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Brief Review on Dissimilar Welding Using Cold Metal Transfer

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Abstract. Hybrid joint configuration nowadays has been an essential process for fabrication in both industrial and construction industry. However, the challenges in welding two varied materials need to consider both metal characteristics since the joint of the different metals from various properties cause the formation of intermetallic compounds (IMCs) layers can cause the failure. Various parameters (i.e; welding current, welding speed) and factors (i.e; materials' thickness and properties) need to be considered when joining two different metals using welding. Common methods use for joining two different metals are friction stir welding, laser welding, resistant spot welding and gas metal arc welding (GMAW). Cold metal transfer method (CMT) is new technique that recently applied for joining dissimilar metal weld especially for thin metals of 0.3~2.0 mm. Major advantage of CMT is using low power and green technology process. This review provides explanation of common field which applying dissimilar metal welding and discuss the previous related researches with example of different materials being used. This including factors that need to be concerned to produce good welding joint and the current research using cold metal transfer for hybrid joint configuration.

*Keywords:*Cold Metal Transfer (CMT); Dissimilar Metal Welding; Aluminium Alloy 6061; Hybrid Joint

1. Cold Metal Transfer: Technique in Joining Different Material

Cold Metal Transfer (CMT) is a technique introduced when the need of joining dissimilar metals welding arises recently especially in nuclear plants[1], automotive[2], [3], followed by aerospace[4], [5] and aviation industry. This welding technique use low power input [6] and spatter free[7], [8], therefore eliminate secondary process or post-processing. The reduction in thermal heat input provides better advantages such as low distortion and

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higher precision[9]. Higher quality and precision refer to the uniformity and reproducibility of the CMT which then results in few rejects. The advantage of CMT process is it capability to weld aluminium and other materials such as steels due to its properties of no-spatter and low heat input during the welding process[10][11]. Besides, its advantage on joining thin materials can be utilized in automotive and manufacturing industry in order to improve fuel consumption by reducing the weight of the car body. Hence, it reduced the gas emissions. This method can be applied to join the frame rails, rail reinforcement, side rails, pillars and seat frames in automotive manufacturing industry.

2. Cold Metal Transfer Process Principle

Cold Metal Transfer (CMT) adopt high short-circuiting current flows when the electrode wire tip contacts and immerse in the molten pool. This mark the onset of sudden melting such that droplet transfer occurs by surface tension of pool of molten metal. The arc continues to re-initiate as the droplet transfer is completed to continue the hot process. While the electrode tip in contact with the molten pool, the wire retracts and promotes the droplets cutting with the current decreases approaching zero. The final process involving the transfer phase where the current plummeting to near-zero reading with any generation of spatter.

Arching: Wire move towards molten pool

As wire dips into molten pool, arc is extinguished. The welding current is reducing

Wire withdrawal assist detachment of droplets cutting during short-circuit period. The current is remains small approaching zero.

Wire motion is fed toward workpiece and the process repeated.

Figure 1. Details on wire motion on CMT [12]

3. Base Metals

Mg alloys are the best and lightest metal which are applied in automotive, electron and aerospace industry[13]. This is due to their low density, high strength-to-weight ratio, good castability and eased for recycling[3]. Therefore, Jing Shang *et. al*, conducted research in welding of AZ31B Mg alloy and 6061 Al alloy with 3 mm thickness were welded using butt-joint configuration[13]. R. Cao *et. al* applied CMT technique to join 1mm Mg AZ31B and 1 mm thick Al A6061-T6 sheets. Lap-shear joint configuration was applied.

Introducing the use of aluminium in automotive manufacturing is one of the keys enabling technologies for vehicle weight reduction. Hence, deeper research in welding

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using aluminium is crucial in order to determine the advantages and disadvantages of its properties. Chen Zhang *et. al* carried out experiment using CMT by joining two plates of AA6061-T6 aluminium alloy with 2 mm thickness[14]. In contrast, Minjung Kang *et. al* adopted dissimilar metal welding by joining 1 mm Al 6K32 alloy sheets to aluminized and galvanized mild steel[15]. L. Bereteu*et. al* conducted vibration test at 1.3 mm Ni-Cr stainless steel welded joint to determine the elasticity modulus of the weldment[16]. Shanglu Yang *et. al* used CMT to join 2 mm aluminium alloy 6061-T6 with 1.2 mm thick zinc coated low-carbon steel[17] while HaiYang Lei *et. al* adopted 1 mm AA 6061-T6 with lap joint configuration[18]. HaiYang Lei *et. al* also reported a research on CMT Spot Joints of AA6061-T6 To Galvanized DP590 with thickness of 1 mm and 1.2 mm respectively[19]. In 2018, ChaojieXie*et. al* studied the microstructure and mechanical properties on the weldment of two Al5.5Zn2.5Mg2.2Cu aluminium alloy plates that had been aged artificially (T6). Their thickness is 3mm and the metals were weld together in butt joint configuration[20].

4. Filler Materials

Table 1 summarises, base material and filler wire used by previous researchers has similar properties where they use filler wire that is 1.2 mm diameter except Sravanthi who uses 1.3 mm diameter filler wire.

Table 1. Filler wire of CMT

Authors	Base metals	Filler wire
Gang Mou*et. al*[1]	TC4 titanium alloy (2mm) 304 L austenite stainless steel plates (2mm)	Cu based wire (1.2mm): Cu, CuNi10, CuNi30
Paola Luchtenberg*et al*[21]	Duplex stainless steel (DSS) Gr 60 plate. (12mm)	ER2209 (1.2mm)
Zhenglong Lei *et. al*[22]	S355J2W+N steel plates (6mm)	NiCu 1-IG (1.2mm)
Chen Zhang *et. al*[23]	AA1060-H112 Al plate (12mm)	Al-6Mg alloy filler wire (1.2 mm)
Jaivindra Singh *et. al*[24]	Galvanized dual phase (DP780) steel (1.2mm)	CuAl10Fe filler (1.2mm)
Jin Yang *et. al*[25]	AA5754 aluminum alloy (2 mm) Q235 low carbon steel sheets (1.8mm)	An Al-Si based alloy (ER4043) (1.2 mm)
Liu *et. al*[26]	AZ31B Mg plate and 6061-T6 Al plate (2mm)	ER4043 with 1.2 mm diameter
S.S. Sravanthi*et. al*[28]	5052 Al alloy (3 mm) Galvanized mild steel(3mm)	Aluminium alloy BA4043 Al (Al-5% Si) (1.3mm)
Jing Shang *et. al*	AZ31B Mg alloy (3mm) 6061 Al alloy were (3mm)	Pure copper (HS201) (1.2mm)

A research conducted by Agudo and his team members in 2008 described the characteristics of dissimilar joint of Al and Steels produced by Cold Metal Transfer[29]. They use 1mm thick DX54D+Z200 steel sheets and 1.5mm thick AW5182-H111 sheet. Three years later, R. Ahmad and M. A. Bakar came out with the results of their research which studied the effect of post-weld heat treatment on the mechanical and microstructure properties of 10mm AA6061 that was welded by GMAW-CMT method[11]. The samples were divided into as welded and PWHT samples. The PWHTs used on the samples are solution heat treatment, water quenching and artificial aging. On 2012, Jing Shang et al. also investigate the microstructure characteristics and mechanical properties of CMT welding joint but on different materials which are magnesium and aluminium with pure

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copper (HS201) as filler wire[13]. In 2013, Shanglu Yang *et. al* conducted a research on welding using cold metal transfer method where they joining two different materials; aluminium alloy to low-carbon steel[17]. Their research highlighted the effects of pre-setting gap at the interface of aluminium alloy sheet and steel sheet. Besides, the research discussed the effects of offset distance of the electrode torch from the aluminium alloy sheet edge on the weld qualities.

In the same year, R. Cao *et. al* conducted another research which investigate the microstructures and properties of lap joint welding of 1 mm titanium-copper which were joint using the same method; Cold Metal Transfer (CMT). They use ERCuNiAl copper wire as filler wire. Their research revealed the microstructure and tensile shear strength of the affected mechanism of lapped location between two metals of lapped location. They used two different joint design to weld both metals. Cu-T2 sheet was placed on the top of the Ti-TA2 and was marked as the first joint design while second design with Ti-TA2 sheet was placed on top of the Cu-T2 sheet.

In 2014, Roata*et. al* execute a research on welding of aluminium 5456 thin sheets using CMT where the thickness of the material is 0.7 mm. Their aim includes finding the optimal welding parameter to weld aluminium thin sheets. They applied AlMg5 as filler wire and use synergic regime of welding with low linear energy were used[31]. The weld joint was characterized by microscopic analysis and, mechanical tests which involving tensile test and microhardness test. The results obtained highlighted the parameters that give major influenced over the weld bead geometry and tensile behaviour of the joint.

In 2015, Zhang et al. published a paper in which he investigate the feasibility of the Cold Metal Transfer process for cladding of AZ31 magnesium alloy to obtain fundamental understanding into the effect of welding speed in clad geometrical, microstructure characteristics [32]. A 3 mm magnesium alloys were used, and the joining process was observed using a high-speed camera to determine the arc characteristics. The analysis on the weld joint was studied using optical microscope, scanning electron microscope and energy dispersive spectrometer to determine the microstructure characteristics.

Proceed to 2016, further research on cold metal transfer method in joining dissimilar material is continued by Peng Wang and colleagues. Materials with 2 mm Mg alloy AZ31B and Al alloy 6061 was joined using variable polarity cold metal transfer process with ER4043 as filler metal. In their study, they investigated the effects of the ratio of electrode positive/negative CMT cycles on the microstructures-strength relationships of welded joints. The results showed that hard brittle Mg-Al intermetallic compounds (IMCs) layers were formed in the weld interfaces and it consists of three intermediate layers which are Mg_2Al_3 layer, $Mg_{17}Al_{12}$ layer and $Mg_{17}Al_{12}$ + α-Mg solid solution eutectic layer (very thin)[33].

Dissimilar joining of aluminum to steel possess a challenge for arc welding. In a study conducted by Lin. Z et. al, aluminum AA6061-T6 and hot dipped galvanized DP590 steel with thickness of 1.2 mm were joined using the Fronius cold metal transfer (CMT) welding process applying an edge plug welding mode (EPW). The correlation of the welding parameters, weld characteristics, and weld strength was systematically investigated. It was found that the EPW mode created a zinc rich zone at the weld root along the Al-steel faying interface which transitioned to a continuous and compact intermetallic compounds (IMC) layer in the middle portion of the joint. The fracture propagation in lap-shear specimens was affected by this increase of IMC layer thickness[19].

Another research published by Peng Wang *et. al* in 2017 highlighted the results of the research investigated that were concerned on the effects of characteristic parameters on the energy input characteristic, metal transfer behaviour, weld geometry and microstructure deposited weld metal. However, the stable CMT process is difficult to achieve due to some limitations. They claimed that three distinct energy input periods of CMT cycle were controlled by characteristics parameters so that stable CMT process is achieved and indirectly affected the deposited weld metals features [34].

In 2018, ChaojieXie*et. al* investigate Al5.5Zn2.5Mg2.2Cu aluminium alloys that was butt welded using the robot cold metal transfer method. Based on experiments, optimal welding parameters were defined to ensure penetration of low heat input[20]. They studied the morphology and evolution of the microstructure, mechanical properties and fracture behaviour.

5. Conclusion

Previous studies on dissimilar metal welding using CMT has been discussed. The main conclusion from this study is that, CMT can join magnesium alloy with aluminium alloy and aluminium alloy with steel successfully with minimum thickness of 0.7 mm ever welded. This method is also able to join thin different materials successfully. The most common welding configuration applied is butt-joint and lap-joint with the filler wire range between 1.2mm-1.3mm.

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