A Critical Review on Dissimilar Metals Joining Using Cold Metal Transfer Welding

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Abstract

Cold metal transfer now a day is a modern fabrication process with minimum heat affected zone with higher strength is used in industry. Cold metal transfer welding can be used for both similar & dissimilar material joining. Joining of dissimilar material have certain drawbacks such as formation of brittle IMC's which makes the joint brittle & reduces strength that causes failure. Various parameters such as current (I), voltage (V), welding speed, nozzle angle, root gap, material thickness have to be considered when joining of two dissimilar materials. Dissimilar joining can be done by using different methods such as stir friction welding, submerged arc welding, laser welding, electron beam welding, gas tungsten arc welding, gas metal arc welding. But now a days Cold metal transfer welding is the best joining technique to join dissimilar materials of very small thickness with better joint efficiency. The major advantage of Cold metal transfer welding is the low heat generation with lesser Heat affected zone also the power consumption is very less compared to conventional welding techniques. This review includes Cold metal transfer process, Joining of dissimilar materials. In this paper various researches to join dissimilar material are thoroughly analysed. This review includes the major parameters by which problems such as Intermetallic compounds can be reduced to get better joint stability.

Number: 10.14704/nq.2022.20.7.NQ33238 **Neuro Quantology 2022; 20(7):1896-1906**

1. Introduction

Now cold metal transfer welding (CMT) is widely used in automobile industries, defense sector, additive manufacturing, pin fabrication etc.[2] Welding is a process of joining of similar or dissimilar materials with the application of heat and pressure or both. In fusion welding the edges of two materials are heated up to melting temperature and fused together to form welded joint [1]. Sometimes filler material is required in fusion welded joint. Fusion welding comprises of two parts the weld bead and heat affected zone. Weld bead is the strongest part of joint whereas the heat affected zone (HAZ) is the weakest part due to uncontrolled heat treatment. During welding, temperature variation on weld bead and parent material affects the mechanical properties, distortion and induce residual stresses and dimensional inaccuracy of welded products[2]. Various fusion welding techniques are present to join materials. The major challenge in fusion welding is to join dissimilar materials due to different melting points and coefficient of thermal expansion[3]. Intense heat generation is also a major problem in convention fusion welding techniques which results in distortion and residual stress generation, also mechanical properties get affected due to intense heating.

Due to technological limitations, it is not possible to manufacture a production without fabrication (welding). A product comprises of various parts is not possible to manufacture at a time and hence by joining different parts by welding is a benefit to engineers. Selection of material is the major step for a product design[4]. In present situation, light weight and efficient structure is the basic need which can be obtained by combining various materials results in multilayer hybrid structure is possible through fabrication. Need of these hybrid materials are required in various industries such as automotive[5], aerospace [6], marine [7] & nuclear power plant [8] etc.

Joining of dissimilar metals was major challenge, to join dissimilar materials various processes has been applied to minimize the cost without compromise of strength. Dissimilar metals can be joined through Gas metal arc welding (gmaw) [8], gas tungsten arc welding (gtaw) [9], friction welding [10], submerged arc welding (saw) [11], laser welding [12], electron beam welding [12].

Friction Stir Welding (FSW) is used to join dissimilar materials especially aluminium to other metals but the strength of material must be less that stirrer [10]. Friction Stir Welding (FSW) has wide applications in marine, automobile, nuclear, aerospace industry. FSW is a fusion welding process and has major advantage of low temperature, low distortion, low energy input, short welding time [13].

Gas metal arc welding (GMAW) is a type of fusion welding process most commonly used in automotive industry, joining of dissimilar metals [14]. GMAW has a major advantage of high efficiency, no flux requirements, low defects, less cost, good appearance[15]. Gas Tungsten Arc Welding (GTAW) is used to join dissimilar metals without using flux is generally used. Limitations of GTAW is low penetration and poor tolerance[16]

Laser Beam Welding is a fusion welding process which uses laser beam to create heating effect to produce weld bead. Principal variables are laser intensity, welding speed, laser focus size [17]. Electron Beam Welding is also a type fusion welding process which is mainly used in aerospace industry where precision weld is required. Weld quality is excellent in EBW process. Recently investigations are in progress for joining of dissimilar metals[12]. Submerged arc welding generally used for butt weld joints for similar materials. Dissimilar metal joining is difficult task by SAW due to buttering effect.

2. COLD METAL TRANSFER PROCESS

CMT is advance version of MIG welding process which is based on short circuiting process, developed by Fronius of Austria in 2004. The main feature of CMT welding is low heat generation, results in good dimensional accuracy, less heat affected zone (HAZ) and low residual stress in the parent material. CMT based on wire retracting principle. When the electrode wire is in contact with the weld pool, the electrode wire retracts which is done by servo motor called robacter drive and this enables the wire to retract and metal droplet is detached. During metal transfer current drops to zero, hence spatter is significantly minimized. As metal transfer is completed, arc reignites and current flow occurs and wire feed in forward direction once more with set current. During the whole cycle voltage and current varies many times and hence CMT cycle parameters is the main research topic. And many investigations were performed to optimize the parameters to increase the performance of weld characteristics. Phase involved in CMT cycle as demonstrated in Fig. 1

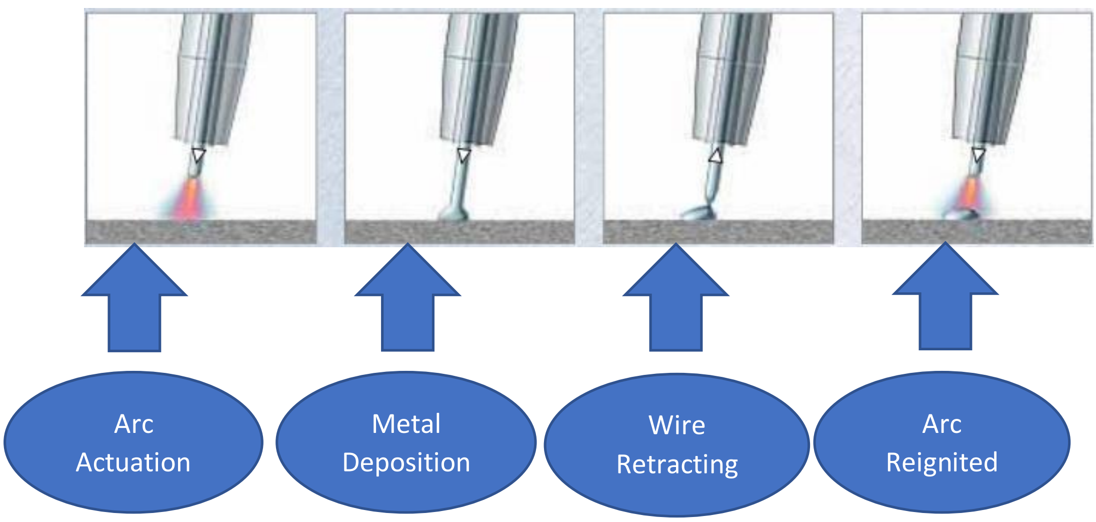

Fig 1. Demonstration of CMT Welding

- ***The peak current phase:*** This is the highest pulse of current at constant arc voltage causing the ignition of welding arc so that electrode wire melts to form droplet for weld pool.
- ***The background current phase:*** In this phase allows the lowest current which prevents the globular metal transfer of metal formed on the electrode wire tip, minimizes the chance of spatter. This phase continues up to short circuiting.
- ***The short-circuiting phase:*** In this phase, the return signal is given to the wire feeder which allows the wire to draw backward, at same time, arc voltage is became zero. This phase assists in the liquid fracture and transfer of material into the weld pool. Current & Voltage variation of CMT is shown in Fig. 2.

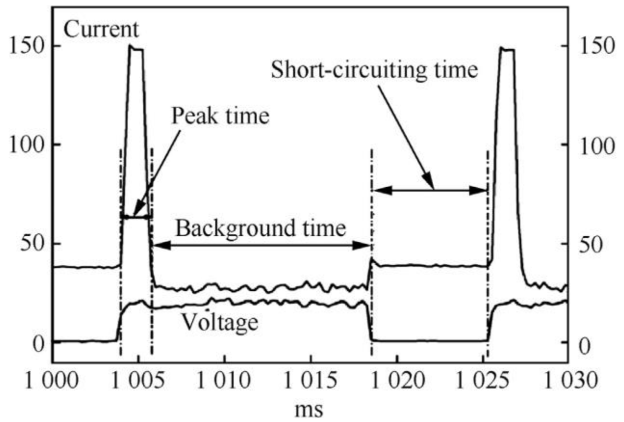

Fig. 2 Current (I) & Voltage (V) waveforms of CMT [2]

3. Literature review on CMT Welding

Selvi et al. () CMT welding technology is a fusion welding technology which is used to join similar & dissimilar materials, thick & thin plates with low heat input which improves the aesthetics of weld bead due to low spatter tendency and controlled deposition rate, welding quality is far superior in comparison to other fusion welding processes. It is found that welding of aluminium and steel shows better result compared to other fusion welding techniques. Better mechanical properties are obtained compared to other fusion welding process such as MIG. Now a day CMT is widely used in automobile industries, defense sector, additive manufacturing, pin fabrication etc.[2]

Stanciu et al. ()Automotive industry has major problem to reduce the weight for better fuel efficiency. Lighter material of better strength is used in modern vehicles to reduce the overall cost and weight of the vehicle. It is found that to join thinner and lighter material is the major challenge with conventional welding processes, as thin material gets overheated quickly which reduces the strength and creates distortion. Laser technology is best used to join dissimilar thin plates but equipment's are expensive and extra preparation of material is required. Hence CMT is modern way to join dissimilar material.[18]

Yacob S et al. found the effect of welding parameter on surface quality of aluminium metal. Surface roughness is decreased by increasing the welding speed and material thickness whereas surface roughness is increased by increasing contact tip to work distance. It is concluded that better surface finish is obtained by increasing the welding speed and thickness and decreasing the contact tip to work distance.[19]

Dharmik et al. has joined the CRNGO electrical sheets of 0.5 mm by using GTAW welding and CMT welding. Mechanical properties, microstructures using scanning electron microscopy (SEM) of welded samples of CRNGO electrical sheets were studied. It is found that by using CMT welding HAZ is minimum which results in less hardness and better properties due to its short-circuiting action. CMT is best alternative to TIG & MIG processes.[20]

Paola et al has found that DSS duplex stainless steel has good mechanical properties such as fatigue strength, wear resistance, corrosion resistance etc. It is found that DSS has decreased the cost of paper and pulp industry, and used as coatings on mild steel or low carbon steel. Deposition (coating) of DSS layer on mild steel has done by both GMAW & CMT welding at different heat input. Austenite and ferrite phase has formed. Austenite phase increased the wear resistance.[21]

Kannan et al. has found the effect of arch length correction on weld bead geometry and mechanical properties of steel by using CMT welding process. Arc length correction has varied from -20 to +20%, and found that top reinforcement and tensile strength increases as arc length correction varies from -20 to +20%. It is observed that best weld bead profile is obtained when arc length correction is 10%.[22]

Prakash et al. has found the effect of heat treatment of CMT welded aluminium plates and its improvement on mechanical and metallurgical properties. Using CMT, welding has performed and post weld heat treatment has done. 1. Solution treatment 2 aging. Solution treatment of weld sample, samples were heated to 530 deg centigrade for 45 min in box furnace, then water quenching is performed. Sample now again heated to 175 °C for 8 hours in box furnace itself. It is found that sample with aging has better tensile and yield strength compared to solution treatment.[23]

3.1 Literature review of joining of dissimilar materials

Burhanuddin et al has reviewed the joining of dissimilar materials with different processes such as friction stir welding (FSW), GMAW welding processes and compared results with CMT welding process which is new technology used to join dissimilar materials with thickness as low as 0.3 to 2 mm. it is found that during fusion of dissimilar metals intermetallic compounds layers cause failure. It is found that CMT is giving better results when joining magnesium alloys to aluminium alloys, aluminium alloys to steel alloys of lesser thickness of 0.7 mm, with filler wire range from 1.2 to 1.3 mm. [24]

3.1.1 Ferritic Stainless Steel to AISI 316L Austenitic Stainless Steel

Ghosh et al performed the experiment to join two dissimilar material, AISI 409 ferritic stainless steel & AISI 316L austenitic stainless steel. AISI 308 as filler wire. Effects of welding parameters on weld bead were analysed such as gas flow rate, welding current & distance between nozzle & plate on ultimate tensile strength and yield strength, and applied taguchi method to optimize the result with 3 variables.[8]

Rajput et al has investigated the microstructural behaviour and mechanical properties of dissimilar welding to austenitic ferritic stainless steel at different root gap and notch angles by using MIG welding. It was observed earlier that yield strength and tensile strength was highest with 60° notch angle & 2mm root gap with similar material. Also, in case of dissimilar materials same results were obtained as similar material joining i.e., yield strength and tensile strength is highest at 60° notch angle & 2mm root gap.[25]

3.1.2 Titanium TA2 to Copper T2

Cao et al has performed the experiment to join pure 3 mm titanium TA2 to copper T2 by using cold metal transfer (CMT) welding technology in the form of butt joint by using ERCuAl copper wire as a filler material with 1.2 mm diameter. Microstructure and intermetallic compound distribution were analysed, different parameters: wire feed speed, groove angle and mechanical properties of weld bead were investigated. Different fracture modes were observed: at the copper interface, titanium interface and copper heat affected zone. It is found that tensile strength is minimum at copper heat affected zone and also intermetallic compounds layers was non uniform distributed.[26]

3.1.3 Aluminum 5083 to Austenitic Stainless Steel SUS304

Xu et al has experimented to join dissimilar joining of aluminium (5083 aluminum alloy) and stainless steel (SUS304 austenite stainless steel) sheets of 3 mm thickness and Al-Si filler material. It is found that intermetallic compounds (IMC's) were detected layer of Fe_2Al_5 on steel side and $Fe_3Al_2Si_4$ on aluminium side, Fe_4Al_{13} in between the joints. Tensile test was performed and found that fracture occurred at the brazing interface and maximum tensile strength was 96 MPa which is 35% of base material. Joint efficiency and wetting characteristics are best obtained at high feed rate and low welding speed. Excessive heat input reduced the mechanical properties.[27]

3.1.4 Aluminium (AA6061) to Zinc Coated Steel

Lin et al checked the shear strength of brazed lap joints between aluminium and zinc coated steel by using cold metal transfer method (CMT). Shear strength of joint was checked by experimental and numerical modelling. Fusion line failure was observed when plate thickness 1.2 mm on CMT lap brazed joint. When aluminium was brazed with thickness less than

0.7 mm, it is observed that low shear strength and interface failure took place. Fusion line failure was observed when plate thickness 1.2 mm on CMT lap brazed joint.[28]

3.1.5 Aluminium to Copper

Cong et al has attempted to join Aluminium Copper alloy weld by CMT and investigated the influence of heat input on welded joint. Cong used to weld two dissimilar materials by using different CMT process: narrow finger shaped geometry and bead porosity was observed by using Conventional CMT process, weld melting area is increased by using CMT-P compared to Conventional CMT and also found that appropriate heat input is required to reduce the porosity in weld bead. By using CMT ADV porosity is eliminated and finger shaped bead geometry is obtained due to reduction of melting depth. When CMT-P ADV is used spherical shape bead geometry is formed and porosity is completely eliminated.[29]

3.1.6 5083-H111 and 6082-T651 Aluminum alloys

Beytullah et al has observed the mechanical and microstructural properties of welded joint using cold metal transfer technique of 5083-H111 and 6082-T651 aluminum alloys. Both similar and dissimilar alloy fabrication with 6 mm plate thickness, both destructive and non-destructive test were examined. In destructive testing tensile, fatigue and bending test, in non-destructive testing scanning electron microscopy (SEM) & light optical microscopy (LOM) were examined. Joining has performed by both Pulsed CMT and MIG technology. 5083 similar weld showed best fatigue results than 6082 welds. In both similar and dissimilar samples, it is observed that CMT welded specimens has good tensile strength compared to MIG due to low heat generation quality of CMT and also no distortion in parent material[30].

Table 1 Summary of different dissimilar metals joining

Author	Material	Filler Material	Shielding Gas	Properties Evaluated	Key Findings
Koli et al. 2021a [31]	AA6061 (3.18 mm) and AA6082 (2 mm) aluminium alloys	ER4043 (Al–5%Si) wire	Argon gas (Ar) with 15L/min flow rate	Mechanical properties & Residual stresses	• Dissimilar aluminium sheets are joined by using CMT welding with better joint efficiency. • Joint efficiency is increased by 7-11% on removal of reinforcement. • In the fusion zone brittle IMC's (Mg_2Si) are formed which increases the brittleness in weld bead.
Xu et al. 2021 [27]	5083 aluminium alloy and SUS304 austenitic stainless-steel sheets (3 mm)	4043 aluminum alloy	Argon gas (Ar) with 15L/min flow rate	Tensile strength	• 2-4 μm thick IMC's were formed Fe_2Al_5 near the steel side, $Fe_3Al_2Si_4$ near the aluminium side. • Fracture occurred at the brazing side, tensile strength found 96 Mpa which is 35% of base metal aluminium. • Groove gap of 1 mm showed the good bead appearance.

Rajeshkumar et al. 2021 [32]	A5754-H111 & A5083-H111 aluminium alloys sheets (3mm)	ER4043 wire		Mechanical properties & tensile strength	• The ultimate tensile strength found 271 Mpa which is greater than base metal A5754. • Grains in equiaxed zone of A5754 were coarser that grains in equiaxed zone of A505083.
Wen et al. 2021 [33]	5052 aluminum alloy & Q235 low carbon steel plates (2mm)	ER5356 welding wire	Argon gas (Ar) with 15L/min flow rate	Tensile strength & microstructural properties	• Tensile strength of Ni coated joint was found 93.5 Mpa which is 12% greater than bare joint. Tensile strength of Ni/Zn double coated joint was found 112.6 Mpa which is 35% greater than bare joint. • IMC's layers were formed, Fe2Al5 near the steel side and Fe4Al13 near the aluminum side. • IMC's thickness of Ni/Zn double coated joint was reduced
Singh et al. 2020 [34]	Galvanized DP780 steel & AA5052 aluminium alloys with 1 mm thickness in lap joint configuration	Pure Al ER1100, ER4047 AlSi12, AlSi5 ER4043	Argon gas (AR)	Wire feed rate, mechanical & microstructural properties	• At higher WFR welding was less stable. • Addition of Si in filler wire increased the wettability compared to pure Al filler wire which showed less wettability. • IMC's layer got smoother also average thickness of IMC's were also reduced with addition of Si alloyed filler compared to pure Al filler, AlSi5 & AlSi12 IMC's were formed in case of Si based filler whereas in case of pure Al filler different IMC's were formed which made the bead brittle.
Rajput et al. 2019 [25]	AISI 316L austenitic stainless steel and AISI 409M ferritic stainless steel	AISI 308L 1.2 mm in diameter	Pure Argon gas (flow rate 23 L/min)	Microstructural, mechanical properties & tensile strength	• Welded joint of different notch angles and root angles were tested for tensile test & found that maximum strength 58.5 Mpa was observed with 2mm root gap & 60° notch angle which is max among all the configuration. • With 0 mm root gap & 45° notch angle hardness was found maximum. • Coarse grain was found in HAZ and fine grains was observed

					near the parent metal weld interface.
(Mercan et al. 2020 [35]	AA5754 & AA6013 aluminium plates	ER5356 filler wire 1.2 mm in diameter	Argon gas (Ar) with 12L/min flow rate	Microstructural properties & tensile strength, microhardness test	• Increase in welding speed leads to decrease in penetration. • Increase in welding speed, tensile strength dropped. • Hardness value of weld bead varied between 70.5 to 82 HV which is in between of hardness value of both parent metals.
Wang et al. 2020 [36]	Mg-AZ31B & Al-6061 with 3 mm thickness in lap joint configuration.	Inconel 625 wire of 1.2mm diameter	Argon gas (Ar) with 20L/min flow rate	Tensile & shear test	• In weld bead Mg substrate consist of 6 areas i.e. Mg2Al3 based area composed of Mg2Al3 matrix, Al3Ni phase, Al7Cr, Al13Cr2 phase, and Al–Fe-Ni phase. • Fracture was occurred near Mg substrate due to brittle Mg-Al IMC's. • It is found that dissimilar Mg-Al joining by using Ni based filler wire has higher tensile strength compared to Al based filler wire. • By using Ni based filler wire tensile strength increases but formation of Mg-Al based intermetallic compounds elimination was found essential.
Tang et al. 2020 [37]	Inconel 718 superalloy (Nickel) & SUS 316 (FE) with 3 mm thickness in butt joint configuration.	ERNiFeCr-2 filler wire	Argon gas (Ar) with 15L/min flow rate	Tensile strength & macroscopic properties	• Wettability & spreadability were found better when current was 160 A. • Tensile strength of joint was 424 Mpa which is 87% of SUS 316 & 67% of Inconel 718. Failure of joint was of ductile nature. • At high temperature (above 750°) segregation of Ni was observed & found maximum Ni near the SUS 316 side, deteriorates the mechanical properties.
Koli et al. 2021b [38]	AA6061 T-6 & AA6082 T-6 aluminiu	ER4043 filler wire	Argon gas (Ar) with 15L/min flow rate	Optimized welding parameters	• Most dominant parameter was welding speed. • When welding speed was 5 m/s & current value is 100 A the ultimate strength was 226 Mpa which is 90% of base

	m alloys				metal. • Shielding gas has negligible contribution in welding parameter.
Ramarao et al. 2021 [39]	alloy steel (SA387) & stainless steel (SS304)	ER308 filler wire of 0.8 mm diameter	Argon gas (Ar)	Optimized welding parameters	• It is found that optimum parameters were, current 160 A, voltage 22 V, bevel angle 75° by using Taguchi's L9 orthogonal arrays. • By using Anova analysis it is found that welding current was prominent parameter for good impact strength followed by bevel angle.
Rajeshkumar et al. 2020 [40]	AA6061 T-6 & AA6082 T-6 aluminium alloys with 3 mm thickness	ER4043 filler wire		Role of interfacial microstructural properties on mechanical properties	• Dendrites near the partially melted zone of AA6082 T-6 were found finer whereas dendrites near the partially melted zone of AA6061-T6 was found coarser. • Mechanical properties (UTS, YS, % elongation) was found higher at AA6082 than that of AA6061 due to finer dendrites at AA6082.
Rajeshkumar et al. 2021 [15]	A5754 and A5083 aluminium alloys with 3 mm thickness	ER5356 (Al - Mg) wire 1.2 mm in diameter	Argon gas (Ar) with 15L/min flow rate		• a-Al, Al3Mg2 and Al6Mn phases were found at weld metal zone confirmed by EDS. • Weld metal zone shows higher hardness compared to heat affected zone & partially molten zone. • A5083 interface showed higher hardness compared to A5754 interface.
Cao et al. 2014 [41]	Pure titanium TA2 & pure copper T2 of 3 mm thickness	ERCuNiAl copper wire of 1.2 mm diameter		Mechanical properties & microstructural properties	• On Cu side Welded joint was formed whereas on Ti side brazing joint was formed. • Non uniform IMC's layers were found in the joint, at brazing side Ti2Cu, TiCu, AlCu2Ti IMC's were found. • During tensile test, fracture occurred at Cu HAZ & maximum tensile load of 5.17 KN was observed.

5. Conclusion

Joining of dissimilar metals is very important now days due to demand of light weight components & higher strength. But the major challenge of joining dissimilar materials is formation of brittle intermetallic compounds (IMC's) at the joint interface during welding. In this paper joining of different metals are thoroughly reviewed.

- During dissimilar material joining strength depends on root gap, notch angle.
- The main problem is case of dissimilar metal joining is formation of IMC's which can be controlled by using different filler materials. Aluminium and galvanized steel is joined by using Si alloyed Al as filler wire IMC's were reduced compared to pure Al as filler wire.
- Mechanical properties are also improved by coating the base material with Ni. In case of aluminium and low carbon steel plates are coated with Ni tensile strength increased by 12% compared to bare material. IMC's thickness also reduced.
- Wettability increases with Si based filler wire; also the IMC's becomes smoother which increases the strength.
- Higher welding speed decreases penetration & tensile strength.

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