



Systematic literature review: Impacts of vibration-assisted welding and step aging on corrosion and fatigue in AA5083–AA6061 joints

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Abstract

The use of dissimilar aluminium alloys, particularly AA5083 and AA6061, has continued to increase in the maritime and automotive industries due to their combination of high strength and good corrosion resistance. Nevertheless, challenges persist due to microstructural heterogeneity and high residual stresses following welding. Various approaches have been developed to improve joint performance, including the application of vibration during welding (vibration-assisted welding) and step aging heat treatment. Although each technique has been shown to be effective in improving microstructural and mechanical properties, systematic reviews that integrate both methods and evaluate their influence on corrosion and fatigue resistance remain limited. This study conducts a Systematic Literature Review (SLR) based on the PRISMA method, focusing on publications from 2015 to 2025 indexed in Scopus Q1–Q3 journals. A total of 52 articles met the inclusion criteria, consisting of 28 experimental studies on vibration-assisted welding of aluminium, 19 studies on step aging, and 5 articles that partially addressed both phenomena. The findings indicate that vibration-assisted welding can refine grain structures and reduce defects, while step aging optimizes precipitate distribution and enhances corrosion resistance. However, research that combines both processes, particularly for dissimilar AA5083–AA6061 joints, remains scarce. Further studies are needed to investigate the correlation between vibration parameters, post-aging precipitate morphology, and corrosion–fatigue resistance to support applications in lightweight and marine industries.

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Keywords

Vibration-assisted welding, Step aging, Dissimilar aluminium, Fatigue performance, Corrosion resistance

Introduction

Aluminium alloys are widely used in modern industries due to their high strength-to-weight ratio, good corrosion resistance, and ease of fabrication [1]. However, the welding of aluminium-particularly dissimilar welding between different alloy types, often leads to complex microstructural challenges [2]. One commonly applied dissimilar

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joint is the combination of AA5083 (Al–Mg) and AA6061 (Al–Mg–Si), especially in the maritime and transportation sectors [3][4][5].

The main issue in AA5083 and AA6061 joints arises from the formation of the Heat Affected Zone (HAZ), which undergoes significant changes in grain size, precipitate distribution, and residual stress [6]. These conditions can promote corrosion and fatigue crack initiation. Various efforts have been made to improve joint quality, including the use of AC current or hybrid welding techniques, control of heat input, and the application of mechanical vibration during welding, which has been shown to refine grain size and reduce porosity defects.

In addition, post weld heat treatments such as solution heat treatment and aging are commonly applied to enhance joint hardness and strength [7][8]. A more recent approach, step aging, involves subjecting the material to multiple heating stages at different temperatures, enabling the formation of fine and stable precipitates (such as Mg₂Si and β' phase) that contribute to improved mechanical properties and corrosion resistance [9].

Although these techniques have been studied individually, no systematic review has yet provided a comprehensive assessment of the combined influence of vibration-assisted welding and step aging heat treatment on the corrosion and fatigue performance of dissimilar aluminium joints. Therefore, this study aims to: 1). Conduct a systematic literature review (2015–2025) on vibration-assisted welding and aging heat treatment in aluminium alloys; 2). Identify research gaps in integrating these two techniques; 3). Propose future research directions to enhance corrosion and fatigue performance in AA5083–AA6061 joints.

Method

Literature search strategy

The literature search was conducted using three major databases: Scopus, Web of Science, and ScienceDirect, covering publications from 2015 to 2025. The search was carried out using the following combination of keywords: (“vibration-assisted welding” OR “ultrasonic welding vibration” OR “vibratory welding”) AND (“step aging” OR “multi-step heat treatment” OR “aging treatment”) AND (“AA5083” OR “AA6061” OR “dissimilar aluminium”) AND (“corrosion” OR “fatigue”).

These keywords were designed to ensure comprehensive coverage of relevant literature related to vibration-assisted welding, step aging heat treatment, dissimilar aluminium alloy joints, and their corrosion and fatigue characteristics, presented in [Table 1](#).

Inclusion criteria and exclusion

Table 1. Inclusion criteria and exclusion

Criteria	Inclusion	Exclusion
Type of publication	Scopus Q1–Q3 journals	Conferences, internal reports
Topic	Welding vibration or heat treatment on aluminium	Non-aluminium topics or numerical simulations
Method	Experimental studies or experimental reviews	Simulations, FEM modelling
Key variables parameters	Corrosion, fatigue, microstructure	Non-mechanical parameters

PRISMA flow

A total of 247 articles on vibration welding were identified, covering a wide range of topics such as welding parameters, selected methods and vibration variables, types of joined materials, and tested properties. After the screening process, 52 articles were found to be eligible for inclusion in this study. However, further analysis revealed that only 8 articles specifically and systematically explained the causal relationships involved and the strategies for improving mechanical properties through the vibration welding method. The article selection process is illustrated in Figure 1.

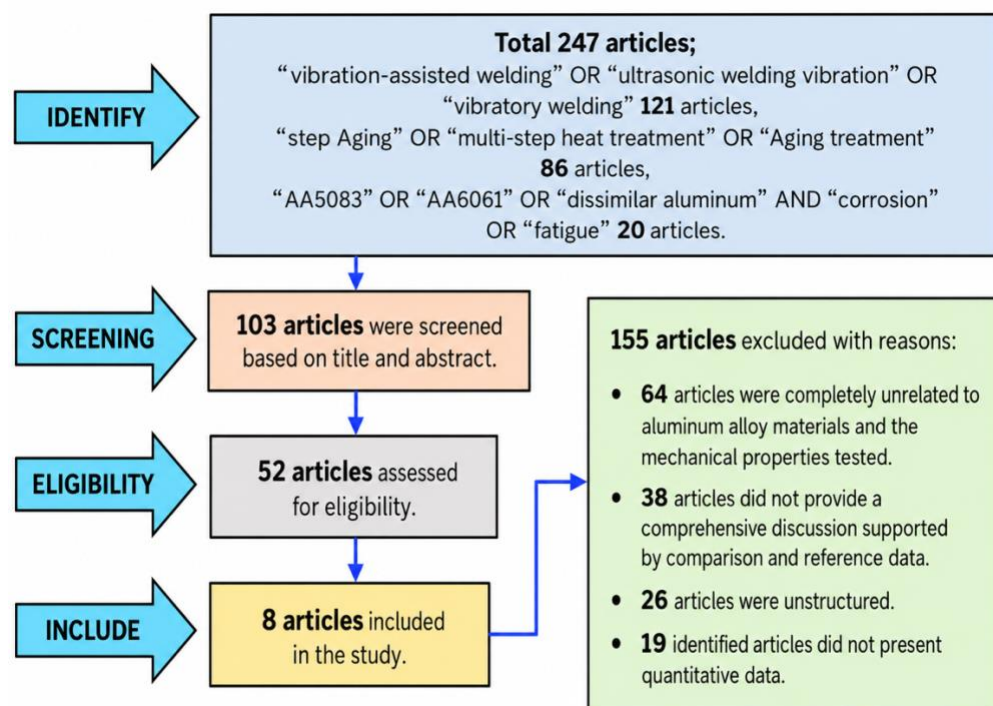


Figure 1. Diagram of studies retrieved in PRISMA flow

Results and discussion

Research distribution

The eligibility assessment included 52 articles, detailed in Table 2.

Table 2. Articles distribution by years and topic

Years	Number	Focus	Journal
2015–2017	12	Vibration-assisted welding	Welding Journal, Materials & Design
2018–2020	17	Aging treatment	Journal of Materials Processing Technology
2021–2025	23	Corrosion and fatigue integration	Metals, Materials Characterization

The effect of vibration during welding

The addition of vibration during welding has been proven to refine the microstructure and improve the homogeneity of the weld zone, presented in Table 3. Several key findings include:

Table 3. Articles on vibration welding and microstructure

No.	Author	Material	Method	Findings	
				Microstructure	Mechanical properties
1.	[10]	Aluminum alloy 6061-T4 series and Mg alloy AZ31B series.	Ultrasonic Vibration Friction Stir Welding (UVEFSW).	Ultrasonic vibration causes a reduction in the thickness of the weld layer, but does not change the chemical composition of the compound layer formed by Al ₃ Mg ₂ .	The tensile strength of the weld increases, because the vibration will increase the mechanical interlocking of the Al-Mg alloy.
2.	[11]	7075-T651 aluminum alloy.	Vibratory stress relief (VSR).	The fatigue life diminishes as the amplitude increases from 0.05 to 0.1 mm. Vibratory stress relief (VSR) at 0.1 mm amplitude reduces fatigue life by 11.11%.	
3.	[12]	C10100 and AA6061-T6	Vibration Friction Stir Welding (VFSW).	The surface roughness of the weld joint area is reduced by the addition of ultrasonic energy during welding.	
4.	[6]	AA6061 and AA5083	MIG Vibration Welding, 0-50 Hz	able to refine the grain size from 200 μm to 115 μm	increase the tensile strength from 287 Mpa to 295 Mpa.
5.	[13]	AA5083	MIG Vibration Welding, 100-300 Hz.	There was a significant reduction in grain size with the application of 300 Hz vibration.	Weld metal tensile stress and heat effect zone (HAZ) increased 51.3% as 300 Hz vibration was applied during welding

The application of vibration during the welding process leads to a reduction in the size of the microstructure within the weld joint area compared to welding without vibration. This refinement is caused by the fragmentation of columnar grains, which produces a finer grain structure [14]. Accordingly, the welded microstructures under each vibration force condition are presented in Figure 2.

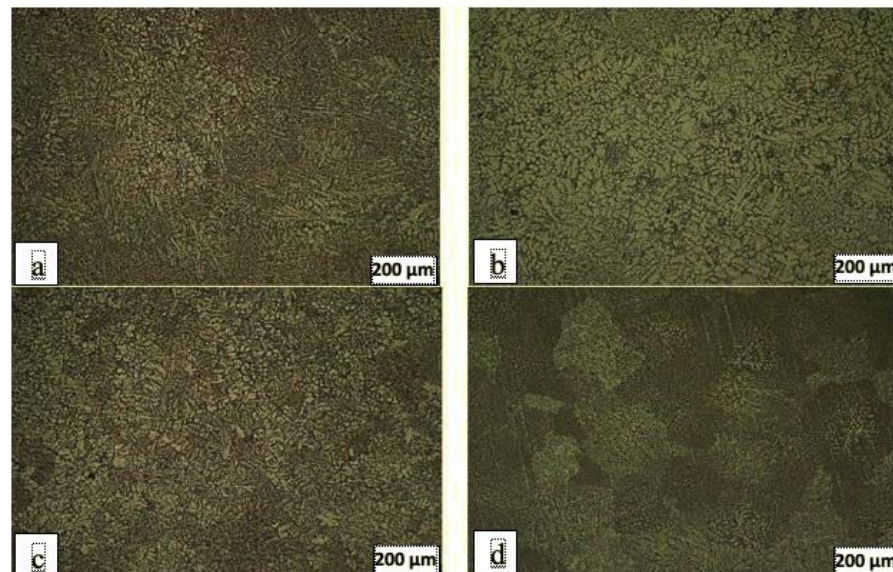


Figure 2. The samples weld center microstructures were welded using varying vibration forces: a) 400 N, b) 750 N, c) 1000 N, and d) without vibration [15].

The effect of step aging heat treatment

Step aging aims to regulate the precipitate so that it forms gradually, preventing overaging presented in Table 4 and Table 5.

Table 4. Articles on step aging and microstructure

No.	Author	Material	Method	Findings	
				Microstructure	Mechanical properties
1.	[16]	AlMg5Mn1	Single step aging,	Microstructural analysis reveals that pre-aging causes notable changes in the precursors of the S- or T-phases, as well as in the density of precipitates.	Single-step artificial aging increased hardness by 58% under peak-aged conditions in the Zn-only modified alloy and by 56% in the alloy containing both Zn and Cu.
2.	[17]	SA508/Alloy 52	thermal aging	The microstructure and carbide type, morphology and size in the carbide precipitation zone up to 1.5 μm from fusion boundary	Long-term thermal aging increases the microhardness peak close to the fusion boundary.
3.	[18]	AA7075	pre-ageing	For the first time, the results show that 8 h pre-ageing at 80 °C can produce a microstructure consisting of GP zones with an average radius of approximately ~0.9 nm, which remains stable up to at least 7 months	94% of the T6 hardness can be obtained by uniformly distributed precipitates with an average radius of approximately ~2.6 nm
4.	[19]	Titanium alloy	Isothermal aging treatment	During the aging treatment, increasing the treatment temperature resulted in a increase in the size of a phase	
5.	[20]	AA7075	Two stepeageing		two-step ageing regime with the parts achieving up to 99% and 98% of the T6 yield strength of Alclad 7075 and 7021p, respectively.

Table 5. Mechanical properties of the 7075 Al sheets subjected to different aging treatments [20].

Aging Time (h)	YS (MPa)	UTS (MPa)	Elongation (%)	Microhardness (HV)
0	168.7	302.9	20.6	36.4
8	427.1	503.2	11.7	173.4
10	450.3	515.3	12.2	179.8
12	443.6	509.5	11.8	168.8
14	441.2	508.8	11.6	170.4
16	447.5	511.6	11.8	183.6
DA treatment	491.1	541.4	10.7	199.6

Corrosion and fatigue in aluminium joints

Pitting corrosion and stress corrosion cracking frequently occur in the HAZ due to precipitate heterogeneity. Meanwhile, fatigue life is strongly influenced by grain size and residual stress conditions. Articles discussing corrosion and fatigue are presented in Table 6.

Table 6. Articles on corrosion and fatigue

No.	Author	Material	Method	Findings	
				Microstructure	Mechanical properties
1.	[21]	AA6061-T6	Vibration	Grain refinement of columnar dendritic and equiaxed dendritic microstructures in the weld metal region.	Have better corrosion resistance than as-welded weld joint, was likely attributable to suppression of intermetallic compound formation such as Mg ₂ Si by mechanical vibration during weld solidification.
2.	[22]	7N01 aluminum alloy	Non-isothermal aging	The results show that the steady phase and metastable Precipitated in the grain boundary of 7N01 aluminum alloy after non-isothermal aging, and their distribution is discontinuous	Compared with single-peak aging, the corrosion current density of non-isothermal aging is reduced by 15.5%, and that of two-stage aging is reduced by 28.9%.
3.	[23]	AA7050	step aging	Stress corrosion crack resistance can be significantly enhancing as the result of fine grain structure.	
4.	[24]	Alloy 625	Aging Treatments		Double aging resulted in a considerable acceleration in the hardening response compared to single aging
5.	[25]	Al-Cu-Li alloys	Aging precipitation		Precipitation strengthening contributions of 58 % of the yield strength.

However, there are hardly any studies that investigate the synergistic effects of vibration and step aging on corrosion–fatigue in dissimilar aluminium joints. Vibration

during the welding process accelerates cooling and enhances nucleation, resulting in finer grains and a more uniform distribution of precipitates. When followed by step aging, the precipitates can grow more uniformly, thereby stabilizing the transition zone between AA5083 and AA6061 against galvanic corrosion. Diagram phase for Al-Mg₂Si of an age-hardening as presented in Figure 3.

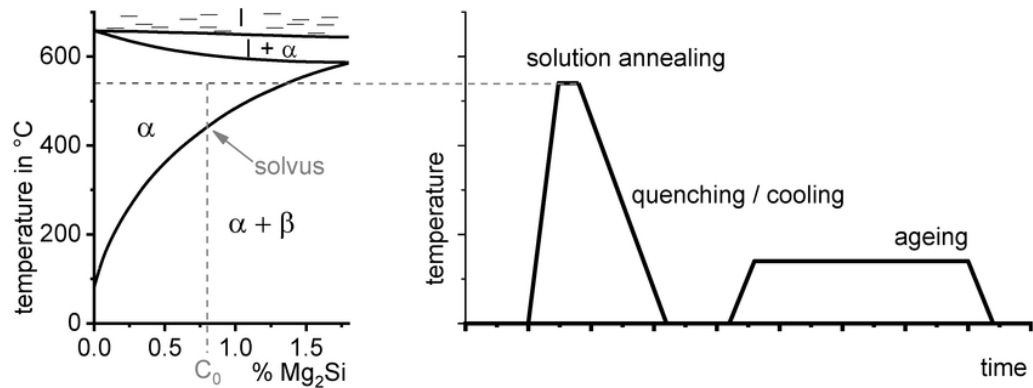


Figure 3. Phase diagram for Al-Mg₂Si and schematic temperature-time profile of an age-hardening procedure

Table 7. Recommendations for future research

No.	Research Direction	Description	Novelty Potential
1.	Combination of vibration and step aging	Integration of two techniques in a single process cycle	Optimization of microstructure
2.	Integrated Corrosion-Fatigue	Study Simultaneous testing in NaCl environment + load cycles	Understanding synergistic mechanisms
3.	Parameters Optimization	Optimization of DoE Parameters for frequency (50–300 Hz) and step aging (100–180°C)	Experimental empirical model
4.	Advanced Microstructure Analysis	TEM/EBSD for precipitate characterization	Quantitative relationship between precipitates and fatigue life
5.	Industrial Application	Validation for ship components/aluminum extrusions	High practical relevance

The relationship among microstructure, corrosion, and fatigue is complex; coarse precipitates may form preferential pathways for intergranular corrosion, while residual stresses can accelerate crack initiation. The combination of vibration and stepwise aging offers potential mitigation of both degradation mechanisms. Nevertheless, several key research gaps remain, including the absence of experimental studies that directly correlate vibration frequency, post-aging precipitate distribution, and fatigue life; the predominance of studies focusing on single materials rather than dissimilar joints such as AA5083–AA6061; and the scarcity of long-term corrosion–fatigue data in marine environments. From this literature review, future research can be recommended as presented in Table 7.

Conclusion

This Systematic Literature Review reveals that vibration-assisted welding can refine grain structure and reduce residual stresses, while stepwise heat treatment effectively promotes fine precipitate formation and improves corrosion resistance. However, the integration of these two approaches in dissimilar AA5083–AA6061 joints remains largely unexplored, offering a high level of novelty and strong potential for publication in reputable Q1–Q2 journals. Future research directions include designing an optimized experimental DoE to determine the most effective processing parameters, conducting simultaneous corrosion–fatigue testing, and performing advanced microstructural analyses to elucidate the precipitation mechanisms occurring in dissimilar joints.

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