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Review on Heat and Mass Transfer in Submerged Arc Welding (SAW) and Gas Metal Arc Welding (GMAW)

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Abstract: The quality of welded joint is depends on metallurgy of weld bead, Weld metallurgy depends upon the rate of heat and metal transfer to the joint. Many authors reported that quality of weld can be enhanced by optimize the factors i.e. current, electromagnetic force, surface tension. In order to control the size of droplet, rate of detachment and mode of metal transfer plays a vital role. Out of various mode of metal transfer, cold metal transfer has a extensive and promising performance in the application of ferrous to non-ferrous joining. Submerged arc welding (SAW) and Gas metal arc welding (GMAW) is more popular due to its inherent advantage such as faster metal deposition, deeper penetration, good surface emergence and high strength in the application of steel structural building, turbines, pressure vessels and for the joining of thick plates. In the present studies, work carried out by many authors on heat transfer and mass transfer for similar and dissimilar metal joining applications have been reviewed under various aspects. ***Keywords: Mass transfer; Mode of metal transfer; CMT; HAZ; IMC***

I. INTRODUCTION

The liquid metal exchange from electrode to workpiece is a standout amongst the most trademark wonder of arc welding in light of the fact that the conduct of liquid pool legitimately influence the weld quality in this manner it is basic to investigate the metal move conduct in arc welding. The American Welding Society (AWS) has additionally arranged the method of metal move into three noteworthy sorts, for example impede, globular exchange and splash exchange [1]. The metal is exchanged when the electrode is in contact with the weld pool in the short circuiting exchange, and no metal is exchanged over the arc gap. The method of globular exchange is portrayed by droplets with breadths more prominent than the wire of the electrode, and the metal is exchanged over the arc gap. The metal is likewise exchanged through the arc gap in splash exchange, however the droplet is littler or a lot littler than the electrode wire distance across. Shower exchange mode driving over a globular exchange by its nonstop separation, directional droplet exchange and low scatter [2]. Anyway shower exchange mode accomplished just at high current, which causes a very high warm burden and make it unacceptable for warmth touchy material. The International Institute of Welding (IIW) further characterizes the spray move into the projected spray or drop spray, gushing spray and pivoting spray [3]. In the event that the fluid metal pending at the electrode wire is short (not essentially more prominent than the diameter of the electrode wire) at that point the exchange is the anticipated spray. On the off chance that the fluid metal pending is moderately long, at that point it will be the gushing spray or the turning spray if the fluid metal pivots. Distinctive methods of metal exchange are created by various dimensions of currents. At the point when the current is little, the bead may not be segregated until the bead contacts the weld pool. For this situation, the exchange mode is short circuiting. On the off chance that the present increments, however not sufficiently vast to produce an adequately huge electromagnetic power [4] to disconnect the framed bead, at that point the drop may outperform the width of the terminal wire and be confined for the most part by gravity. This exchange mode is globular. In the event that the current further expands, at that point the exchange mode may turn into the anticipated spray if the separating electromagnetic power turns out to be adequately extensive. On the off chance that the current further expands, at that point the spilling or pivoting spray exchange may happen. To investigate the phenomenon of metal transfer and their supporting parameters, series of experiments and software based modeling have been performed by researchers. In this review paper tries to summaries and covered all related articles to understand the concept of metal transfer and its related facts to affect various mechanical properties.

II. MATHEMATICAL APPROACH FOR METAL TRANSFER IN WELDING

(Wêglowski, Huang, and Zhang 2008) depict the effect of weld current and wire feed speed on the droplet diameter, droplet velocity and droplet transfer rate by mathematical modeling. The result also compare by the droplet size and falling rate observed with high speed video (HSV) images. The basic relation for evaluate the droplet velocity is represented by the following equations and HSV camera images.

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$$v = \frac{I \,.3\, \mu_o^{1/2}}{D\, \rho\, \pi^2}\, \Psi \qquad and \qquad F_m = \frac{\mu_o I^2}{4\pi}\, f(s) ----(1)$$

Where:

D – The droplet diameter,

ρ – The density of the droplet,

μ_o – The magnetic permeability of the free space.

Ψ– Geometrical shape factor, determines the electromagnetic work done on the drop during growth and detachment process at a given current.

$f(s)$ – A, geometric shape factor depending on the droplet radius and neck diameter during droplet growth and detachment [5]

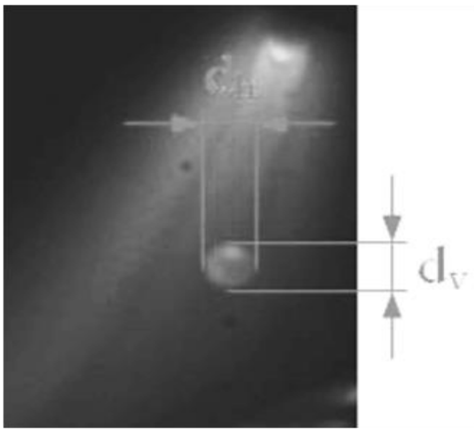

Fig. 1. Methodology for calculating the diameter of a single droplet in GMAW. d_h and d_v

Zhao and Chung 2017 [6] Describe the effect of variable polarity on droplet transfer and formation of arc. Gas metal arc welding (GMAW) utilizing a alternating current waveform is typically named as variable polarity GMAW (VP-GMAW), amid which the electrode extremity switches among positive and negative occasionally. The arc properties and the droplet move in VP-GMAW observed to be a not the same as conventional direct current GMAW. So as to elucidate the droplet exchange wonders amid a VP-GMAW process, a bound together numerical model including the cooperation between the arc plasma and the moving droplet was created. The reproduction results demonstrate that the arc plasma arrangement at negative terminal extremity demonstrates a less tightened shape, a lower plasma temperature and speed, contrasted with positive extremity. The resultant droplet is found to have a bigger size and a lesser temperature than that of direct current gas metal arc welding with a similar normal welding current.

Hu and Tsai 2007 [7] simulate the process to analyze molten droplet during its detachment and impingement to the workpiece. Higher current results in higher electromagnetic force which dominant the detachment of the droplet from tip of electrode. It was investigated that higher current is responsible for smaller size of droplet and a higher droplet velocity. It was also reported that high depth of penetration and wide weldpool was obtained during constant supply of high welding current, while in case of pulsating current mode, control of droplet frequency , size, and velocity can be achieved , which influence the depth of penetration and size of weld pool [8-9]. Droplet detachment also involves electromagnetic force, the arc pressure, surface strain and the plasma shear pressure phenomenon, which influences the size and state of the electric arc. In the fig 2. demonstrates that the temperature profile in the droplet isn't uniform, the droplet was more sultry at the surface and cooler at the center. The metal stream in the withdrew droplet blends the hot fluid metal at the surface with the chilly fluid metal in the center of the droplet. A progressively uniform temperature dispersion in this manner shows up in the droplet disconnected than in the drop hanging at the tip of the electrode likewise finds that the withdrew drop constantly gains heat from the encompassing plasma arc when it is quickened towards the workpiece. The arc plasma was additionally warmed before the droplet impacts the workpiece, however the workpiece's surface temperature is still low. At the point when the droplet hits the strong workpiece, it spreads rapidly and the overheated warm vitality contained in the droplet softens the metal and blends with the droplet. Hence, the droplet blends the mass, force, and warm vitality and converges into the workpiece. Since the speed and warmth conveyance in the liquid metal additionally influence the geometry of the pool is likewise demonstrated [7].

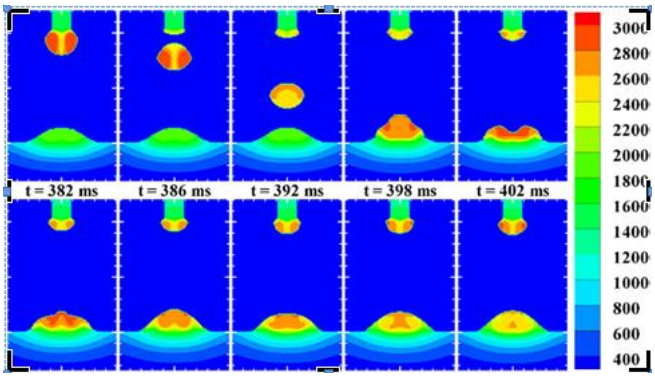

Fig 2. Temperature distributions and dynamics of droplet [7]

Kiran et al. 2014 [10] considered the removal of the trailing circular segment focus at a similar welding current that is more touchy than the main curve. This game plan utilizes at least two wires to nourish into a similar weld pool, consistently. The principal wire is associated with a positive DC supply and the second to an AC supply. The trail wire current heartbeats essentially impacts the fortification stature and weld width while lead wire current influences the profundity of entrance [11-12].The utilization of AC on the second and ensuing wires additionally lessens the circular segment blowing impact of the wires [1, 13]. Noteworthy impact of the curve cooperation on the course of the liquid droplet exchange is clear for a consistent driving arc current. At the season of separation, the liquid droplets from the main and trailing anodes pursue the comparing curve pivot and achieve the welding pool.

Ghosh et al. 2011[14] has derives analytical solution from the equation of transient heat conduction in three dimensions. The energy input applied to the plate is taken as the amount of heat lost from the electrical arc and the kinetic energy of filler droplets driven specifically by gravity, electromagnetic force, arc drag force, mass, momentum and thermal energy. These driving forces permeate the base metal periodically, leading to a puddle of liquid weld. The electrical arc is supposed to be a double central heat source with close proximity to a Gussian distribution.

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Chandel et al. 1987 [15] suggested a mathematical model to predict the melting rate for a given wire diameter, electrode polarity and electrode extension, results reported that the increase in melting rate with an increase in welding current and at given welding current, higher melting rates are obtained when longer electrode extension with electrode negative and smaller wire diameter electrodes are used. For the same welding variables, melting rate for AC is slightly higher than that for DC electrode positive. Arc voltage and power source type do not show any significant effect on melting rate [15]

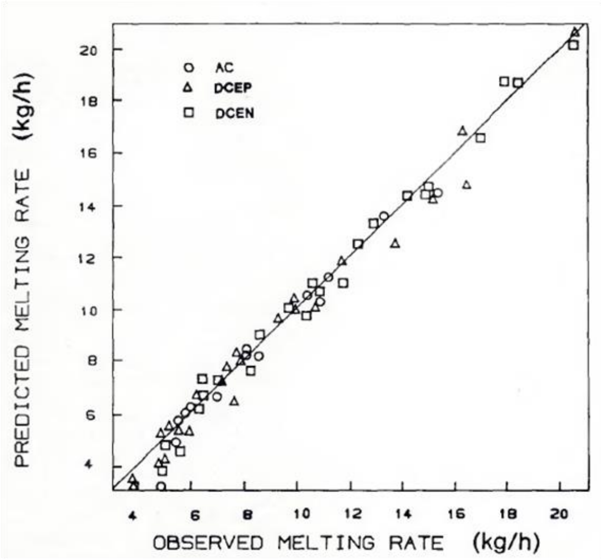

Fig.3 Relationship between measured and calculated melting rates [17]

Chandel et al. 1990 [16] describe a mathematical approach to calculate a electrode and plate melting efficiency and also predict the melting rate and fusion area and to explore these characteristics various relation derived.

Eern or Eprn (%)

$$\frac{Measured\ deposited\ or\ plate\ fusion\ area\ (mm2)}{\text{Theoretical cross−sectional area (mm2)}} \times 100\% \text{ -------(1)}$$

SAW fusion Area (mm2)

$$\text{DCEN} = \frac{1}{43.28} \times \frac{I^{1.521}V^{0.45}L^{-0.1463}}{D^{0.399}S^{0.697}} \text{ ------------(2)}$$

$$\text{DCEP} = \frac{1}{69.39} \times \frac{I^{1.606}V^{0.0728}L^{1.41}}{D^{0.481}S^{0.727}} \text{ --------------(3)}$$

where *V*, *I*, and S are welding voltage(V), current (A), and travel speed (mm s^{-1}),

Sharma et al. 2008 [17] describe the mathematical modeling by consideration of practical approach for twin wire melting. Submerged arc welding with the twin-wire electrode has been known practically speaking for quite a while back [19 - 20] as the past articles that the dissolving rate and productivity for single electrode relies upon welding current, voltage and electrode expansion and as per along these lines Sharma et. al. inferred a rearranged model where the current is considered to be distance across ward and the augmentation of the electrode is esteemed to be the equivalent in the two wires for an instance of equivalent wire width. On account of unequal wire width, in any case, the expansion of the electrode would shift because of unequal current dispersion and the unequal wire distance across.

$$DR_{DCEP} = \left(a_1 + a_2\left(\frac{D_L^4+D_T^4}{D_L^2+D_T^2}\right)\right)I + a_3\left(\frac{L_{0L}D_L^2+L_{0T}D_T^2}{\left(D_L^2+D_T^2\right)^2}\right)I^2 - \varphi \text{ ----------------(4)}$$

$$DR_{DCEN} = \left(a_1 + a_2\left(\frac{D_L^4+D_T^4}{D_L^2+D_T^2}\right) + a_4\left(\frac{D_L^4+D_T^4}{\left(D_L^2+D_T^2\right)^2}\right)I\right)I + a_3\left(\frac{L_{0L}D_L^2+L_{0T}D_T^2}{\left(D_L^2+D_T^2\right)^2}\right)I^2 - \varphi \text{-------------(5)}$$

Where a_1, a_2, a_3, a_4 are the model constant and D is the diameter of electrode corresponding to leading and trailing electrode, L is the length of electrode extension for leading and trailing electrode. Model was validated with practical approach by 99% confidence level. The melting pattern of both the electrode wire demonstrate identical behavior.

Junez et al. 1999 [18] infer a numerical model by ongoing checking of welding with different wire terminal and set up a connection for measure the metal dissolving per unit time in term of vitality expended in welding. The amount of warmth created is a component of welding current force, wire breadth, wire augmentation [24-15] and sort of material weld. The absolute warmth contribution to the wire electrode of welding with triple wire is communicated by a condition (6).

$$Q_j + Q_s + Q_0 - Q_r - Q_p \pm Q_t = \rho S \Delta x \int_T^{T+\Delta T} C_p(T)dt \text{ -------------------(6)}$$

Q_j is the heat energy due to ohmic resistance in wire

$$= \frac{I^2 L}{s}\rho_r(T),$$

where I = current density,

L = wire extension length,

ρ_r = specific Resistanceand

s = cross sectional area.

Q_s is the heat energy introduced into wire doe to radiation of neighbouring arc in jules

Q_0 is the heat energy transfered from the arc to the wire extension due to conduction.

Q_r is the heat loss in the wire due to radiation

Q_p is the heat loss due to heat transfer from the wire into shielding medium

Q_t is the heat generated in the wire extension due to the Thompson effect

By the above approach J Tusek obtain a model for calculation of melting rate for multiple wire electrode i.e.

$$M = \frac{I.n.(U_E + \alpha.L.j.n^{-0.2})}{Q_k + \beta} \text{ ---------------------(7)}$$

The derived model for calculation and prediction of melting rate is much closed with the experimental value. Author also spread light on the weakness of this model i.e. the four different coefficients should be known for each filler material [18].

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S.K. Choi et al 1999 [21] discuss a theoretical and mathematical formulation to find a value of forces involved for the detachment of droplet from the electrode such as gravitational force, electromagnetic force, plasma drag force and surface tension and there controlling parameters.

- Gravitational force responsible by the mass of droplet. $F_g = \frac{4}{3}\pi R^3 \rho D g$
- Electromagnetic force on drop due to current flow in electrode. $F_{em} = \bar{J} \times \bar{B}$

J – current density and B – magnetic flux

- Plasma drag force. $F_d = C_d A_p \left(\frac{\rho f v_f^2}{2}\right)$, where Cd – drag coefficient, Ap – Projected area, $\rho_f -$ fluid density, $v_f -$ velocity of gas
- Surface tension force. $F_s = 2\pi\alpha\gamma$,

Where $\alpha -$ radius of electrode, $\gamma -$ surface tension of liquid

Detached droplet is subjected to : - $F_{em} + F_g + F_{arc}$

The No. of droplet calculated by $n = \frac{3}{8} \times \frac{d^2}{D^3} \times v_{el}$, n= no. of droplet per second, D – diameter of droplet, V_{el} – wire feed rate.

III. EXPERIMENTAL APPROACH FOR METAL TRANSFER IN WELDING

G. Zhang et al. 2017 [22] describe the mechanism of droplet transfer at constant voltage and constant current power supply and also introduce the arc climbing up phenomenon and it observed at constant wire feed rate, during the experiments three kind of metal transfer mode appeared at, three different arc pattern i.e. Globular, spray and droplet transfer. During the detachment of molten drop from electrode, various forces act on the droplet i.e. gravity, anode spot pressure, surface tension, electromagnetic force and plasma jet force [23]. Combined effect of these forces start the droplet necking process but at the necking root area of drop becomes very less and the path of electromagnetic force change the direction and try to move the droplet upward that promote the arc climbing up and this electromagnetic force prevent the droplet transfer and produce the globular transfer. It is found that globular transfer mode cause a spatter and also poor weld quality [24] therefore it's application in production is rare. In the second pattern, increasing effect of electromagnetic force between the side wall and electrode tip, accelerate the necking of droplet detachment process globular mode with smaller size of droplet was obtained. In third pattern, three arc conductive paths found and result of more no. of conductive path is that the detachment is made easier and spray transfer mode is established.

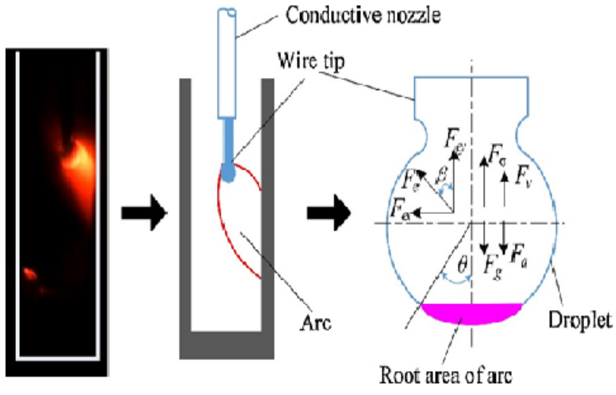

Fig. 4. Force pattern on the droplet under simplified arc [6].

Li et al. 2017 [25] Analyze the metal transfer experimentally and also simulate for the validation and observed the metal transfer by fast camera through a pre-set passage and by consolidating rapid camcorder of welding and physical displaying tests, he proposed that there may be a three strategies for metal exchange are repulsed by expanding welding current without short circuit, flux divider - guided transmission without short circuit and flux divider - guided transmission with short circuit.

Mendez et al. 2015 [26] discussed the metal transfer by high speed videos with variance of wire feed rate , voltage and current, for observing metal transfer a experimental setup were prepared as shown in fig. that have longitudinal tunnel to the weld direction. By observing and data acquisition it was clearly indicate the absence of short circuit metal transfer in all cases and also find that the depth of penetration increases by increasing welding current.

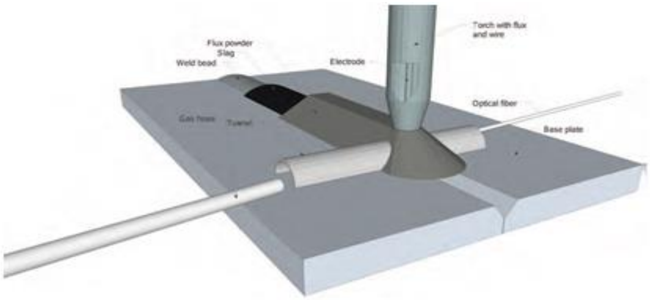

Fig 5. Experimental arrangement to create high speed videos of metal transfer in SAW. [26]

Zhou et al. 2017 [27] contemplated a trial structure and factual examination uncovered a direct connection between the weight of the deposited metal droplet and the yield vitality of the cold metal transfer (CMT) and the weight can be controlled correctly by modifying the CMT parameters. The droplet surface contact angle has no unmistakable connection with CMT parameters and is autonomous of the yield vitality. Furthermore, amid the CMT procedure, the metal droplet exchange is exposed to a wonder known as attractive arc blow influencing the arrival position. (Chen et al. 2016) The contacting exchange and the free exchange creating splash free welds can be acquired. While different powers are comparable as in regular GMAW, the electromagnetic power has been on a very basic level changed.

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The separation from the underlying position of the wire to the weld pool, the current on the wire and the separation from the tungsten to the weld pool are the real parameters deciding the exchange time frame and the droplet measure. With the pulse current including into the wire, the droplets can without much of a stretch move into the weld pool, the period is dictated by the pulse cycle [28]

Patchett n.d. et.al. [29] Describe the Metal statement rates, infiltration, dab width and fortification and transition utilization as elements of welding current for each wire measurement and for all motion syntheses. The metal affidavit versus current outcomes demonstrates that flux composition had no noticeable impact on softening rates. For a given current, dissolving rates were proportionate for the 6.4 and 3.2 mm wires, yet higher for the 1.6 mm wires; this demonstrates l2R warming is critical just with the littlest wire for a stickout of 25 mm. The globule measurement results demonstrate that dab widths at first expanded with current, at that point dropped or stayed steady in the wake of achieving a most extreme; then again, support expanded somewhat up to the dimension of greatest dot width, and after that expanded at a more noteworthy rate with the 1.6 mm wire. This impact was increasingly articulated on infiltration, which expanded in all respects quickly at flows over the dot width most extreme. Most extreme dot widths and support esteems expanded as terminal distance across expanded.

S. Shan Zhang et al. 2009 [30] introduce a new method of arc welding i.e. Twin wire indirect arc welding (TWIAW). In this method the workpiece is not a part of power supply and twin wire is connected with a different pole of power supply. Therefore most of the heat concentrated at the end of the pole and focused to melt the base metal. A series of test performed to observe the droplet transfer behavior with a variant of current, voltage and shielding gas and the result is match with the conventional theory, i.e. by increase current the transition frequency also increasing and big globular droplet become a small and mode of metal transfer sifted to streaming mode. By increase current electromagnetic force also increase and makes the detaching process rapid. Similarly by increasing welding voltage mode of transfer sifted from short-circuiting to continuous streaming. As the previous literature various forces are involved to detached the metal from electrode i.e. gravity force, plasma force and electromagnetic force etc. and the conductivity or ionization of shielding gases also affect the heat distribution in plasma column.

Wu and Kovacevic et. al. 2002 [31] Mechanically assisted droplet transfer process in GMAW is done by oscillating the electrode during droplet formation and the upward movement of electrode is forced to detached the droplet from the tip and find that expanding the wire wavering recurrence, the droplet exchange rate increments even at a similar welding current, and the droplet measure diminishes likewise to be practically identical with the distance across of the wire electrode, however the dimension of this improvement is very needy upon the swaying recurrence. The cycle of the droplet development and droplet separation is incredibly abbreviated, subsequently prompting an expanded drop exchange rate of 55 drops/sec. This esteem is intently double the exchange rate without wire wavering. In the interim, the state of the disconnected droplets turns out to be more standard and uniform than those created without wire wavering, this sort of handiness can be embraced to the extra mechanical power produced by wire swaying. The droplet exchange rate achieved a generally steady dimension of 70±80 drops/s in the current range from 210 to 220 A. with 85Hz wavering meanwhile, the droplet estimate is just about equivalent to the distance across of the wire electrode and splash exchange mode was set up and an entirely steady uniform separation of little droplets are accomplished. Also reported the quality of weld surface improved at set parameter of current and oscillation frequency and this mode of metal transfer can be add with classification of metal transfer reviewed by Iordachescu et al.[32]

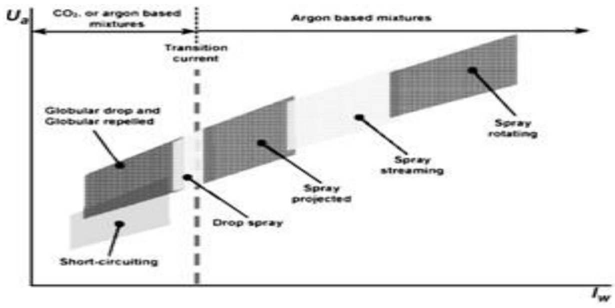

Fig.6 (a) Natural transfer modes

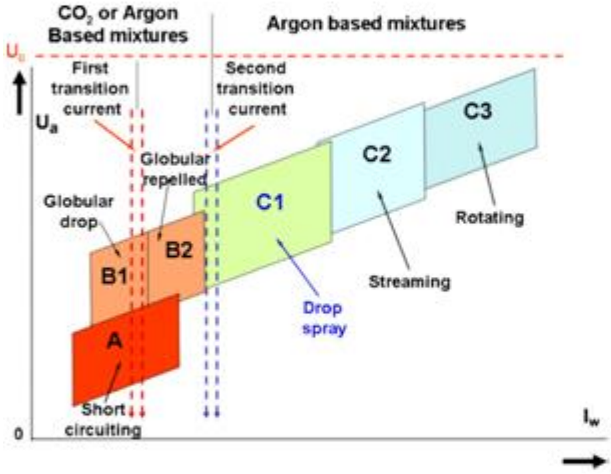

Fig. 6(b) Fundamental transfer modes

IV. PARAMETRIC EFFECT ON METAL TRANSFER

Cho, Kiran, et. al. 2017 [33] explore the motion divider guided metal move in SAW. A three-dimensional numerical warmth exchange and liquid stream demonstrate was created to comprehend the temperature conveyance and liquid pool conduct in a low-current submerged arc welding process. This paper depicted CFD numerical models and liquid pool stream designs in low-current V-groove submerged arc welding. This examination recreates how porosity can be caught in the V groove joint with a motion divider guided exchange. In FWG mode, as the liquid droplet crashes to the motion divider and after that provisions to V-groove and the temperature profile show that heat is exchange on a more extensive territory of V-groove so it is deficient to liquefy the pool further and aftereffect of that the liquid pool don't soften V-groove joint and it remains porosity close to V-groove joint. In the fig. 7, show the fragmented infiltration (IP) in the longitudinal course of weld

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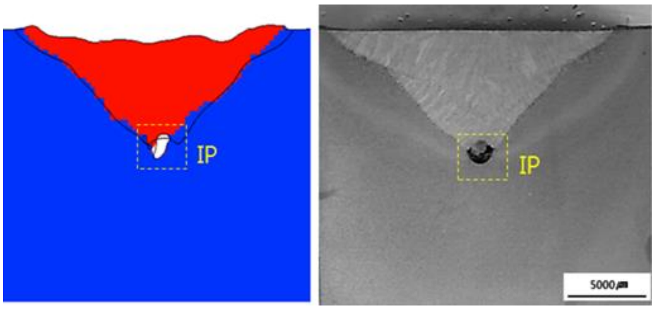

Fig. 7 Validation of simulated result with experimental result

. (Guo et al. 2017) Found the impact of welding speed on metal exchange modes. Metal move process in submerged transition cored welding are examined by X-beam transmission strategy for welding speed from 0.5 mm/s to 9.5 mm/s. The metal exchange method of submerged transition cored wire welding is the blended exchange mode chiefly made out of four principal exchange modes for example wide-point globular repulsed exchange mode,
little edge globular repulsed exchange mode, surface pressure exchange mode and short out exchange mode. With expanding welding speed, the unpleasant power including the gas stream drag compel (FL) and electromagnetic power (Fe) increments bit by bit, in the interim the liquid metal and warmth input decline, causing that the sort and extent of crucial modes establishing the blended mode depend firmly on the welding speed The class and extent of central modes comprising the blended mode depend emphatically on the welding speed attributable to the variety of power condition on droplet. With expanding welding speed, the extent of the wide-point globular repulsed exchange mode increments persistently while that of the surface strain exchange mode and short out exchange mode diminishes, and the extent of the little edge globular repulsed exchange builds right off the bat and afterward diminishes gradually[34].

Chandel and Bibby et. al. [35] Describe the impact of different procedure variable like weld current .voltage, extremity and wire measurement on weld stored zone and detailed that the weld saved region diminishes by expanding voltage. As indicated by the extremity it was accounted for that higher store territory esteems are gotten when the electrode is negative. Welding current significantly affect the weld saved zone with electrode expansion, at lower electrode augmentation (25.4mm), the impact of welding current on the store zone appears to have little importance yet at higher electrode expansion current considerably affects store region. The consolidated impacts of welding current and electrode measurement on the normal store zone diminishes significantly with electrode distance across. It tends to be found in table that the store region increments as the normal welding rate or current is increased.
(Taylor et al. 2007) observed that many variants of SAW, for example, twin arc, couple arc, different wire, strip terminals, and so on., are currently accessible and broadly utilized for explicit applications. With the utilization of appropriate parameters and SAW variation, it is currently conceivable to accomplish testimony rates more than 50 kg/hr. The expansion in statement rate as a rule is, be that as it may, accomplished by expanding welding current and consequently the warmth input, which will in general weaken joint toughness.[36]

(Sun et al. 2018) characterized the external magnetic field assisted cold metal transfer (CMT) lap welding of Al and Ti alloys. Magnetic field modify the arc characteristic and droplet transfer. As in arc welding the effect of magnetic field create a problem of arc blow but controlled external magnetic field enhance the flowability, spreadability of molten droplet and due to effect of Lorenz force, droplet is rotated. Rotated molten droplet affected by centrifugal force, a necking started for detaching. Detached drop fall in the molten pool and it improve the heat distribution and also homogenization of base metal and filler metal this also improve fracture strength.[37]

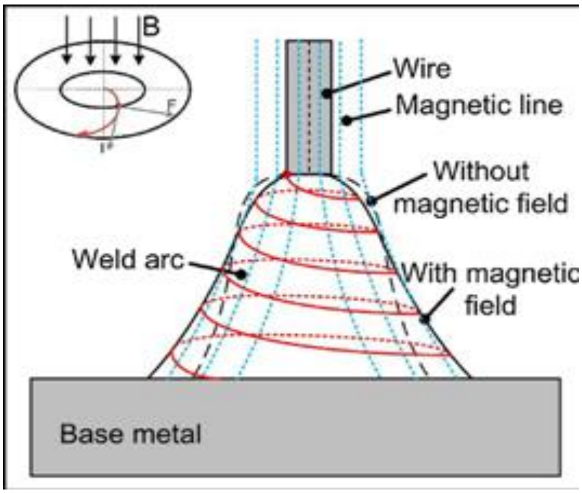

Fig.8 Movement of axial magnetic field [37]

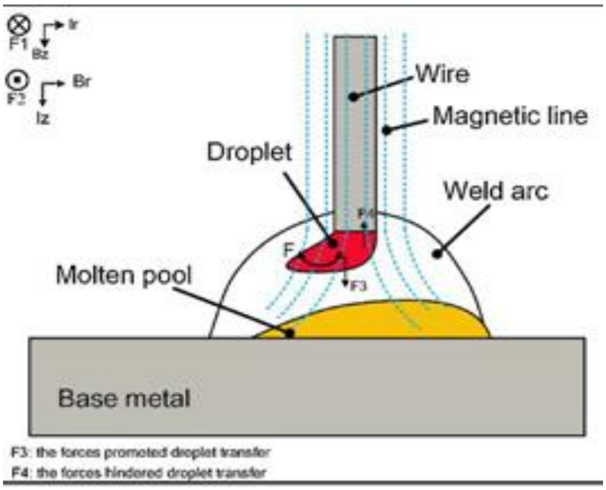

Fig.9 Droplet deviation under axial magnetic

V. COLD METAL TRANSFER (CMT)

Cold Metal Transfer welding is a tweaked MIG welding process dependent on shortcircuiting exchange process created by Fronius of Austria in 2004. This procedure contrasts from MIG/MAG welding process just by the kind of mechanical droplet cutting strategy not recently experienced In the CMT procedure, when the terminal wire tip reaches the liquid pool, the servomotor of the 'robacter drive' welding light is turned around by computerized process control.

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This makes the wire withdraw advancing droplet exchange which is appeared in Fig. 10. Amid metal exchange, the present drops to close to zero and in this way any splash age is kept away from. When the metal exchange is finished, the arc is re-lighted and the wire is encouraged forward yet again with set welding current reflowing [38-39]. According to the material application CMT can be classified in two different variance i.e. CMT for similar and dissimilar metal. A series of test has been performed for similar and dissimilar metal to validate the quality of weld.

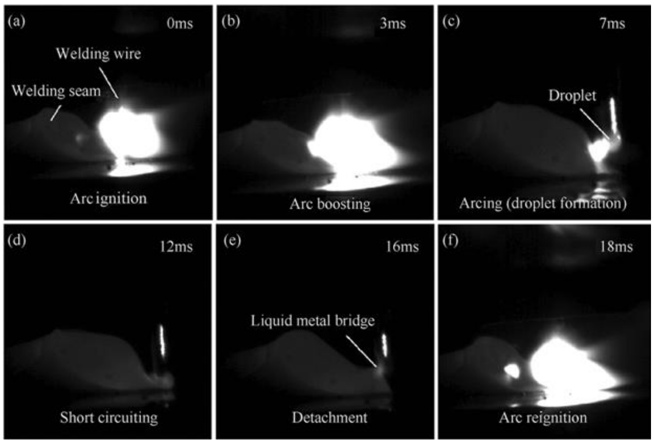

Fig.10 High-speed images of droplet transfer.

Table 1: CMT Weld for similar metal

S.No.	Weld Metal	Weld Quality & Heat Affected Zone (HAZ) for Similar Metals
1	Inconel 718 Alloy[40]	No lack of fusion, good weld quality,very small HAZ (0.5mm), large dendrites, residual stress found to be minimum (compare with MIG) according to above desription Inconel 718 Alloy is best suitable for CMT weld.
2	Alluminium 7075 Alloy[41]	No spatter & crack found, very low porosity, there is no bead hardening, hardness slightly decreases in HAZ compare to base metal.
3	Aluminium AA6061 Alloy[42]	The weld exibited quasi binary composition, very less solidification cracking, narrow HAZ & intermetallic phase area, fine recrystallization at the joint.
4	Galvanized steel[43]	Very less tendency to formation of porosity in weld bead for low heat input condition (heat input perameter can be optimized for better performance.
5	Aluminium 5083-H116 alloy[44]	Using Al 5183 & Al 5087 electrode demonstrated better mechanical execution in pliable tests, Crack Tip Opening Displacement strength test results show that the connected mixes of base and feed material yield great splitting opposition qualities

Table 2: CMT for dissimilar metal welding

S.No	Resercher	Base Metal	Filler Metal	Process variable	Enhancement	Mode of Metal Transfer	Remark
1	(Feng, Zhang, and He 2009)[45]	Thin Aluminium Sheets	AlSi5 alloy wire	Current	Gap bridging ability at low current	Short circuit metal transfer	Decreased Deformation by reducing heat input, current transfer in three phase (1) peak current phase (2) background current phase (3) short-circuiting phase.
2	(Pang et al. 2016))[44]	AA6061-T6	ER4043	1. Boost Phase Current - Spray transfer 2. Boost Phase Duration (increased) superheat the droplet and lead to the short circuit transfer	Metal Deposion Rate, Penetration Depth and decrease the contact angle by 110o to 24o	The CMT+P transfer mode	The CMT+P exchange mode is a mix of an anticipated exchange mode with one bead for each heartbeat and a short circuit exchange mode amid the virus metal exchange period SC Transfer control the fast cooling rate.

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				3. Burn Phase Current ought to be low enough to help the smooth short circuit exchange 4. Wire Feed Motion should be very close to wire melting for globular droplet			
3	(Z. Sun et al. 2015)[46]	Ti-6Al-4 V Alloy	As base metal	1. Wire Feed Rate 2. Droplet Size 3. Current and Volatage Waveform 4. Inductance Currection Value	1. By increasing wire feed rate droplet transfer frequency, diameter and length increases 2. By decreasing inductance currection value droplet frequency will increasing by early arrival of short circuit phase and no effect on droplet diameter.	short -circuit Transfer	The experiment setup is design as, when liquid droplet come into the contact of molten pool, a signal returned to digital control pannelled wire feeder then welding wire pooled back and it lead to short circuit phase. The controlled CMT facilitate the effective welding at low heat input without affecting other parameters
4	(Mezrag, Deschaux-Beaume, and Benachour 2015)[47]	Zink Coated sheet with Aluminiu m Alloy	A4043	1. Boost current (Ib) 2. Duration of pulse (tb) 3. Wait current (Iw) 4. Short circuit current 5. Filler wire speed (Vf)Constant	Expanding in the short circuit recurrence and diminishin g in drop weight stored amid each short out this sort of waveform produce the best outcome with steel alluminiu m joining	short circuit metal transfer at variable frequenc y	

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5	SS Sravanthi et al (2019)[48]	5052 Al Alloy+ Galvanized Mild steel 10µ thick layer of Zinc	BA404 Al wire diameter 1.3mm	Current and voltage ranged between 67-75 A and 16.0 ± 0.2 V respectively. Welding torch angle 70°	The nearness of al-Fe-Si IMC layer improved the hardness at weld dab gentle steel interface, the framework result in high rate of confined erosion	MIG (Argon) Metal transfer mode CMT	Intermetallic compound of Al3F3Si2, Al5FeSi, FeAl, Fe2Al5 are found
6	Xiaohu Hao et al 2019 [49]	TC4 alloy + ST16 Steel	CuSi3	Welding Current 30A & 40A Travelling speed 2mm/s & 8mm/s	The dissemination of Ti and Si into ST16 steel substrate encourage arrangement fortifying, it increment micro hardness at interface	GMAW	Various IMC are formed such as Ti2Cu, TiCu, AlCu2Ti and TiCo2

CMT is a mechanized welding process i.e. based on dip transfer and the welding of aluminum has a unique problem by its lower melting point compare to steel. CMT is most widely used for the welding of dissimilar metal like aluminum to steel, it shows satisfactory results when optimized short circuit duration and electrode melting coefficient. In the welding of dissimilar metals the formation of inter-metallic compound (IMC) have a decisive role in the strengthening or weaken of the joint. IMC formation may reduce the corrosion resistance of the weldment. IMC and its effect still a key point to the researcher for further studies.

VI. Conclusion

This Review of Heat and mass transfer of submerged arc and gas metal arc welding under various approaches is discussed here. The main conclusions of this study are:

a) Gravity, surface tension and electromagnetic force play a critical role of metal transfer and its mode, these forces can be controlled by welding current, voltage and polarity. Modify pulse metal transfer, total time duration is the combination of growth period and detachment period and by controlling the parameter during detachment period, it facilitate the one drop per pulse (ODPP) transfer.
b) Various author reported that the constant voltage and current is not suitable for desirable metal transfer mode. Constant voltage power supply (CVPS) and low current result in arc climb up and very low electromagnetic force for detachment, surface tension for detachment depend on chemical composition so gravity responsible for globular transfer. By increasing welding current globule volume become smaller, and transition frequency increase result in necking of droplet become earlier, method of metal exchange change from globular to spilling splash exchange.
c) Twin wire arc welding present two distinctive class of metal exchange at variable welding current is free flight exchange and spanning exchange. In submerged arc welding three distinctive method of metal exchange proposed at lower current, repulsed globular exchange without short circuit and at medium current motion divider guided exchange and at higher current, transition divider guided exchange with short circuit will happen.
d) In submerged arc welding anode dissolving effectiveness and plate softening proficiency is complementary to one another. Cathode liquefying proficiency increments with increment in current and anode augmentation and diminishes with voltage and electrode diameter. Similarly electrode melting efficiency in GMAW increases when C25 (25% CO_2 + 75% Ar) compared with M2 (2%O_2 +98% Ar)
e) CMT allows depositing regular electrode on base metal; CMT is best suitable for welding of aluminium to steel. The lessening in the 'boost' time coupled to the expansion in the lift current of the CMT waveform delivers an increment in the short out recurrence and an abatement in the drop weight kept amid each short out. This sort of waveform creates the best outcomes in steel-aluminum joining on the grounds that the warmth exchanged to the base metal is decreased for an equal stored weight.

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Influence of external magnetic field with arc produce axial EMF, both arc and molten droplet were rotated by Lorenz force. This rotational movement homogenized the heat distribution on the base metal.

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