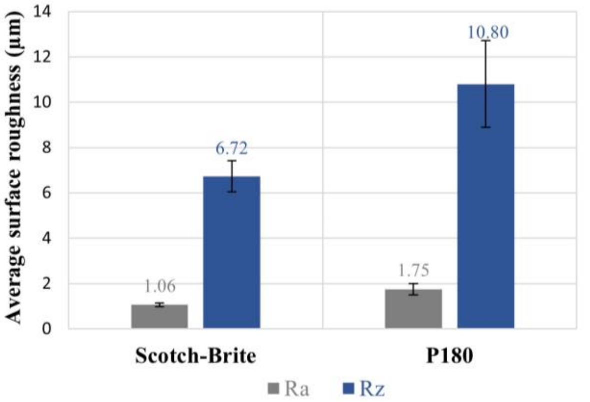

Fig.3. Average surface roughness of aluminium alloy EN AW 5754 depending on the surface preparation

After preparation with Scotch-Brite, the samples exhibited lower surface roughness, with average Ra and Rz values of ± 1.02 μm (ranging from 0.9 to 1.12 μm) and ± 6.64 μm (ranging from 5.94 to 7.54 μm), respectively. In contrast, aluminium alloy surfaces prepared with P180 sandpaper showed higher roughness, with average Ra and Rz values of ± 1.69 μm (ranging from 1.46 to 1.91 μm) and ± 10.49 μm (ranging from 8.65 to 12.33 μm), respectively.

The results of the static tensile shear test of the single-lap bonded aluminium joints in relation to two different surface preparations and adhesive types are shown in the form of a graph in Fig. 4.

The aluminium samples bonded with SikaPower®-492 G exhibited higher strength. The results suggest that surface roughness prior to bonding significantly influences bond strength, as preparation using P180 sandpaper showed slightly better results. The better strength results in the sample with higher roughness can be attributed to the increased surface area available for the adhesive to bond to, which enhances mechanical interlocking and improves overall adhesion.

Adhesive SikaPower®-880 demonstrates that surface preparation using Scotch-Brite leads to better strength outcomes. This suggests that SikaPower®-880 is more suited for smoother surfaces, where its formulation allows for improved wetting and adhesion, resulting in a stronger bond even with lower surface roughness.

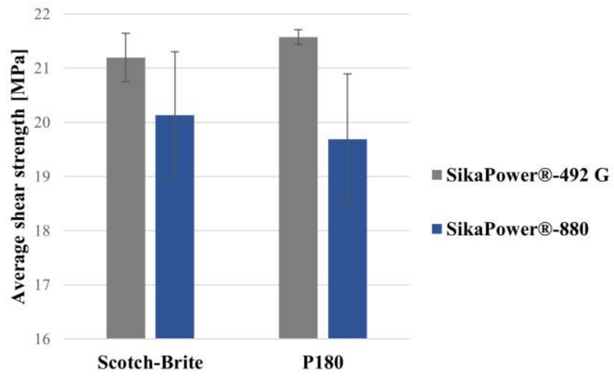

Fig.4. Average shear strength of bonded joints in relation to the method of surface preparation for aluminium alloy EN AW 5754

Fig. 5 and Fig. 6 show examples of fractures in bonded joints made with the SikaPower®-492 G and SikaPower®-880 adhesive.

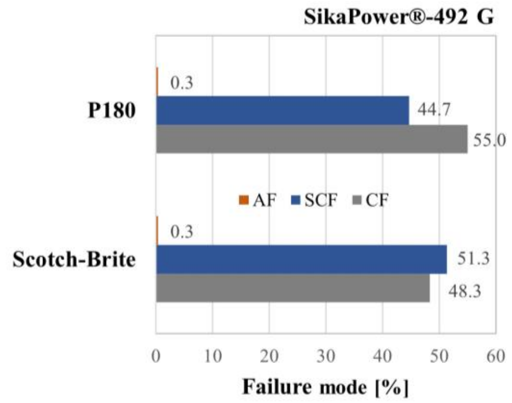

Fig.5. SikaPower®-492 G, AF - Adhesion failure; SCF - Special cohesion failure; CF - Cohesion failure

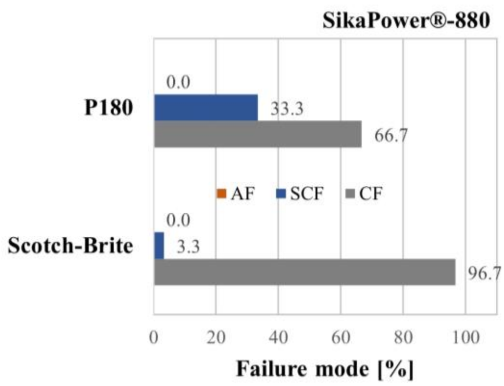

Fig.6. SikaPower®-880, AF - Adhesion failure; SCF - Special cohesion failure; CF - Cohesion failure

Adhesive SikaPower®-492 G exhibited adhesion failure in a small percentage of cases across both preparation methods, yet overall provided consistent results, predominantly showing cohesive or special cohesive failure. Notably, surface preparation with P180 sandpaper led to a greater occurrence of cohesive failure, correlating with higher measured bond strength.

Adhesive SikaPower®-880 demonstrated a dominant cohesive failure mode after surface preparation with Scotch-Brite, with 96.7% of failures occurring cohesively, which was further supported by the corresponding strength data.

4. CONCLUSION

The adhesive bonding of aluminium alloys in railway vehicles plays a crucial role in enhancing durability, reducing weight, and improving the overall efficiency and safety of modern rail systems. In this study, the effect of two surface preparation methods (hand sanding with Scotch-Brite and P180 sandpaper) on the single-lap shear strength of aluminium alloy EN AW 5754 using two different epoxy adhesives, SikaPower®-492 G and SikaPower®-880, was investigated. SikaPower®-492 G adhesive showed better bond strength with increasing surface roughness, suggesting that its adhesive properties benefit from a rougher surface that improves mechanical interlocking. In contrast, SikaPower®-880 performed better on smoother surfaces, with Scotch-Brite preparation giving better results compared to P180 sandpaper. This suggests that SikaPower®-880 is more sensitive to the wetting and adhesion properties of the surface, showing stronger bonds even at lower surface roughness. These findings emphasize the importance of selecting the appropriate adhesive and surface preparation method based on the specific application and material conditions.

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REFERENCES

[1] Zangani, D., Fuggini, C., *Towards a New Perspective in Railway Vehicles and Infrastructure*, Procedia - Social and Behavioral Sciences, 48:2351-2360, 2012.

[2] Suzuki, Y., Adhesive bonding for railway application, Handb. Adhes. Technol. Second Ed. 2, 1367–1390, 2018.

[3] Marques, C.A.; Mocanu, A.; Tomić, Z.N.; Balos, S.; Stammen, E.; Lundevall, A.; Abrahami, S. T.; Günther, R.; de Kok, J.M.M.; de Freitas, S.T. *Review on Adhesives and Surface Treatments for Structural Applications: Recent Developments on Sustainability and Implementation for Metal and Composite Substrates*, Materials, 13(24), 5590, 2020.

[4] Ebnesajjad, S., Adhesives technology handbook, 2nd ed.; William Andrew: Inc., Norwich, NY, pp. 1-7, 2008.

[5] Liao, L., Huang, C., Sawa, T., *Effect of adhesive thickness, adhesive type and scarf angle on the mechanical properties of scarf adhesive joints*, Int. J. Solids Struct., 50, 4333–4340, 2013.

[6] Ozel, A., Yazici, B., Akpinar, S., Aydin, M.D., Temiz, ¸S., *A study on the strength of adhesively bonded joints with different adherends*, Compos. Part B Eng., 62, 167–174, 2014.

[7] Đurić, A., Klobčar, D., Milčić, D., Marković, B., Samradžić. S., Zdravković, N., Milčić, M., *Analysis of the possibility of joining DP steel and CFRP with epoxy adhesive and hybrid joining technology*, The 12th International Conference on Machine and Industrial Design in Mechanical Engineering (KOD 2024), Balatonfüred, Hungary, 2024.

[8] M. Beseda, M. Suchánek, P. Sehnoutka, F. Huvar, M. Weisz, P. Klaus, *Mechanical Properties of laser Cleaning Surface, used for bonding joint of aluminium metal sheet EN AW 5754*, Metal 2023, Brno, Czech Republic, May 17 - 19, 2023.

[9] Boutar, Y., Naïmi, S., Mezlini, S., Sik Ali, M. B., *Effect of surface treatment on the shear strength of aluminium adhesive single-lap joints for automotive applications*, Int. J. Adhes. Adhes. 67, 38-43, 2016.

[10] Kowalczyk. J; Ulbrich, D.; Jósko, M.; Mańczak R. *Influence of surface preparation of glued parts on strength of joint,* Journal of Research and Applications in Agricultural Engineering 61(1), 41-43, 2016.

[11] Ghumatkar, A., Budhe, S., Sekhar, R., Banea, M.D., de Barros, S., *Influence of Adherend Surface Roughness on the Adhesive Bond Strength,* Latin American Journal of Solids and Structures 13, 2356-2370, 2016.

[12] Łyczkowska, K., Miara, D., Rams, B., Adamiec, J., Baluch, K., *The Influence of MSR-B Mg Alloy Surface Preparation on Bonding Properties,* Materials, 16, 3887, 2023.

[13] Da Silva, L.F.M., Ferreira, N.M.A.J., Richter-Trummer, V., Marques, E.A.S., *Effect of grooves on the strength of adhesively bonded joints*, Int. J. Adh. Adhes. 30 (8), 735-743, 2010.

[14] Thyssenkrupp Materials Services GmbH, Material Data Sheet EN AW-5754 (EN AW-AlMg3) Essen, Germany, 2017.

[15] EN 1465; Adhesives—Determination of Tensile Lap-Shear Strength of Bonded Assemblies. European Standard: Brussels, Belgium, 2009.

[16] API- SikaPower®-492 G. Material Card 2022; Sika Services AG, Zurich, Switzerland.

[17] API- SikaPower®-880, Material Card 2022; Sika Services AG, Zurich, Switzerland.

[18] ISO 10365*;* Adhesives — Designation of main failure patterns. ISO: Geneva, Switzerland, 2022.

[19] *ISO 4587;* Adhesive Lap—Shear Strength of Rigid-to-Rigid Bonded Assemblies. ISO: Geneva, Switzerland, 2003.