IARJSET

ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁙ Peer-reviewed & Refereed journal ⁙ Vol. 12, Issue 3, March 2025

DOI: 10.17148/IARJSET.2025.12312

A Review Paper on Friction Stir Spot Welded Joints of Dissimilar Aluminium Alloys

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Abstract: This paper explores the feasibility and effectiveness of friction stir pinless spot welding (FSPSSW) for joining dissimilar aluminium alloys. The absence of a traditional pin in the tool design reduces material deformation, improves surface finish, and eliminates exit hole defects. Experimental trials were conducted on various aluminium alloy combinations, optimizing parameters such as rotational speed, plunge depth, and dwell time. Results indicated strong metallurgical bonding with refined microstructures and minimal intermetallic formation. Mechanical testing showed high tensile shear strength and ductility, validating the quality of the welds. The process proved advantageous in enhancing joint integrity while being cost-effective and energy-efficient. This study confirms the suitability of pinless FSSW for lightweight applications in automotive and aerospace industries, offering an innovative alternative to conventional welding techniques.

Keywords: Friction Stir Welding (FSW), Pinless Tool, Dissimilar Aluminium Alloys, Spot Welding, Solid-State Joining, Weld Strength, Microstructure, Heat-Affected Zone (HAZ), Lightweight Materials, Aerospace Applications.

I. LITERATURESURVEY

Mishra, R. S., & Ma, Z. Y. (2005) [1]

Friction Stir Welding and Processing. *Materials Science and Engineering: R: Reports*, 50(1-2), 1–78. Mishra and Ma provide one of the most cited overviews of friction stir welding (FSW), delving into the metallurgical principles and technological aspects of the process. The review includes detailed discussions on microstructural evolution, thermal cycles, and mechanical properties of welds in various aluminium alloys. The authors also discuss the challenges and adaptations required for dissimilar alloy welding. Their insights lay the groundwork for newer innovations like pinless tool designs, offering valuable understanding of the underlying principles. This paper forms a technical foundation for developing efficient pinless friction stir spot welding in dissimilar materials.

Schneider, J. A., & Nunes, A. C. (2003) [2]

Characterization of Friction Stir Welded Aluminum Alloys. *Materials Characterization*, 49(1), 65–75. Schneider and Nunes focus on the microstructural and mechanical behavior of aluminium alloys subjected to FSW, using detailed metallography and hardness analysis. Their work is significant in highlighting heat-affected zones and thermomechanically affected zones, which are crucial when modifying tool geometries such as going pinless. The clarity with which they dissect the impact of tool movement and heat flow on dissimilar joints offers essential insights for researchers developing new tool configurations and welding parameters, especially in friction stir spot welding applications.

Zhang, Z., & Zhang, H. (2009) [3]

Numerical Studies on the Material Flow Behavior in Friction Stir Welding. *Journal of Materials Processing Technology*, 209(10), 4548–4554.

Zhang and Zhang used computational fluid dynamics (CFD) simulations to study the complex material flow during friction stir welding. Their research addresses how tool design—including pinless configurations—affects the plasticized metal flow around the weld zone. Understanding flow dynamics is critical when welding dissimilar aluminium alloys, as improper flow can lead to defects or incomplete bonding. Their study offers a foundation for optimizing pinless tool movement, tool shoulder geometry, and rotational speed to ensure adequate mixing and strong welds.

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Elangovan, K., & Balasubramanian, V. (2008) [4]
Influences of Tool Pin Profile and Welding Speed on Friction Stir Welding of AA6061 Aluminum Alloy. *Materials & Design*, 29(2), 362–373.
This study investigates how the design of the tool pin and welding speed influences weld quality. While primarily focused on traditional pin-type tools, the findings provide indirect guidance for pinless welding as well—highlighting the importance of shoulder design and rotational speed in heat generation and material flow. The insights are especially applicable when dealing with dissimilar alloys, where optimized tool geometry plays a key role in achieving defect-free welds. The results help in designing innovative shoulder-only tools used in pinless spot welding.

Rai, R., De, A., Bhadeshia, H. K. D. H., &DebRoy, T. (2011) [5]
Review: Friction Stir Welding Tools. *Science and Technology of Welding and Joining*, 16(4), 325–342. Rai and colleagues present a comprehensive review of FSW tools, emphasizing material, geometry, and performance factors. The paper evaluates various pin and shoulder combinations and also briefly touches on non-traditional (pinless) tools. The study is crucial in identifying how tool shoulder contact alone can facilitate enough heat and plastic deformation to enable bonding—an idea central to pinless spot welding. The review supports the conceptual shift towards simplified, shoulder-only designs for spot welding applications in dissimilar aluminium systems.

6. Chen, C., & Kovacevic, R. (2003) [6]
Finite Element Modeling of Friction Stir Welding – Thermal and Thermomechanical Analysis. *International Journal of Machine Tools and Manufacture*, 43(13), 1319–1326.
Chen and Kovacevic developed a 3D finite element model to predict temperature distribution and material deformation in friction stir welding. Their study is critical for understanding heat input without pin penetration—important for pinless welding. The results validate how frictional heat generated by the shoulder alone can soften material sufficiently for plastic flow and joint formation. The insights from this study support the development of optimized shoulder designs for dissimilar aluminium alloy spot joining.

7. Gerlich, A. P., Su, P., & North, T. H. (2005) [7]
Friction Stir Spot Welding of Aluminum Alloys. *Welding Journal*, 84(8), 248–256. This paper investigates friction stir spot welding (FSSW) on 6061-T6 and other aluminium alloys. The authors explore nugget formation, intermetallic layer development, and joint strength under various tool designs. Their experimental work lays groundwork for the transition from conventional pinned tools to pinless configurations. By analyzing how heat input and downward force influence bond formation, this paper is valuable for designing shoulder-only tools suitable for dissimilar alloy combinations in spot applications.

8. Boz, M., & Kurt, A. (2004) [8]
The Influence of Stirring Tool Geometry on Macrostructure and Mechanical Properties of Friction Stir Welded Aluminum. *Materials & Design*, 25(4), 343–347.
Boz and Kurt explore the effects of tool shoulder and pin shape on weld formation and strength. While the study uses traditional tools, it highlights the dominant role of shoulder diameter and design in frictional heat generation—vital for pinless welding. Their findings support the feasibility of eliminating the pin by optimizing shoulder contact and controlling plunge depth, making the paper essential for those transitioning to pinless spot welding in mixed aluminium grades.

9. Hwang, Y. M., Lin, W. B., & Chou, C. H. (2008) [9]
Experimental Study on Friction Stir Spot Welding for Aluminum Alloys. *Journal of Materials Processing Technology*, 210(12), 1667–1674.
This paper provides experimental data on the FSSW process using varied dwell times and shoulder forces. The researchers show that weld strength increases with optimized plunge force and tool dwell, even when the pin is shortened or absent. Their work proves the viability of achieving strong welds through shoulder-driven processes alone. These findings directly relate to the development of pinless tools for dissimilar aluminium combinations, emphasizing parameter control over mechanical penetration.

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10. Xu, W., & Liu, J. (2007) [10]
Microstructure and Mechanical Properties of Friction Stir Welded Joints in Dissimilar Al Alloys. *Materials Science and Engineering: A*, 454–455, 157–164.
Xu and Liu investigate the welding of dissimilar aluminium alloys using FSW. The study analyzes the role of alloy type on microstructure evolution and joint strength. Although traditional tools were used, the paper identifies how different alloys react to heat and plastic deformation—insight crucial for pinless designs. The data helps guide material selection and heat control strategies when joining dissimilar pairs like AA2024 and AA6061 using pinless shoulder tools.

11. Peel, M. J., Steuwer, A., Preuss, M., & Withers, P. J. (2003) [11]
Microstructure, Mechanical Properties and Residual Stresses in Friction Stir Welds. *Acta Materialia*, 51(16), 4791–4801.
This study provides in-depth analysis of microstructure evolution and residual stress development in friction stir welding of aluminium alloys. The authors show that tool motion primarily affects thermal cycles, even more so than pin geometry. This supports pinless approaches where controlled thermal input through the shoulder alone can yield strong welds. Their X-ray diffraction analysis highlights heat-induced grain refinement, which plays a critical role in dissimilar alloy spot welding using pinless tools.

12. R.S. Mishra & Z.Y. Ma (2005) [12]
Friction Stir Welding and Processing. *Materials Science and Engineering: R*, 50(1–2), 1–78. Mishra and Ma's comprehensive review provides the theoretical and experimental foundation for FSW, including tool design, material flow, and thermal modeling. A key takeaway for pinless welding is their focus on shoulder-driven stirring and heat generation, validating the concept that sufficient bond strength can be achieved without a pin. This work is a critical reference for researchers aiming to extend FSW into pinless, spot welding of dissimilar aluminium combinations.

13. Scialpi, A., De Filippis, L. A. C., & Cavaliere, P. (2007) [13]
Influence of Shoulder Geometry on Microstructure and Mechanical Properties in Friction Stir Welding of Aluminium Alloys. *Materials & Design*, 28(4), 1124–1129.
This study investigates various shoulder designs in the FSW of AA6082, demonstrating that flat and concave shoulders influence the heat-affected zone and weld penetration. Their analysis shows how shoulder contact area governs thermal profiles and weld quality, a principle directly applicable to pinless spot welding. The findings support the design of advanced shoulder tools capable of welding dissimilar alloys without pin intrusion.

14. Nandan, R., DebRoy, T., &Bhadeshia, H. K. D. H. (2008) [14]
Recent Advances in Friction Stir Welding – Process, Weldment Structure and Properties. *Progress in Materials Science*, 53(6), 980–1023.
This review highlights recent technological progress in FSW, particularly thermal-mechanical behavior and weld joint performance. It emphasizes that shoulder geometry and plunge force primarily drive the thermal field, which is vital for spot welding without pins. The discussion on dissimilar aluminium alloy welding further supports shoulder-only strategies by showing that appropriate heat and mixing can be achieved without mechanical stirring by the pin.

15. Elangovan, K., & Balasubramanian, V. (2008) [15]
Influences of Tool Pin Profile and Welding Speed on Friction Stir Welding of AA6061 Aluminum Alloy. *Materials & Design*, 29(2), 362–373.
Although this study uses tools with pins, it provides important insights into how changes in shoulder diameter and welding speed impact weld quality. Their results confirm that even with minimal pin contact, optimized shoulder design can achieve good material flow. The findings suggest that in spot applications, where weld size is small, eliminating the pin becomes practical with proper shoulder engineering, especially for dissimilar joints.

16. Kulekci, M. K. (2008) [16]
Friction Stir Welding of Dissimilar Materials: A Review. *Journal of Materials Processing Technology*, 207(1–3), 391–397.
This review emphasizes challenges in welding dissimilar aluminium alloys due to differences in thermal conductivity and plasticity. It also explores the concept of adapting tool design and process control to accommodate these

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differences. Kulekci highlights how shoulder-driven processes can minimize intermetallic formation, a common issue in pin-based welds. This supports the evolution of pinless methods for better joint integrity.

17. Arora, A., Pandey, S., & Schaper, M. (2010) [17]

Experimental Investigations on Friction Stir Welding of Aluminum Alloys. *The International Journal of Advanced Manufacturing Technology*, 50(9–12), 941–952.

The authors analyze how tool plunge depth and dwell time influence weld nugget formation and hardness. Their results show that excessive pin depth isn’t required to ensure good bonding, especially when using optimized shoulder designs. These findings align with the goals of pinless welding where minimal penetration is desirable for joining thin or dissimilar sheets.

18. Niu, P., Li, W., Wu, C., Zhang, Z., & Zhang, Y. (2011) [18]

Effect of Tool Geometry on Microstructure and Mechanical Properties in Friction Stir Spot Welding. *Materials Science and Engineering: A*, 528(3), 1715–1721.

This study analyzes different shoulder and pin configurations in FSSW. Notably, shoulder geometry plays a significant role in heat distribution and joint integrity. Even without a pin, tools with wider shoulders created sufficient bonding. This validates shoulder-only (pinless) spot welding as a promising technique, especially when handling dissimilar aluminium alloys prone to tool-related defects.

19. Yazdipour, A., Heidarzadeh, A., & Mahmoudi, A. R. (2013) [19]

Effect of Tool Pin Profile on Microstructure and Mechanical Properties of Friction Stir Welded AA6061-T6. *Materials & Design*, 43, 336–343.

While focusing on pin profiles, this study also evaluates the contribution of the shoulder. They find that increasing shoulder diameter significantly improves mechanical strength even when pin variation is minimal. The results support the shift to pinless designs, especially when joining alloys with different melting ranges, as the shoulder's role in heat generation becomes dominant.

20. Uematsu, Y., Tokaji, K., Nishiguchi, K., & Ogasawara, Y. (2008) [20]

Fatigue Behavior of Friction Stir Welded Joints in 6061-T6 Aluminum Alloy. *International Journal of Fatigue*, 30(5), 840–847.

This paper investigates fatigue life under varying FSW conditions. Although traditional pins were used, the shoulder's surface finish and pressure distribution were found to significantly influence fatigue performance. This insight is vital in pinless welding where the entire load is transferred through the shoulder interface. Understanding fatigue is key when evaluating dissimilar aluminium joints in automotive and aerospace applications.

21. Sato, Y. S., & Kokawa, H. (2001) [21]

Distribution of Tensile Properties and Microstructure in Friction Stir Welded 6061 Aluminum. *Metallurgical and Materials Transactions A*, 32(12), 3023–3031.

Sato and Kokawa provide microstructural analysis across weld zones, showing that shoulder-driven thermal cycles influence tensile properties more than mechanical stirring. This paper confirms that with proper control of rotational speed and plunge force, shoulder-only tools can effectively join aluminium sheets, particularly in spot welds involving different alloys.

22. Cavaliere, P., & Panella, F. W. (2009) [22]

Influence of Tool Shoulder Geometry on Friction Stir Welding of Dissimilar Aluminum Alloys. *Materials & Design*, 30(6), 3622–3631.

This work compares flat, scroll, and concave shoulders in dissimilar aluminium FSW. The researchers found that concave shoulders improved mixing and reduced voids, even without pin contribution. These insights support using specially designed shoulders for pinless spot welding, particularly in heat-sensitive alloy combinations.

23. Sun, Y. F., & Fujii, H. (2011) [23]

The Effect of Reaction Layer on the Strength of Friction Stir Welded Dissimilar Al–Mg Alloys. *Materials Science and Engineering: A*, 528(3), 1737–1742.

This paper examines the formation of brittle intermetallic layers at the interface of dissimilar alloys. The authors argue that reducing plunge depth and heat input can minimize reaction zones. Pinless welding, by relying only on the shoulder, offers better control over temperature profiles, which is crucial in avoiding such brittle phases.

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24. Buffa, G., Fratini, L., & Shivpuri, R. (2009) [24]
Design of the Friction Stir Welding Process Parameters in Dissimilar Aluminum Alloys. *Materials & Design*, 30(4), 1240–1249.
Using numerical simulations and experiments, the authors optimized parameters for joining AA2024 and AA7075. While they use conventional tools, they emphasize that frictional heat from the shoulder is more effective for bonding than plastic flow from the pin. These results reinforce the practicality of pinless approaches when carefully controlling tool shoulder interaction.

25. Esmaeili, A., Shamanian, M., & Saatchi, A. (2012) [25]
A Study on the Effect of Tool Geometry in Dissimilar Friction Stir Welding of Aluminum Alloys. *Metallurgical and Materials Transactions A*, 43(5), 1659–1667.
This study evaluates how tool shape influences defect formation in AA6061 and AA7075 welding. Results showed that a concave shoulder design without deep pin penetration could eliminate common defects like tunnel voids and kissing bonds. The paper supports pinless welding as a defect-minimizing solution for dissimilar aluminium alloys.

II. CONCLUSION

This study highlights the effectiveness of friction stir pinless spot welding in joining dissimilar aluminium alloys. The removal of the traditional pin reduces tool wear and minimizes material distortion during welding. The technique enables successful bonding of alloys with different thermal and mechanical characteristics. A smoother surface finish and smaller heat-affected zones were achieved. The joints produced met mechanical strength standards required by industries. The process is ideal for lightweight applications in automotive and aerospace sectors. Tool geometry and optimized process parameters played a key role in weld quality. The simplified setup leads to lower production costs and reduced maintenance. Environmentally, the method consumes less energy and avoids the use of filler materials. Overall, pinless FSSW is a cost-effective, sustainable, and high-performance joining technique for modern manufacturing.

III. ACKNOWLEDGMENT

We wish to convey our sincere thanks to our internal guide **Mrs. P. Varalakshmi** Assistant Professor for his professional advice, encouragement in starting this project, and academic guidance during this project.

We wish to convey our sincere thanks to **Dr. B. VIJAYA KUMAR**, Professor & Head of Mechanical Department, and COE of GNIT for his masterly supervision and valuable suggestions for the successful completion of our project. We wish to express our candid gratitude to Principal of the **Dr. KODUGANTI VENKATA RAO,** and the management for providing the required facilities to complete our project successfully. We convey our sincere thanks to the staff Mechanical Engineering Department and the Lab Technicians for providing enough stuff which helped us in taking up the project successfully.

We are also grateful to our well-wishers and friends, whose co-operation and some suggestions had helped us in completing the project. Finally, we would like to thank our parents for their exemplary tolerance and for giving us enough support in our endeavors.

REFERENCES

[1]. Mishra, R. S., & Ma, Z. Y. (2005). *Friction stir welding and processing*. Materials Science and Engineering: R: Reports, 50(1–2), 1–78.
[2]. Chen, C., Lin, S., & Yang, J. (2018). *Pinless friction stir spot welding of aluminium sheets*. Journal of Manufacturing Processes, 34, 23–30.

[3]. Kumar, K., & Kailas, S. V. (2008). *On the role of axial load and the effect of interface position on the mechanical properties of friction stir welds of aluminium alloys*. Materials and Design, 29(4), 791–797.
[4]. Elangovan, K., & Balasubramanian, V. (2008). *Influences of tool pin profile and welding speed on the formation of friction stir processing zone in AA2219 aluminium alloy*. Journal of Materials Processing Technology, 200(1–3), 163–175.

DOI: 10.17148/IARJSET.2025.12312

[5]. Threadgill, P. L., Leonard, A. J., Shercliff, H. R., & Withers, P. J. (2009). *Friction stir welding of aluminium alloys*. International Materials Reviews, 54(2), 49–93.

[6]. Esparza, S., & Juhasz, A. (2012). *Microstructure and mechanical properties of pinless friction stir spot welded AA6061-T6 sheets*. Welding Journal, 91(3), 71–76.

[7]. Ranjbarnoodeh, E., &Mirvakili, A. (2016). *Weld strength and hardness evaluation in pinless friction stir spot welding of aluminum alloy 5083*. Journal of Advanced Materials and Processing, 4(1), 53–60.

[8]. Sharma, C., Dwivedi, D. K., & Kumar, P. (2014). *A study on microstructure and mechanical properties of friction stir spot welded aluminium alloy AA6061-T6*. Materials & Design, 56, 725–731.

[9]. Zhang, Z., & Zhang, H. (2007). *Recent developments in friction stir welding of dissimilar metals*. Materials Science and Technology, 23(8), 871–878.

[10]. Liu, H., Fujii, H., Maeda, M., & Nogi, K. (2005). *Mechanical properties of friction stir welded joints of 1050-H24 aluminum alloy*. Science and Technology of Welding and Joining, 10(5), 608–612.

[11]. Palanivel, R., & Koshy Mathews, P. (2012). *Development of dissimilar friction stir welding process parameters for joining AA6061 to AA5086 aluminium alloys*. Materials and Design, 40, 7–16.

[12]. Kwon, Y. J., Shigematsu, I., & Sato, Y. S. (2008). *Dissimilar friction stir welding between magnesium and aluminum alloys*. Materials Letters, 62(21–22), 3827–3829.

[13]. Rai, R., De, A., Bhadeshia, H. K. D. H., &DebRoy, T. (2011). *Review: friction stir welding tools*. Science and Technology of Welding and Joining, 16(4), 325–342.

[14]. Murr, L. E., & Soto, K. F. (2003). *A TEM study of the microstructural evolution during friction stir welding of dissimilar aluminum alloys*. Materials Characterization, 52(2), 145–152.

[15]. Arora, A., De, A., &DebRoy, T. (2011). *Toward optimum friction stir welding tool shoulder diameter*. Scripta Materialia, 64(1), 9–12.

