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An Overview of Dissimilar Metals Welding by Cold Metal Transfer Technique

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Abstract

Cold Metal Transfer (CMT) welding has emerged as a promising technique for joining dissimilar materials, offering enhanced weld quality and mechanical properties. This review article explores the application of CMT welding in joining different metal alloys, focusing on two significant cases: magnesium-aluminium and aluminium-stainless steel combinations. CMT welding minimizes intermetallic compound formation and produces high-strength joints in magnesium-aluminium combinations. CMT welding with a friction-surfaced aluminum coating offers strong metallurgical bonding in aluminum-stainless steel joints. Precise penetration control and superior tensile strength compared to MIG welding are notable advantages. Optimizing welding parameters and understanding microstructure characteristics are crucial for successful CMT welding of dissimilar materials, presenting promising applications across industries. The review also discusses the impact of welding parameters on the properties of CMT-welded joints, emphasizing the importance of optimizing these parameters to achieve desired results.

Keywords: Cold Metal Transfer (CMT), Microstructure, Mechanical properties, Dissimilar metals.

INTRODUCTION

Cold metal transfer (CMT) welding is a technique used for joining different fragile metals metals using low-power and green technology processes [1]. It has gained interest due to its potential to reduce heat input, improve gap-bridging ability, and increase deposition rate [2]. CMT welding has been applied in various industries, including aerospace, for fabricating aluminum structures [3]. The technique involves using a welding wire that is fed into the weld pool in a controlled manner, resulting in a stable arc and reduced spatter [4]. The quality of CMT welds depends on parameters such as welding speed, accuracy, and the depth of the weld root into the base material [5]. CMT welds' weld geometry and failure modes have been studied to determine the ultimate shear strength and accurately predict failure modes. Overall, CMT welding offers advantages such as low power consumption, improved weld quality, and the ability to join dissimilar metals.

CMT welding stands out as an advanced and increasingly important technique, particularly in the realm of welding dissimilar materials. This innovative method provides practical and effective strategies for the seamless joining of aluminum alloys, encompassing series such as 2xxx, 5xxx, 6xxx, and 7xxx because of low heat input, precision droplet detachment, minimal spatter, distrotion reduction and versatility in aluminium alloys [6]. With its adaptability to various aluminum alloys, including series 2xxx, 5xxx, 6xxx, and 7xxx, CMT welding emerges as a preferred choice. Its versatility addresses the diverse needs of industries working with different aluminum alloys. It has been found that CMT

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welding, especially when combined with ultrasonic vibrations, can improve the mechanical properties, surface strength, material flow, and grain growth of the welded joints [7]. The CMT process exhibits unique characteristics, microstructure, and mechanical properties in dissimilar metal welded joints, such as titanium, stainless steel, aluminum, copper, and magnesium [8]. Additionally, CMT welding has been studied for its effect on the corrosion behavior of dissimilar aluminum joints, with heat input found to impact mechanical properties and corrosion resistance [9]. Overall, CMT welding offers a viable solution for joining different materials with improved mechanical properties and corrosion resistance [10].

CMT welding has been applied for dissimilar joining of various materials, including aluminum alloy and galvanized low-carbon steel [11]. The CMT process allows for the control of weld heat input, resulting in visually acceptable welds with clear ripples and high reproducibility [12]. Intermetallic compounds (IMCs) were detected in the dissimilar joints, with varying thicknesses and compositions depending on the welding parameters [13]. Adding pulses in the weld cycle and increasing the wire feeding rate improved the wettability and load-bearing capacity of the joints [14]. Robot-assisted CMT welding at different speeds improved joint efficiency, tensile strength, and flexibility [15]. CMT welding has been recognized as an effective method for joining dissimilar materials, offering the potential for enhanced performance and functionality in hybrid structures.

The study discusses various dissimilar metal and metal alloy joints made by CMT technique, including magnesium-aluminium, aluminium and stainless steel, and titanium with copper. The objective of the study is on variation of microstructural characteristics, such as the thickness of the intermetallic compound (IMC) layer and the effect of IMCs on the physical properties of the joints. Moreover, the depth of penetration and the influence of heat input on joint strength are also taken into consideration.

CMT WELDING OF DISSIMILAR MATERIALS

Joints of similar metals/metal alloys have been accomplished by the CMT welding technique giving a better weld appearance and joint strength. Some of the similar metal/metal alloy joints are briefly discussed below:

Magnesium and Aluminium Alloy

Cold metal transfer (CMT) welding has been explored as a promising technique for joining magnesium and aluminum alloys. CMT welding controls heat input and spatter, allowing dissimilar metals like magnesium and aluminum to be welded with minimal formation of brittle intermetallic compounds (IMCs) that weaken the joint [16, 17]. Several studies found that CMT welding produced defect-free, high-strength joints between AZ31B magnesium alloy and 6xxx series aluminum alloys. Madhavan et al. [18] reported tensile strengths up to 360 N/mm for AZ31B-A6061 joints. Pramod et al. [4] achieved a joint efficiency of 66.61% for AZ31B-6061 joints. Elrefaey et al. [19] found that CMT-welded 7075 aluminum joints had 77% of the yield strength and 69% of the elongation of the base metal. The microstructure of CMT-welded magnesium-aluminium joints contains some IMCs, but the low heat input limits their formation. Mg-Al IMCs like Mg_2Al_3, $Mg_{17}Al_{12}$, and Mg_2Si form at the interface between the magnesium base metal and weld metal, as shown in Figure 1 [20].

The thickness of the IMC layer depends on factors like welding current, speed, and wire feed rate as shown in Figure 2 [18]. Minimizing IMC formation, especially Mg-rich IMCs, is key to improving joint strength [17].

In summary, CMT welding is a promising technique for joining magnesium and aluminium alloys with minimal IMC formation and good mechanical properties. By controlling heat input and wire deposition, CMT welding can produce high-quality, defect-free dissimilar metal joints between magnesium and aluminium.

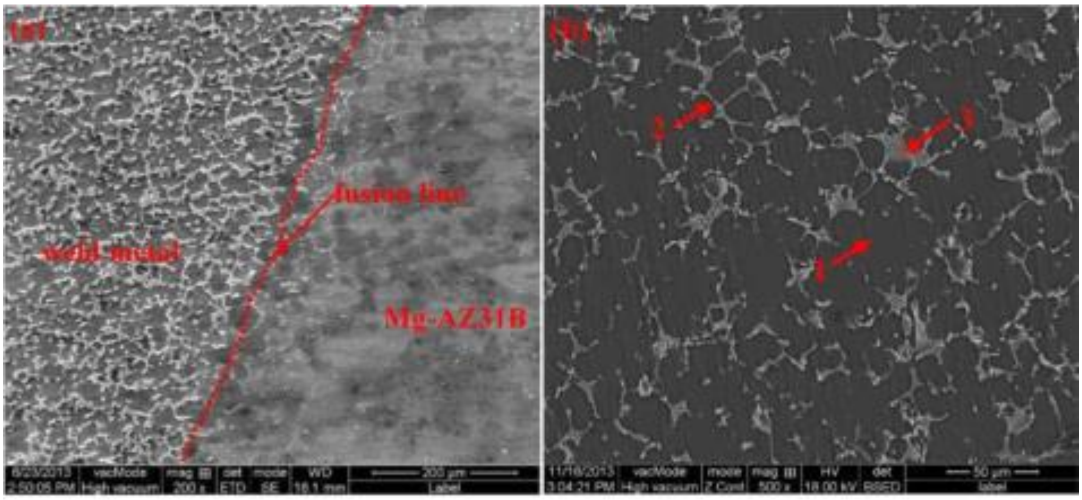

Figure 1. Microstructure of CMT-welded magnesium-aluminium [16].

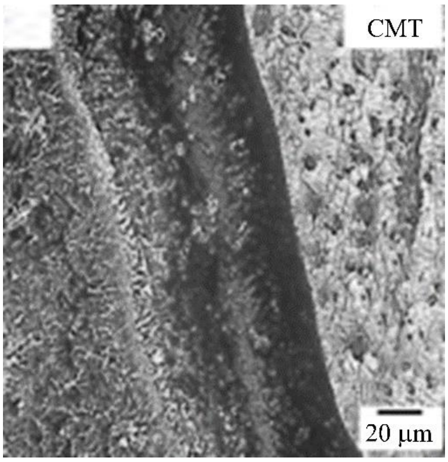

Figure 2. Nugget and Magnesium interface [18].

Aluminium Alloy and Stainless Steel

Cold metal transfer (CMT) welding has been explored as a promising method for joining dissimilar metals like aluminum alloys and stainless steel. Multiple studies have investigated the feasibility and quality of CMT welding aluminum alloys to stainless steel. Babu et al. [21] found that CMT welding aluminum alloy AA 2219 to stainless steel AISI 321 after friction surfacing the stainless steel with the aluminum alloy produced joints with the highest strength when using a 0.6 mm thick aluminum coating. In the experiment, the area between the weld metal and layer in Figure 3 showed excellent metallurgical bonding with a distinct boundary in Figure 3b and 3c. In contrast, joint (0.3) lacked this interface as the Al coating completely melted during CMT welding, as seen in Figure 3a. Initially without intermetallics, the interface developed a thin Fe-Al intermetallic layer after CMT welding.

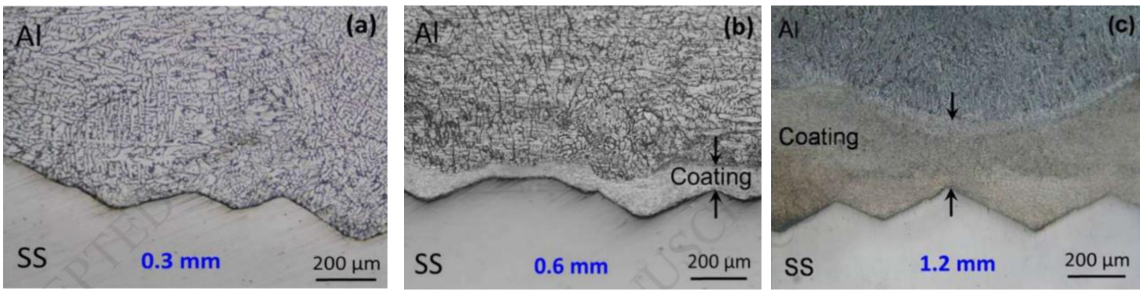

Figure 3. Interface microstructure having coating thickness (a) 0.3, (b) 0.6, and (c) 1.2 [21]

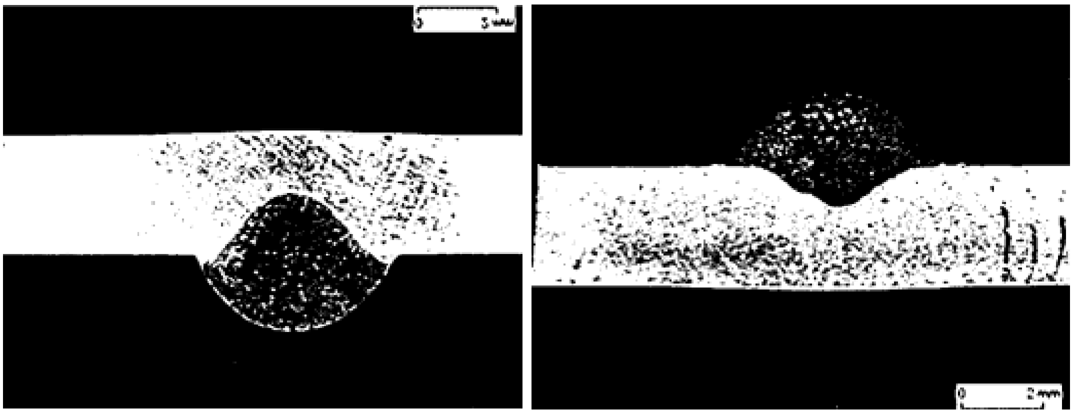

Figure 4. Effect of duration on penetration (a) low duration, and (b) high duration [22].

Pickin et al. [22] discovered that compared to pulsed MIG welding, CMT welding aluminium alloy had a higher electrode melting coefficient and by adjusting the short circuit duration, penetration could be controlled as shown in Figure 4 with only a small change in electrode deposition. Mixing pulsed MIG and CMT welding also greatly extended the working envelope, allowing thicker sections to be welded with improved weld bead aesthetics

Elrefaey et al. [19] established that CMT welding 7075-T6 aluminum alloy resulted in better joint tensile strength and flexibility than MIG welding. The heat-affected zone was very soft, but the welded metal had a more enormous hardness gap than the base metal. The joint had 77%, 60%, and 69% of the yield strength, ultimate tensile strength, and elongation of the base metal, respectively. Pramod et al. [4] focused on achieving an optimum CMT welding parameter for joining a 3.5-mm thick 6061-T6 aluminum alloy pressure vessel liner and examining the weld's mechanical properties and metallurgical nature. The welded joint was defect-free and had 66.61% joint efficiency and 59.78 HV microhardness. Grain coarsening in the heat-affected and weld zones was due to thermal gradients during welding. Loss of strengthening elements Si and Mg led to reduced mechanical properties. Intermetallics Al-Si and Fe-Si were present. Failure was ductile. Yang et al. [23] studied CMT welding aluminum alloy 6061-T6 to zinc-coated steel, pre-setting a gap at the interface and offsetting the electrode torch affected weld quality. Tensile shear tests evaluated weld strength. The intermetallic layer thickness was under ten µm, enabling relatively high power. A pre-setting gap and post-weld heat treatment improved stability, but increasing offset distance reduced it. The opening also affected intermetallic layer morphology. The remaining zinc suppressed brittle Al_xFe_y formation. In Figure 5, refined grains were observed in the HAZ and the aluminum base metal. Nevertheless, in the weld zone, there was grain coarsening and a reduction in the density of grain boundaries.

Gungor et al. [24] examined the mechanical and microstructural properties of CMT welding 5083-H111 and 6082-T651 aluminum alloys. Non-destructive and destructive tests were conducted on similar and dissimilar alloy welds. CMT-MIG provided good joint efficiency, high speed, and good tensile and fatigue performance. Zapico et al. [25] proposed an improved model for simulating CMT welding 3-mm AA5754 aluminum alloy. COMSOL Multiphysics calculated temperature distributions in the weld seam and heat-affected zone. Comparing simulated and measured temperatures validated the model. Significant differences between peak and average calculated weld pool temperatures highlighted improvements in weld quality for thin sheets with CMT versus conventional processes. The model enables process optimization and sensitivity analysis. Cao et al. [26] found CMT brazing feasible for joining various 1-mm aluminum alloys to 1-mm mild steel (Q235). The weld configuration for the same is shown in Figure 6. Optimal process variables for 200 mm x 50 mm x 1 mm aluminum-galvanized steel were Al4043 wire, 100% argon, 12-14 V, 2-3.5 mm deviation, 6-8 mm/s speed and 4-6 m/min wire feed. Joint strength depended on intermetallic thickness and Al heat-affected zone softening. Controlling heat input (100-200 J/mm) minimized degradation and intermetallic thickness, producing comparable power to Al-Al CMT weld-brazed joints. In summary,

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CMT welding has been shown by multiple studies to be a promising method for welding dissimilar metals like aluminium alloys and stainless steel. By properly controlling process parameters and geometry, high quality joints with minimal defects and intermetallic formation can be achieved. CMT welding thus enables the fabrication of hybrid structures incorporating aluminium alloys and stainless steel.

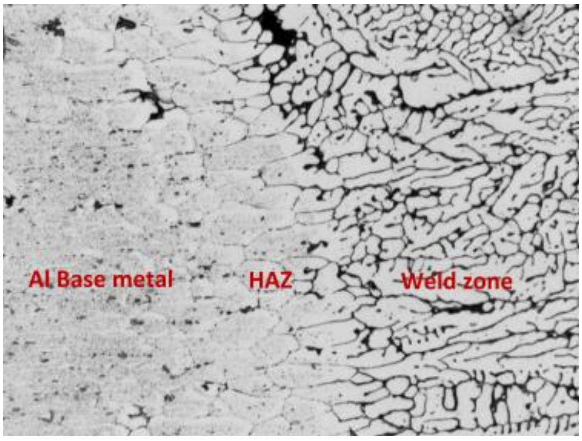

Figure 5. Microstructure of HAZ region along with Al base metal and weld zone [23].

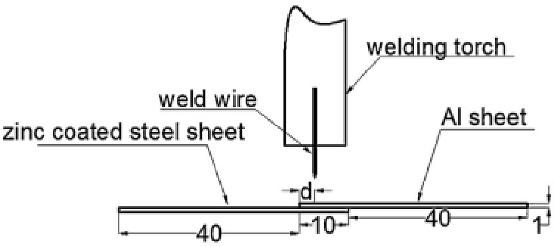

Figure 6. Schematic view of lap joint configuration of aluminum-to-galvanized mild steel workpiece [26].

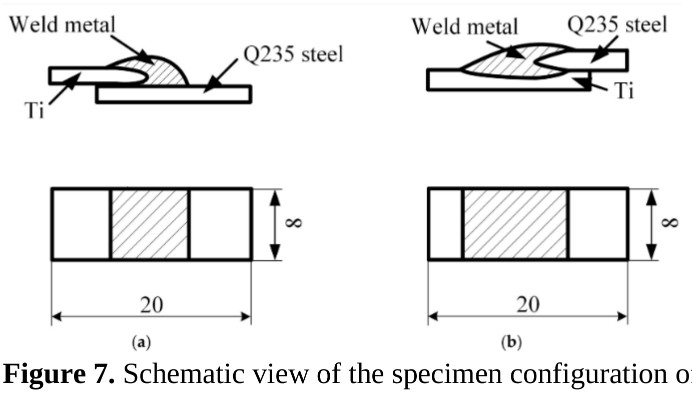

Figure 7. Schematic view of the specimen configuration of (a) joint 1, and (b) joint 2 [29].

Titanium and Copper

Cold metal transfer (CMT) welding has been used to join titanium (Ti) with copper (Cu) in various studies. The influence of interfacial microstructure on the mechanical properties and fracture behavior of the joints was investigated [27]. The formation of intermetallic compounds (IMCs) at the Ti/Cu interface was observed, including Ti_2Cu, TiCu, and $AlCu_2Ti$ phases [28]. The morphology and distribution of the $AlCu_2Ti$ phase significantly affected the properties of the joints [8]. The welding heat input played a role in the transformation of the $AlCu_2Ti$ phase, resulting in different fracture behaviors, such as cleavage, ductile-brittle-mixing, and quasi-cleavage fracture the configuration of the weld is shown in Figure 7 [29].

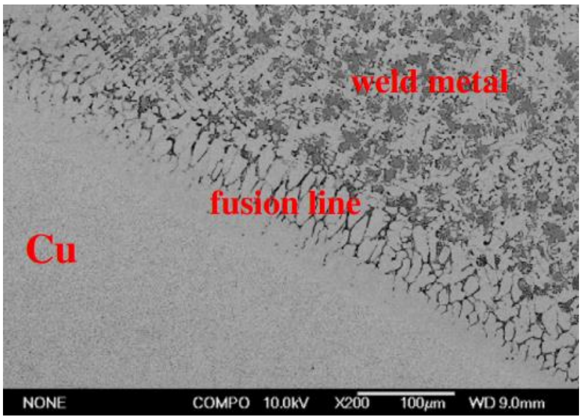

Figure 8. Microstructure of the copper-weld interface layer [30].

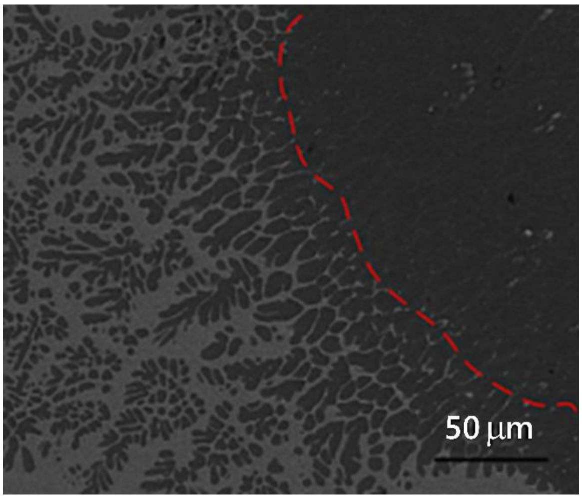

Figure 9. Microstructure of weld/Al interface region [31].

The welding speed also affected the wetting angle, weld width, and microstructure of Ti/SS lap joints [3]. The Fe–Si–Ti ternary phase and Fe_2Ti phase in the fusion zone at low welding speed influenced the mechanical properties of the joints. The CMT process with low heat input produced strong joints between dissimilar metals, such as Ti and stainless steel, with high tensile strength and flexibility. The stacking order of the base metals affected the joining modes and stability of the joints. The presence of $TiFe_2$ IMCs significantly improved the power of the joint between Ti and Q235 steel. The CMT method has been recognized as a low-power and green technology process for joining dissimilar metals, including Ti and Cu.Cao et al. [30] focuses specifically on lap welded joints between titanium and copper, revealing the presence of intermetallic compounds and a multi-phase weld metal. They explores the welding-brazing process of titanium to copper, observing the formation of interfacial reaction layers and discussing the effects of process parameters on joint features and mechanical properties. The microstructural image of the interface layer between copper base metal and weld metal is shown in Figure 8.

Lastly, Feng et al. [31] investigates the microstructures and properties of lap-welded joints between aluminum and copper using CMT, providing insights into the formation of intermetallic compounds and the influence of heat input on joint strength. The interface region of weld and aluminium is depicted in Figure 9.

In summary, these papers collectively demonstrate the feasibility of joining titanium and copper using CMT welding, highlighting the formation of intermetallic compounds and the influence of process parameters on joint characteristics and mechanical properties.

CONCLUSION

- Cold Metal Transfer (CMT) welding has demonstrated its effectiveness in joining dissimilar materials, specifically magnesium-aluminium and aluminium-stainless steel combinations.
- In magnesium-aluminium joints, CMT welding controls heat input and minimizes brittle intermetallic compound (IMC) formation, resulting in high-strength, defect-free joints.
- CMT welding provides precise penetration control and outperforms conventional MIG welding in terms of joint tensile strength and ductility in aluminium-stainless steel joints.
- Optimizing welding parameters is essential for achieving the desired mechanical properties and minimizing IMC formation in CMT-welded joints.
- Overall, CMT welding holds significant promise for various industrial applications, offering enhanced dissimilar material joining capabilities and improved mechanical properties.

REFERENCES

1. B. Naik and M. Madhavan, “Structural performance of cold metal transfer welding technique on cold-formed steel flare v-groove welds,” *Thin-Walled Struct.*, vol. 190, 2023.
2. J. Brezinová and J. Hašuľ, “Evaluation of Fillet Welds Properties Performed By Cold Metal Transfer Robotic Metal Active Gas Welding Technology,” *Transport*, vol. 38, no. 1, pp. 44–51, 2023.
3. N. M. Burhanuddin, N. Redzuan, N. Ahmad, I. Sudin, and M. F. A. Zaharuddin, “Brief Review on Dissimilar Welding Using Cold Metal Transfer,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 884, no. 1, 2020.
4. R. Pramod, N. S. Shanmugam, and C. K. Krishnadasan, “Studies on cold metal transfer welding of aluminium alloy 6061-T6 using ER 4043,” *Proc. Inst. Mech. Eng. Part L J. Mater. Des. Appl.*, vol. 234, no. 7, pp. 924–937, 2020.
5. P. Zhang, G. Li, H. Yan, and Y. Tian, “Effect of positive/negative electrode ratio on cold metal transfer welding of 6061 aluminum alloy,” *Int. J. Adv. Manuf. Technol.*, vol. 106, no. 3–4, pp. 1453–1464, 2020.
6. H. Shanker and R. Wattal, “A comprehensive survey on the cold metal transfer process in welding similar and dissimilar materials and for cladding,” *Pro*
7. *c. Inst. Mech. Eng. Part C J. Mech. Eng. Sci.*, vol. 237, no. 10, pp. 2360–2391, 2023.
8. Y. Koli, N. Yuvaraj, S. Aravindan, and Vipin, “Enhancement of Mechanical Properties of 6061/6082 Dissimilar Aluminium Alloys Through Ultrasonic-Assisted Cold Metal Transfer Welding,” *Arab. J. Sci. Eng.*, vol. 46, no. 12, pp. 12089–12104, 2021.
9. M. Balasubramanian, M. V. Choudary, A. Nagaraja, and K. O. C. Sai, “Cold metal transfer process-A review,” *Mater. Today Proc.*, vol. 33, pp. 543–549, 2020.
10. N. Çömez and H. Durmuş, “Corrosion behavior and mechanical properties of cold metal transfer welded dissimilar AA7075-AA5754 alloys,” *J. Cent. South Univ.*, vol. 27, no. 1, pp. 18–26, 2020.
11. S. Selvi, A. Vishvaksenan, and E. Rajasekar, “Cold metal transfer (CMT) technology-An overview,” *Def. Technol.*, vol. 14, no. 1, pp. 28–44, 2018.
12. M. Peng., H. Liu, Y. Liang, W. Xu, Y. Zhao, S. Chen, J. Weng, and J. Yang, “CMT welding-brazing of al/steel dissimilar materials using cycle-step mode,” *J. Mater. Res. Technol.*, vol. 18, pp. 1267–1280, 2022.
13. W. Xu, H. He, Y. Yi, H. Wang, C. Yu, and W. Fang, “Dissimilar joining of stainless steel and aluminum using twin-wire CMT,” *Weld. World*, vol. 65, no. 8, pp. 1541–1551, 2021.
14. J. Singh, K. S. Arora, and D. K. Shukla, “Joining of Dissimilar Materials—Aluminium to Steel—Using CMT + P Weld-Brazing Process,” *Lect. Notes Multidiscip. Ind. Eng.*, vol. Part F255, pp. 271–284, 2020.
15. S. Balamurugan*, R. Ramamoorthi, I. K. K. Jeysing, S. Kumar, I. M. Sharukhan, G. M. Prakash, and S. Madhan, “Microstructure and Mechanical Properties of Cold Metal Transfer Welding AA6082-T4 Alloys,” *Indian J. Sci. Technol.*, vol. 12, no. 42, pp. 1–8, 2019.
16. S. Venukumar, M. Cheepu, T. Vijayababu, and D. Venkateswarlu, “Cold metal transfer (Cmt) welding of dissimilar materials: An overview,” *Mater. Sci. Forum*, vol. 969 MSF, pp. 685–690, 2019.

17. Husain Mehdi, Sumit Jain, Msomi, V. et al. Effect of Intermetallic Compounds on Mechanical and Microstructural Properties of Dissimilar Alloys Al-7Si/AZ91D. J. of Materi Eng and Perform (2023). https://doi.org/10.1007/s11665-023-08302-9.
18. R. Cao, B. F. Wen, J. H. Chen, and P. C. Wang, "Cold Metal Transfer joining of magnesium AZ31B-to-aluminum A6061-T6," *Mater. Sci. Eng. A*, vol. 560, pp. 256–266, 2013.
19. S. Madhavan, M. Kamaraj, and L. Vijayaraghavan, "Cold metal transfer welding of aluminium to magnesium: Microstructure and mechanical properties," *Sci. Technol. Weld. Join.*, vol. 21, no. 4, pp. 310–316, 2016.
20. A. Elrefaey, "Effectiveness of cold metal transfer process for welding 7075 aluminium alloys," *Sci. Technol. Weld. Join.*, vol. 20, no. 4, pp. 280–285, 2015.
21. J. Shang, K. Wang, Q. Zhou, D. Zhang, J. Huang, and G. Li, "Microstructure characteristics and properties of Mg/Al dissimilar metals made by cold metal transfer welding with ER4043 filler metal," *Xiyou Jinshu Cailiao Yu Gongcheng/Rare Met. Mater. Eng.*, vol. 42, no. 7, pp. 1337–1341, 2013.
22. S. Babu, S. K. Panigrahi, G. D. Janaki Ram, P. V. Venkitakrishnan, and R. Suresh Kumar, "Cold metal transfer welding of aluminium alloy AA 2219 to austenitic stainless steel AISI 321," *J. Mater. Process. Technol.*, vol. 266, pp. 155–164, 2019.
23. C. G. Pickin and K. Young, "Evaluation of cold metal transfer (CMT) process for welding aluminium alloy," *Sci. Technol. Weld. Join.*, vol. 11, no. 5, pp. 583–585, 2006.
24. S. Yang, J. Zhang, J. Lian, and Y. Lei, "Welding of aluminum alloy to zinc coated steel by cold metal transfer," *Mater. Des.*, vol. 49, pp. 602–612, 2013.
25. B. Gungor, E. Kaluc, E. Taban, and A. SIK Ş.Ş, "Mechanical and microstructural properties of robotic Cold Metal Transfer (CMT) welded 5083-H111 and 6082-T651 aluminum alloys," *Mater. Des.*, vol. 54, pp. 207–211, 2014.
26. E. P. Zapico, A. H. A. Lutey, A. Ascari, C. R. Gómez Pérez, E. Liverani, and A. Fortunato, "An improved model for cold metal transfer welding of aluminium alloys," *J. Therm. Anal. Calorim.*, vol. 131, no. 3, pp. 3003–3009, 2018.
27. R. Cao, G. Yu, J. H. Chen, and P. C. Wang, "Cold metal transfer joining aluminum alloys-to-galvanized mild steel," *J. Mater. Process. Technol.*, vol. 213, no. 10, pp. 1753–1763, 2013.
28. L. Huang, H. Dong, Y. Ma, P. Li, J. Wang, J. Yang, and B. Wu, "Interfacial layer regulation and its effect on mechanical properties of Ti6Al4V titanium alloy and T2 copper dissimilar joints by cold metal transfer welding," *J. Manuf. Process.*, vol. 75, pp. 1100–1110, 2022.
29. G. Li, S. Xu, X. Lu, X. Zhu, Y. Guo, and J. Song, "Effect of welding speed on microstructure and mechanical properties of titanium alloy/stainless steel lap joints during cold metal transfer method," *Metall. Res. Technol.*, vol. 117, no. 5, 2020.
30. J. Chang, R. Cao, and Y. Yan, "The joining behavior of titanium and Q235 steel joined by cold metal transfer joining technology," *Materials (Basel).*, vol. 12, no. 15, 2019.
31. R. Cao, Z. Feng, and J. H. Chen, "Microstructures and properties of titanium-copper lap welded joints by cold metal transfer technology," *Mater. Des.*, vol. 53, pp. 192–201, 2014.
32. J. Feng, Y. Liu, Q. Sun, J. Liu, and L. Wu, "Microstructures and Properties of Aluminum-Copper Lap-Welded Joints by Cold Metal Transfer Technology," *Adv. Eng. Mater.*, vol. 17, no. 10, pp. 1480–1485, 2015.

