# On The Analysis of Joints Welded by Cold Metal Transfer Welding–A Review

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***Abstract-*** **Cold Metal Transfer Welding is a unique approach to the welding process, which transformed the way we look at welding. As it is a spatter free, stable and low heat input. Also it offers High welding speed. Due to low heat input the intermetallic layer is reduced and the Heat Affected zone is reduced. As a result we get high tensile strength and good percentage elongation. Fine grains are observed in this process. When fine grains are observed we get High Hardness. Porosity is minimum in this process. Slag formation and Fumes is reduced in this process. Rapid Cooling is observed and Solidification is much faster. CMT welded joints performed well in terms of Tensile Strength, Hardness and microstructure after solution Treatment and Age Treatment. When EMF was applied we get improved Tensile Strength. CMT has found applications in Rapid Prototyping, 3D Printing, Hard facing, Overlay, Cladding and also in Turbines, Restoration of Casting Die and Building of stacks in Electric Vehicles. Overall it is a wholly digitized process.**

## I. INTRODUCTION

CMT is a welding process in which the filler wire is incorporated into the machine which was introduced by Fronius in 2004. Comez and Durmus studied Micro structural and Mechanical properties of Aluminium Alloy under different heat input [1]. Cao et al joined aluminium alloys and Mild steel by CMT process. They studied the Taguchi method using orthogonal experiment which optimizes the welding variables. They found out that wire feed rate was the most influential variable in the welding process [3]. Kumar et al investigated the macrostructure and micro structural aspects of AA6061. He also studied the Techno- economical evaluation of AA6061 [6]. Balamurugan et al performed Welding of Similar welding of AA6082 – T4 alloys were performed by Cold Metal Transfer welding [7]. Silvayeh et al studied the effect of filler composition and process variables on Inter metallic layer of Aluminium steel joint [8]. Comez and Durmus performed dissimilar welding of AA6061 and AA7075 metals [10]. Ahsan et al studied porosity formation mechanism in Zinc coated steels [11]. Irizalp et al investigated the micro structural and mechanical properties of AA1050 [12]. Chen et al studied the importance of Boost duration and Boost current on average droplet size, Wire feed rate and wire deposition rate [13]. Li et al performed welding of Titanium alloy to stainless steel by Cold metal transfer process [14]. Gupta and Yuvaraj performed similar welding of S.S 202 by Cold Metal Transfer process [15]. Singh et al studied the welding of Aluminium alloy and Dual phase steel dissimilar joints by cold metal transfer process [16]. Samantha et al studied the effect of welding speed on corrosion behaviour and mechanical properties of Aluminium and steel dissimilar joint [17]. Du et al performed welding of spot welding Al6061 and DP590 by cold metal transfer process. [18]. Yang et al performed welding of dissimilar welding of Aluminium alloy and Zinc Coated Steel [19]. Feng et al performed dissimilar welding of Aluminium and Copper by Cold Metal Transfer welding [20]. Niu et al performed the welding of Aluminium alloy and Galvanized steel by Cold Metal Transfer process [21].
Different case studies are done to offer some vision in the mechanical and micro structural properties of different joints made from CMT process. These case studies have thrown light on the feasibility of CMT welding in welding similar metals and dissimilar metals which proved the mettle of CMT when compared to other welding process.

## II. OVERVIEW OF THE PROCESS

(1). **The Peak Current phase:** Initially high degree of current is applied with constant voltage. This high degree of current starts the welding arc which heats and ignites the wire electrode.
(2). **Background Current phase:** During this phase the current is lowered and little molten globule is being built up on the wire tip. So to transfer the molten globule the current is lowered and the molten globule remains until the short circuit is sensed.
(3). **Short Circuit Phase:** During this phase the short circuit is sensed and a result the molten globule which was at the tip of the filler wire is transferred to the work-piece. In this way the short-circuit transfer takes place with absence of Current

## III. DIFFERENT CASE STUDIES

[1]. Comez and Durmus studied the dissimilar welding of AA5754 and AA7075. Three Different heat input was applied in welding. It was observed that small pores are formed at low heat input and large pores at high heat input in the Weld zone and Partially Melted Zone. Increasing the heat input caused the grain coarsening at HAZ of AA5754 Base metal. Also grain coarsening in the Partially Melted Zone of AA7075 Base metal took place due to increase in heat input. HAZ of AA5754 is narrower than AA7075. Due to this Hardness of Heat Affected Zone of AA7075 is greater than that of AA5754. Tensile strength decreases with increase in Heat input. Fracture occurred in HAZ of AA5754. Corrosion rate decreases with increase in heat input.

Maximum corrosion was observed in low heat input [1].

[2]. Durmus and Comez studied welding of AA5754 and Galvanized steel by Cold Metal Transfer method. Two samples were studied with different heat input. Grain coarsening took place in Heat Affected Zone of AA5754 due to increase in heat input. A thin dark inter metallic layer is formed between AA5754 and Galvanized steel boundary which is mainly Al-Fe phase. More material loss was observed in sample where high heat input is higher. After welding residual stresses are formed which resulted in corrosion stress cracking, which in turn reduces the strength of the joint. MgZn2 precipitates has influenced the corrosion rate. The change in size and distribution of MgZn2 worsens the corrosion resistance and increase the material loss in the Samples. At last it was observed tensile strength was higher in sample where the inter metallic layer thickness is less [2].

[3]. Cao et al studied the welding of Aluminium alloy to Galvanized Steel. A design of experiment was performed to optimize the welding variable by Orthogonal Array method. 27 welding test were performed to study the contribution of welding variable in the welding process. Welding variable that were studied were Wire feed rate. Welding Speed, Type of the wire used, Deviation Distance, Coating Thickness etc. It was observed that type of wire used was the most influential variable in the welding variable with a contribution of 48.92 %, Followed by Wire Feed Rate with a contribution of 19.35 %. The type of wire used was more used in the welding process because of its chemical composition, followed by Wire Feed Rate. It was also observed that by decreasing the heat input the Heat Affected Zone becomes narrower as a result the joint strength is increased. The heat input is inversely proportional to intermetallic layer thickness. At last it was observed that when intermetallic layer thickness is reduced we get improved joint strength [3].

[4]. Comez and Durmus studied welding of AA5754 to Galvanized Steel by Cold Metal Transfer Welding. Two different heat input was applied and difference was observed. The grains of Aluminium Base metal became coarser, while grains of Galvanized steel did not change. The HAZ of both base metal were restrained due to low heat input, but was observed at high heat input. Intermetallic layer thickness was thinner at low heat input and thicker at high heat input. The intermetallic layer consisted of Al/Fe phase. Due to high heat input, intermetallic layer is thicker and as a result superior hardness and high tensile strength was observed at intermetallic layer. Fracture occurred at intermetallic layer due to pore formation [4].

[5]. Durmus and Comez studied similar welding of AA5754 by Cold Metal Transfer. Four different heat input was applied and difference was noted. Small pores were observed at low heat input in the weld root, but did not come at the top surface, but relatively large pores were observed at high heat input at the surface of the weld. In the weld joint with higher heat input, Solidification is completed for a longer time and as a result the pores at the weld root had the time to come onto the surface, whereas in the weld joint with lower heat input the pores at the weld root had no time to rise to the surface. Grain coarsening took place in the HAZ of base metal of AA5754 due to high heat input. Tensile strength was higher at low heat input and lower at high heat input. Fracture occurred at AA5754 Base metal where fine dimples were observed. At last it was noted that increasing heat input decreased the bending strength of the samples [5].

[6]. Kumar et al performed similar welding of AA6061 by Cold Metal Transfer Welding. It was observed that with increase in heat input, there is decrease in welding speed. We got remarkable depth of penetration and good weld width at low welding speed and high welding speed. The reinforcement height decreases with increase in Welding Current. As the feed rate increases the rate of cooling decreases. Porosity density is low at High welding speed and Low heat input [6].

[7]. Balamurugan et al performed Welding of Similar welding of AA6082 – T4 alloys were performed by Cold Metal Transfer welding. Three different heat input was given and difference was observed. It was observed that maximum tensile strength was obtained at high welding speed and low heat input. Maximum Percentage Elongation was obtained at high welding speed and low heat input. Lowest percentage elongation was obtained at high heat input and low welding speed. It was further noted that lowest hardness was obtained at High welding speed and low heat input. Maximum Hardness was obtained at low welding speed and high heat input. The reason is attributed to increase in heat input that enhanced the formation of martensite in the Heat Affected Zone and increase the hardness of HAZ. Fracture occurred at the Weld Zone [7].

[8]. Silvayeh et al Studied welding of Aluminium alloy and Galvanized steel by Cold Metal Transfer Welding Process. Six fillers were used with different contents. Torches used were CMT Braze+ and Robacto500. It was observed that by increasing heat input causes Intermetallic Layer thickness increases. It was also found that thinner IMCs were formed where the silicon content was highest in the filler material. The reason is because the width of IMCs is influenced or inhibited by silicon element. At the end they found that the distance between torch and the workpiece has negligible chances of influence of IMCs Width. And CMT Braze +torch is more better than Robacta500 torch. The thickness of IMCs was thicker as well as long needle-shaped particles were formed with Robacto500 torch when compared with CMT Braze+ torch [8].

[9]. Comez and Durmus studied the similar welding of AA6061 by Cold Metal Transfer process. Three different heat input was applied and difference was

noted. It was observed that when welding speed was increased size of weld decreased. Pores were observed at intermediate heat input. Grain coarsening occurred at the Heat Affected Zone due to high heat input. Fine grains were observed at low heat input in Heat Affected Zone. Fine grains resulted in improved tensile strength and coarse grains resulted in decreased tensile strength. Heat affected zone become narrower at high welding speed and low heat input. Tensile strength decreases with increase in heat input. Maximum Joint efficiency was observed at low heat input. At last it was observed that maximum Corrosion rate occurred at the low heat input and lowest corrosion occurred at maximum heat input [9].

[10]. Comez and Durmus performed dissimilar welding of AA6061 and AA7075 by Cold Metal Transfer Welding. Three different heat input was applied and difference was noted. Minimum pores formation was observed at low heat input and maximum pores formation was observed at high heat input. By increasing heat input grain coarsening took place in the Heat Affected zone of the weld metal. Fine grains were observed at lower heat input. It was well noted that higher heat input not only increased the amount of porosity but the size of the pores. In the present study by increasing heat input elongated dendritic grains were formed and it also expanded the partially melted zone. While at the low heat input fine grains were observed at the partially melted zone. Intermetallic layer thickness which consisted of Al-Fe phase were detected. Maximum hardness was obtained at low heat input in the HAZ because of fine grains structure. Minimum hardness was obtained at high heat input in the HAZ because grain coarsening took place. By increasing heat input the tensile strength was deteriorated. Fracture occurred at the AA6061 base metal. At last it was observed that by increasing the Welding Heat corrosion rate increased. Pitting corrosion was observed at low heat input. Pitting and intergranular corrosion took place at high heat input [10].

[11]. Ahsan et al performed similar welding of steel plates by Cold Metal Transfer process. They found that slag formation depends on the element contents of the wire. Three different wire with different chemical composition were used and difference was noted. It was observed that the amount of silicon and manganese present in the wire were responsible for the amount of the slag. The highest amount of slag was formed in the weld when the silicon and manganese was highest in the filler wire. The bead cross-section had largest leg length and lowest bead reinforcement when silicon and manganese content was highest. But when silicon and manganese content was lowest lowest leg length and maximum bead reinforcement was reported [11].

[12]. Irizalp et al performed welding of AA1050 by cold metal transfer welding. It was observed that at fast cooling rate the porosity is low because the nucleation and growth of bubbles is severely suppressed. Also at slow cooling rate the porosity is low, because bubbles present in the liquid had time to escape. But at intermediate cooling rate the volume of porosity is high because the bubbles present in the weld pool neither be suppressed nor they had time to escape. Due to low heat input, fast cooling was observed as a result fine grains were observed. Maximum tensile strength occurred at the low heat input. Maximum hardness occurred at the HAZ due to low heat input. Failure occurred in the HAZ of the Aluminium Base Metal [12].

[13]. Chen et al studied the welding of Q-235 mild steel in bead on plate configuration. Boost current (Ib) and Boost period (tb) are the two main parameters which are more influential in the whole process. Boost period (tb) was most influential effect on the stability of CMT process, but when it comes to Boost current it had little effect on Process stability. The transfer frequency of CMT remains unaffected by Boost period and Boost Current. They also found that welding power increased when boost current and boost period increased. After that they found out that wire melting rate increased which in turn increased the deposition rate with increasing boost current and boost duration. The Boost current and boost period has greatest effects on weld dimensions. At last it was found that by increasing Boost current (Ib) or Boost period (tb), the depth of penetration and weld width increases, But reinforcement height varied little [13].

[14]. Li et al performed welding of Titanium alloy to stainless steel by Cold metal transfer process. Four Different Heat input was given and difference was noted. Spherical particles like precipitates were observed in the fusion zone. These particles became coarser and irregular with increase in heat input. These particle mainly contain Fe and Cu particles. The Ti-Cu IMCs were formed at the interface at high input. The micro-hardness increased at the Ti-Cu interface due to high heat input because of formation of IMCs. The shear strength of the joint decreases with increase in heat input. It was observed that with increase in heat input, the wetting angle decreases. Fracture occurred at the Ti-Cu IMCs at low heat input and at Fusion Zone at high heat input [14].

[15]. Gupta and Yuvaraj performed similar welding of S.S 202 by Cold Metal Transfer process. Three different heat input were given and difference were noted. Process optimization was done through quadratic regression by Taguchi Method. Signal to noise ratio is a numerical measure to measure the percentage elongation, Ultimate Strength, Yield Stress. Larger the signal to noise ratio better the Percentage elongation, Ultimate Strength, Yield Stress. Ultimate Tensile strength was maximum at 120 A and Welding Speed of 3mm/sec. Yield Stress was maximum at 100 A and Welding Speed of 4mm/sec. Percentage

elongation was maximum at 100 A and Welding Speed of 4mm/sec [15].

[16]. Singh et al performed dissimilar welding of AA5052 and DP780 by cold metal transfer process. They studied the effect of ratio of Wire Feed Rate to Welding Speed on Arc Stability and its characteristics. Three different filler wire used i,e Pure Al, AlSi5, AlSi12. Bead profile varied with different wire feed rate and welding speed. Maximum bead width was observed at Highest Wire Feed Rate to welding speed ratio. Lowest bead width was observed at lowest wire feed to welding speed ratio. Si content in the filler wire influenced the porosity in the fusion zone. Formation of pores can be attributed due to porous oxides present on the surface of the base metal. Intermetallic layer present were FeAl3 and Fe2Al5. Si Content in the filler wire suppressed the formation of intermetallic layer. Stability was observed at low wire feed rate to welding speed. Joint welded with Pure Al filler wire showed less failure load due to thicker intermetallic layer. Maximum failure load was observed at joint welded with AlSi12 filler wire. Micro-hardness was minimum at the HAZ of the base metal due to HAZ softening. Si content decided the microhardness of the joint. More the Si content more the micro-hardness of the joint. Fracture occurred at the Interface. Fracture occurred due to brittle intermetallic layer [16].

[17]. Sravanthi et al studied the influence of welding speed on mechanical behavior and corrosion resistance of dissimilar joint of 19000 Al Alloy and Galvanized steel by Cold Metal Transfer Welding. Two samples were welded with different welding speed and welding heat input and difference was noted. Later the samples were exposed to NAOH solution and Nitric Acid and weight loss was recorded. Two weld interface were observed. Al-Si-Fe phase IMCs were observed at both the interface. Al5FeSi, Al3FeSi2 were formed. Welding bead- steel and Al-Welding bead interface. Inter-granular corrosion was observed at Welding bead-steel interface. Excessive pitting was observed at the Al–Welding bead interface. After that they conducted the weight loss evaluation. It was found that sample with lower weld speed and high heat input was having highest weight loss and sample with higher weld speed and low heat input has lowest weight loss, which indicates that the sample with high heat input was prone to corrosion. Similarly the sample with high heat input has IMCs width increased and Ultimate Tensile Strength decreased and sample with low heat input has IMCs width decreased and Ultimate Tensile Strength Increased [17].

[18]. Du et al performed welding of spot welding Al6061 and DP590 by cold metal transfer process. Process optimization was done by orthogonal test by Taguchi Method. Optimum parameters were Wire feed rate, Arc length correction, Welding speed. Orthogonal test showed that Wire feed rate was most influential during the welding process, followed by Arc length correction and then the welding speed. When welding was performed at this optimum parameters it was observed that the droplet was uniformly distributed and uniformly covered and Tensile strength was optimum. When heat input increase the nugget becomes larger and the droplet spreads more evenly. When wire feed rate increases the height of the plug decreases slowly and diameter of the plug increases. Intermetallic layer thickness decreases with increase of wire feed rate and Joint strength decreases [18].

[19]. Yang et al performed welding of dissimilar welding of Aluminium alloy and Zinc Coated Steel. The effect of Pre-setting gap and Offset distance on welding process was discussed. Four different pre-setting gap and three different offset distance was used. It was observed that the wetting angle decreased and bonded line length increased when Pre-setting Gap was increased. The tensile strength increased when the Pre-setting gap increased due to improved wetting behavior and reduced lack of Fusion. When Offset distance was increased, the wetting angle increased and bonded line length decreased. As the offset distance was increased the deposition time slightly decreased and thus the spreading of molten metal decreased as a result bonded line length decreased. Two types of failure occurred. First failure occurred in the Heat affected zone of the base metal. Due to heat the softening of HAZ the failure took place in that region. Second failure occurred at the interface of the Aluminium alloy and Zinc Coated steel. The pre-setting gap also influenced the intermetallic layer [19].

[20]. Feng et al performed dissimilar welding of Aluminium and Copper by Cold Metal Transfer welding. 6 different heat input was applied. The effect of heat input on the microstructure and mechanical properties of the joint. With increase in heat input the Cu at the weld-Cu interface melts more and the Al-Cu intermetallic layer becomes thicker and brittle. As a result the mechanical properties becomes weaker with increase in heat input. The weld zone consists of equi-axed α-Al and Al-Cu phase. The IMCs mainly consists of Al2Cu. With increasing heat input the tensile strength decreases because the intermetallic layer became thicker. Two types of fracture was observed. First type of fracture was at the Heat Affected zone and Second type of fracture was at the Weld/Cu interface [20].

[21]. Niu et al performed the welding of Aluminium alloy and Galvanized steel by Cold Metal Transfer process. Galvanized steel was zinc coated. Seven different current were applied and the difference was noted. Two different filler were used i,e ER4043 and ER4047 comparision were made between these two. It was observed that without the zinc coating and with the current increased, the wetting angle reaches maximum due to which the bonded line length was minimum and tensile strength decreased. When zinc coating was applied, wetting angle decreased when current was

increased. And bonded line length also increased with increasing welding current. This phenomenon occurred because the fluidity of the wire increased with the current increased. The wetting angle when used with ER4043 was less than when used with ER4047 under same current. Bonded line length using ER4043 was less than ER4047. As a result the wet ability when used with ER4047 was less than ER4047. Al-Fe-Si phase IMCs were formed near the interface of the joint. No matter using ER4043 or ER4047 the tensile strength decreased with increased welding current. Fracture occurred near the interface of the joint [21].

[22]. A typical CMT cycle was studied by Pickin and Young. There are two phases of CMT Cycle i,e First is Arching Phase and second is Short Circuit Phase. Arching Phase starts with a High pulse of current in which molten globule starts detaching but remains sticked. Short Circuit Phase is initiated with reduction in Welding Current and molten globule is detached. Pickin and Young found out that the duration of Arching Phase and Short Circuit phase plays the major role in CMT process. Degree of penetration is in linear relationship with the current. By controlling the short circuit duration under given heat input, wire feed rate can be controlled which in turns controls the depth of penetration. When short circuit duration is increased degree of penetration is decreased. It is a low thermal Input Process [22].

[23]. Li et al studied the dissimilar welding of Ti alloy and stainless steel by Cold metal transfer welding. When it involves the microstructure the Ti-Cu interface line is uniform, regular and straight. The weld width was increased and wetting angle decreased with increasing heat input. So heat input had impacted weld shape. Many fine spherical particles are observed under low heat input. With an rise in welding current the particles becomes coarser and irregular. The spherical particles mainly are Fe and Cu. The Ti-Cu IMCs are also observed under large heavy input. These are CuTi2, Cu2Ti3 and Cu4Ti3. Micro hardness at Ti-Cu interface was maximum at high heat input. The micro-hardness at IMCs layer near Ti-Cu interface increases at the IMC layer. The lowest tensile strength of joint was noted at highest heat input. The fracture occurs at the Ti-Cu interface under low heat. The IMCs are responsible for the fracture along the Ti-Cu interface [23]

## IV. SOLUTION TREATMENT AND ARTIFICIAL AGE TREATMENT

In solution treatment, the sample was heated to 530°C for 45 Min in a furnace, followed by water quenching. In artificial age treatment, the sample was again heated for 175°C for 8 hours in the Furnace. The difference between micro structural and mechanical properties of Solution treatment and Artificial Age treatment were noted. The average grain size of 7.12 µm and 5.34 µm was observed in the Heat Affected Zone (HAZ) of Solution treatment and artificial age treatment samples respectively. The average grain size of Solution treatment samples was larger than the Age treatment samples. There is a 67% increase in the hardness of HAZ of Artificial age treatment samples than the solution treatment samples. The reason for decrease of hardness for Solution treatment samples was because grains became coarser during high temperature. The tensile strength, yield strength and Percentage elongation decreased in both Solution treatment samples and artificial age treatment samples due to high temperature. But the tensile strength and yield strength of artificial aged samples were more than solution treatment samples. The reason for this is due to refined and fine grains of artificial aged treatment samples [23].

## V. RECENT TRENDS AND APPLICATION

(1). Repairing of MIG Welded joints by Cold Metal Transfer Process
Cold Metal Transfer process was used to repair MIG Welded joints and difference was noted. The repaired heat affected zone exhibited fine grain structure when compared to the Heat affected zone of MIG. The width of repaired heat affected zone is narrower than Heat affected zone due to low heat input of Cold metal transfer process. Due to which hardness of Repaired heat affected zone is better than Heat affected zone. Due to which the crack propagation resistance also improved in case of repaired welded joints by cold metal transfer process. The Heat affected zone showed tearing edges and few small dimples. But the repaired heat affected zone has larger and numerous dimples, which were deeper. Due to this the repaired heat affected zone has improved fracture toughness than heat affected zone. Overall the repaired joint by Cold Metal Transfer process fared well than the MIG welding [24].

(2). Hard-facing, Cladding, Overlay by Cold Metal Transfer Process

(3). Joining Stacks of electrical steel sheets by Cold Metal Transfer Process

(4). Rapid Prototyping by Cold Metal Transfer Process

(5). Wire Arc Additive Manufacturing by Cold Metal Transfer Process

(6). Repairing Fuel Nozzle of Gas turbine Engine Combustors by Cold Metal Transfer Process

## VI. APPLICATION OF EXTERNAL MAGNETIC FIELD ON COLD METAL TRANSFER WELD

EMF was applied through two annular coils which connected work piece and Welding Torch. It was observed that External magnetic field has effect on microstructure of joint welded by Cold Metal Transfer which in turn influenced the Tensile Strength of the joint. When EMF was applied the weld surface seems Wave like structures. It was also observed that IMC layer was reduced to 1µm when EMF was applied, which in turn increased the Tensile Strength of the joint [28].

## VII. CONCLUSIONS

1. Being a low heat input process, less spatter and less emissions was observed
2. Inter metallic layer thickness was less than the conventional welding process
3. Due to low heat input, Fine grains were observed as a result higher tensile strength was noted
4. Due to narrower HAZ, micro-hardness was improved. This result attributed to low heat input
5. Porosity density and Corrosion rate was lowest in CMT process
6. Solution Treatment and Age treatment improved the mechanical properties of the joint
7. CMT has thrown light upon several applications like repairing of the weld joint, Overlay, Hard-facing, Cladding

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