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A Review on Twin Tungsten Inert Gas Welding Process Accompanied by Hot Wire Pulsed Power Source

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Abstract

Tungsten Inert Gas (TIG) welding process is used in the industry due to its positional suitability, good control over metallurgical and mechanical properties and weld integrity. It makes this process more suitable to weld the root pass in the piping industries. However, there is a remarkable limitation to increase the welding current beyond a certain limit in the conventional TIG welding process due to limited current carrying capacity of a single electrode and higher arc pressure. This limits its productivity. To combat it, Twin TIG (T-TIG) welding process is introduced where the two tungsten electrodes are present in one torch. The two separate and synchronized power sources are connected to the two electrodes. To increase the metal deposition rate, the hot filler wire is used because it reduces the requirement of heat from arc plasma. There is another advancement in the TIG welding process which incorporates pulsed power source assisted welding process to control weld bead geometry, microstructure and to weld dissimilar material. This paper presents the effect of parameters of T-TIG, hot wire, and pulsed current welding processes when performed separately. A novel welding set up is proposed to weld dissimilar material with weld integrity. This paper suggests that when these three techniques are used simultaneously by meticulous studies of their process parameters with automation, an outperformed technique can be evolved which multiples the individual advantages of the three processes.

Key Words : Twin TIG, Hot wire, Pulsed heat input, Arc pressure

1. Introduction

In this competitive scenario, industries are forced to adopt the techniques that provide higher productivity without losing quality. Conventional TIG welding process produces sound weld with high integrity with base metal. But due to the lack of productivity its usage is mainly limited to weld root pass, where back side chipping is not possible like in piping industry. To increase the performance of TIG welding process, developments like A-TIG (Activated TIG), T-TIG (Twin TIG), S-TIG (Super TIG), hot filler wire, usage of pulsed heat input, hollow electrode and many others are being carried out[1]. This paper aims to present T-TIG welding process when it is connected with pulsed power source and employed with application of hot filler wire. It will be very interesting to investigate the combined effect of these three techniques to multiply the advantages of individual technique. The literature survey is carried out in tabular form to extract and compare the conclusions.

2. Basic features of T-TIG, Hot wire and Pulsed power source

2.1 T-TIG welding process

In the TIG welding process if current is increased then arc pressure increases which results erratic and unstable arc. It forms undercut and bead humping thus weld bead quality decreases[2,3]. So, there is a limit beyond which current cannot be increased in TIG welding process. Recently to overcome this limit Japanese researchers developed a method namely T-TIG welding process. In it, there are two electrodes connected with the two independent power sources in single torch. This not only increases current carrying capacity of T-TIG welding torch but also decreases the arc pressure[4,5].

Fig. 1 represents the schematic diagram of T-TIG

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welding torch. Here two electrodes are insulated electrically by means of a ceramic insulator so that the arc can exist without fluctuation and interruption. Due to Lorentz force, arcs will be attracted to each other. Fig. 2 and 3 presents the comparison of the arc pressure when TIG and T-TIG torch is used respectively. From these figures it can be observed that the arc pressure and pressure gradient is very low as compared to single electrode for the same current. It can be observed that for the same current T-TIG occupies larger area of anode as compared to TIG welding process[3].

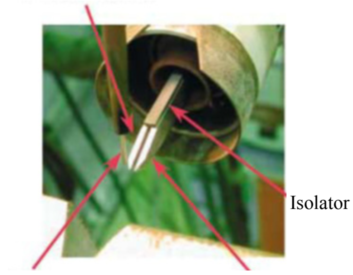

Fig. 1 Design of welding torch for T-TIG[3]

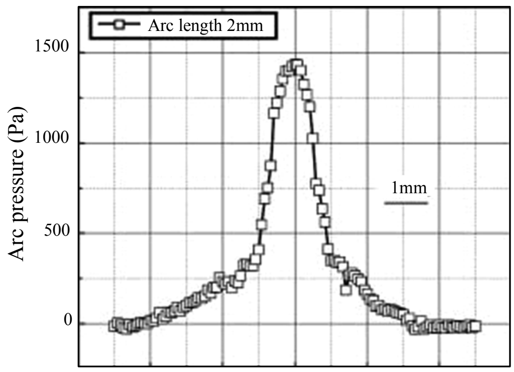

Fig. 2 Arc pressure variation for single electrode for 200 A current[3]

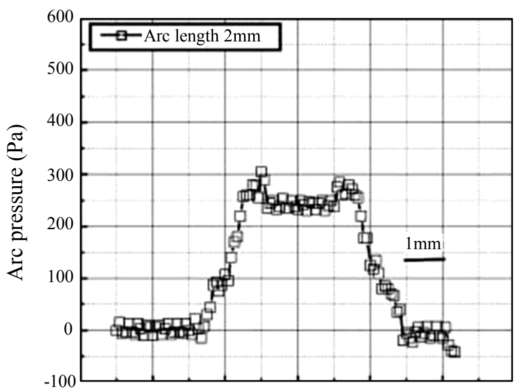

Fig. 3 Arc pressure variations for double electrodes with 100+100 A[3]

2.2 Hot filler wire

In hot filler wire welding, filler wire is heated electrically by resistance heating with separate power source in case of the TIG welding process. By preheating the filler wire, required heat input from the arc reduces to a great extent and higher deposition rate can be achieved even at lower arc current[6]. Fig. 4 represents the principle of hot wire welding process. As per this figure the important components of hot wire process are:

1) Wire feeder.
2) Torch which supplies current to wire.
3) Power source to heat the wire.
4) Power source for generating arc.

There has to be a balance between all these component's parameters to establish stable arc. The polarity of hot wire power source plays a major role with location of hot wire whether front or back to the arc[7].

2.3 Pulsed Heat Input

After 1960 it has been observed that the conventional arc welding processes fail due to evolvement of advance material and complex weld edge preparation. When the thermal capacity of material to be welded is different due to either dissimilar thickness or thermal conductivity, constant heat input raises welding defects like burn through or lack of fusion. To avoid the same, heat is provided at discrete level; low level or background current and high level or peak current. Fig. 5 describes the nomenclature of waveform in which peak current is provided for predefined time and responsible for melting of material. After pulse on duration, current is reduced drastically at base level. During base level, ideally no melting is occurred and only solidification is done. When pulsed power source is controlled in a synergic manner it can change the pulse frequency, pulse on time, peak current and background current independently. There are mainly two types of pulsing viz. thermal and droplet pulsing. Former is used in the TIG welding process

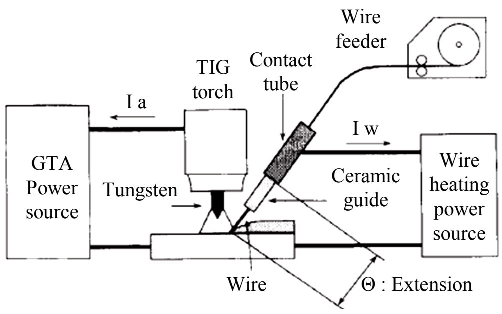

Fig. 4 Block diagram representing hot wire welding process[7]

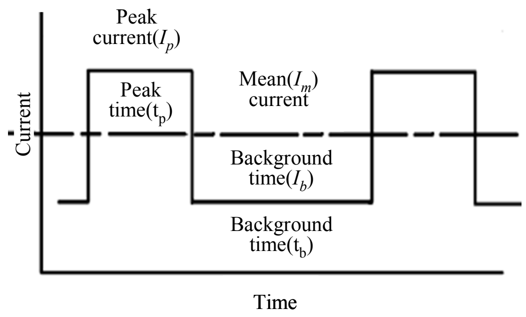

Fig. 5 Waveform of pulse welding[8)]

to weld dissimilar materials and latter is used in the MIG (Metal Inert Gas) welding process to attain the spray mode of metal transfer at lower mean current than in constant current MIG welding process[8)].

3. Literature Survey

To identify the research gap, derive qualitative conclusion and identify the best combination of these three techniques, the literature survey is done separately in Table 1, 2 and 3 respectively.

4. Effect of individual process parameters on welding

4.1 Pulsed power source parameters influencing weld bead properties.

Pulsed power source differs due to its discrete nature to supply current or merely voltage. Albeit other conventional welding parameters are important in pulsed power source welding like travelling speed, electrode diameter, etc. following additional pulsed power source parameters influences more in welding qualities.

a) Peak Current
b) Background Current
c) Frequency
d) Duty cycle (% of time for peak current)

4.1.1 Effect of pulsed welding process parameters on mechanical properties

For magnesium AZ31B and AZ61A alloy, it was found that peak current is most influencing parameter that affect the tensile strength[48,49)]. One contradictory result was found which indicated that when peak current increases the tensile strength reduces for strain hardened Al-6.7Mg alloy. The reason behind it was the generation of high heat input that formed the coarser grain and reduced the strength[50)]. For AA6061, it was investigated that peak current is more sensitive at optimum value of tensile strength i.e. if the value of peak current is varied marginally near the optimum value, the change in tensile strength is more[51)].

Up to certain level if peak current along with pulse frequency (up to 6Hz) is increased, impact strength of weldment is increased for titanium alloy[52,48)].

Table 1 Major literature survey of dual/twin/tandem electrodes

Sr.No.	Remarks
1.	Arc pressure of T-TIG welding process was measured by CCD(Charged Coupled Device) and up to 600 mm/min welding speed was achieved for Q235 2mm thick plate[2)] .
2.	T-TIG welding process was used to weld 9% nickel steel PCLNG storage tank and compared with SAW[3)].
3.	T-TIG welding process was used to clad on low carbon (S235JR) parent material by hot wire T-TIG process with nickel base alloy and less ferrous particle was observed [4)].
4.	Arc pressure was measured in T-TIG welding process when 6mm plate of Q235 material was welded with 240mm/min welding speed and current of 200+200 A. The welding was found without appreciable welding defects[5)].
5.	Arc separation effect was found out on temperature field, plasma flow, peak temperature and arc voltage in T-TIG welding process. Effect of 4% oxygen dilution in argon gas resulted arc restriction and more penetration[9)].
6.	Auto genus tandem TIG welding was done on 1.5mm thick 409L stainless steel with 3 m/min. speed with good control on microstructure and higher tensile strength[10)].
7.	Arc length and distance between two electrodes were examined to find the effect on peak temperature and temperature distribution in T-TIG welding process. At the center between two electrodes maximum temperature was recorded[11)].
8.	2-D numerical model was developed for T-TIG welding process to describe arc characteristics. Higher peak temperature was found in case of shielding gas as helium than argon[12)].
9.	Bead on plate welding was done by T-TIG welding process for mild steel with 600A current and 1.2mtr/min. welding speed to investigate the bead for different electrode distance[13)].
10.	A numerical model was developed to investigate the behavior of arc and weld pool considering metal vapor concentration in T-TIG welding process[14)].
11.	Ultrasonic excitation was generated to improve the weld quality of T-TIG welding process. Finer grain structure and better tensile strength was found for SS 304 material[15)].

Table 2 Major literature survey of hot filler wire welding techniques

Sr.No.	Remarks
1.	A 3D CFD (Computational Fluid Dynamics) model was developed for weld pool geometry. A comparison was made for plate on bead welding between cold wire and hot wire TIG welding process for mild steel[16].
2.	Effect of post weld heat treatment parameters on the impact strength and hardness was investigated for hot wire assisted TIG welded joints of SA213-T91 steel. Remarkable recovery of toughness and hardness was observed and compared with cold wire TIG welding process[17,18].
3.	Inconel 625 alloy was overlayed on AISI 410 plate with hot wire pulsed TIG welding process and Fe content was measured by 1.83% after second layer[19].
4.	New method of heating the filler wire was developed by secondary arc for low resistance wire like copper and aluminum and 95% increment in deposition rate was found. Microstructure was examined with and without hot wire for HS201 filler wire with TIG welding process[20].
5.	Comparison of hardness was done between cladded low carbon steel with Stellite 6 and austenitic stainless steel. With cladded low carbon steel with Stellite material, hardness number was found 420 as compared to 200 on SS316 with TIG process[21].
6.	Relationship between the current and wire feed rate was devised to increase the melting rate. It was found that this relationship is independent from plate thickness with TIG welding process[22].
7.	Relationship between hot wire welding parameters and weld bead geometry was found. For the welding of low carbon steel welding, 200% increment in metal deposition rate was found with hot wire TIG welding process[7].

Table 3 Major literature survey of pulsed heat input with TIG welding process

Sr.No.	Remarks
1.	Optimum pulsed TIG welding parameters were determined for C-276 material. Depth of penetration was selected as response and found that peak current is the most significant parameter for penetration[23].
2.	For AISI 304L, depth of penetration was optimized for both low frequency and high frequency TIG pulsed welding. At high frequency, more penetration is observed as compared to lower frequency[24].
3.	15CDV6 and SAE4130 were successfully welded with inter pulse high frequency TIG welding process. The ultimate and yield tensile strength was measured after post weld heat treatment[25].
4.	Optimized pulsed TIG parameters were found out for bead geometry of Ti-6Al-4V by statistical design[26].
5.	Analysis of mean and RMS value of peak current was done on the SAE 1020 plate where bead width and penetration were investigated[27].
6.	Effect of pulsed TIG welding parameters was investigated on penetration and ripple formation when welding was done on 304L material[28].
7.	Hastelloy (C-276) material was investigated in term of microstructure and ductility which was welded by pulsed TIG and TIG. Autogenus pulsed TIG welding was found superior due to absence of micro segregation[29].
8.	Comparison was made between pulsed and TIG welding process for grain structure refinement[30]. Increment in grain refinement was found in pulsed TIG when pulse frequency increases for Ti-6Al-4V as base metal[31].
9.	Dissimilar material welding was done between Ti-6Al-4V and Aluminum 7075 with filler material as AA 4047 by pulsed TIG welding process. Optimized pulsed TIG welding process parameters were found out for obtaining strength and hardness[32].
10.	Pulsed TIG welding was performed between AISI 904L and Monel 400 with ERNiCu-7 and ERNiCrMo-4 filler metals. Fracture was found at HAZ of Monel 400 due to partially melted zone[33].
11.	Dynamic heat source model was developed in which parabolic model was selected for background current and Gaussian distribution model was selected for peak current. It was experimentally validated that parabolic model during background current was more accurate[34].
12.	A unique finite element model was developed to handle the cathode, arc plasma and anode region for pulsed TIG welding process. Heat transfer, fluid flow and electromagnetic fields were taken as responses. For the same heat input as compared to TIG welding pulsed TIG welding gave larger weld pool[35].
13.	Prediction of porosity was investigated by arc spectral. Hydrogen and argon content were measured from arc spectral and used to predict the porosity when A506 Al-Mg was welded by pulsed TIG welding process[36].
14.	A plate of Inconel 617 was welded by pulsed and constant current TIG welding to compare the microstructure and impact strength. Finer grain with better impact strength was found in case of pulsed TIG welding process[37].
15.	An algorithm was developed which is capable of predicting 3-D weld pool parameters from one weld bead image for pulsed TIG welding process[38].
16.	Dilution of 1% nitrogen was made in argon gas to investigate the effect of delta ferrite in the austenitic phase when welding was done by pulsed TIG welding for AISI 304L steel. Addition of nitrogen lowers the value of peak current required to compensate higher speed[39].
17.	A numerical model was generated for pulsed current TIG welding process to simulate penetration and weld bead width. It was found that high welding speed can be achieved by appropriate high frequency without affecting penetration and bead width for 304L stainless steel[40].
18.	It was investigated that more penetration can be achieved with lower heat input as compared with the constant current welding process. Some guidelines were given for the values of the pulse duty cycle for various thickness range[41].

There should be an optimum value of pulse frequency at which the tensile strength is higher. Due to high frequency, large number of peak current components is involved per unit time which confirms adequate heat input. But for very large frequency the welded material will not exist in thermal equilibrium and agitate the prior semi solidified material which results adverse effect on strength[50].

It has been investigated that there is strong interaction between pulse on time and pulse frequency on tensile strength of AA6061 as shown in Fig. 6.

4.1.2 Effect of pulsed parameters on metallurgical properties

$$I_{mean} = [(I_p \times t_p) + (I_b \times t_b)]/(t_p + t_b) \quad (1)$$

As per equation (1) mean current which is used to find heat input is calculated by peak current so it also governs the size of grain and other metallurgical properties.

As in case of pulsed current welding, the peak current along with background current, frequency and duty cycle influences the heat input and hence microstructure. In double pulsed welding it is found that the value of peak current should be optimum to achieve finer grain for T-joint welding[53].

Lower duty cycle results in finer microstructure due to large time available for cooling[50]. The optimum value of duty cycle was resulted 50% improvement in grain refinement for AZ31B magnesium alloy[49].

It is also observed the interaction effect of background current and peak current for grain size at fusion zone of AA6061[52]. There was no appreciable change in macrostructure of weld joint found due to variation of background current for AZ61A magnesium alloy[50].

4.1.3 Effect of pulsed parameters on weld bead geometry

It was observed while welding of SAE-1020 material

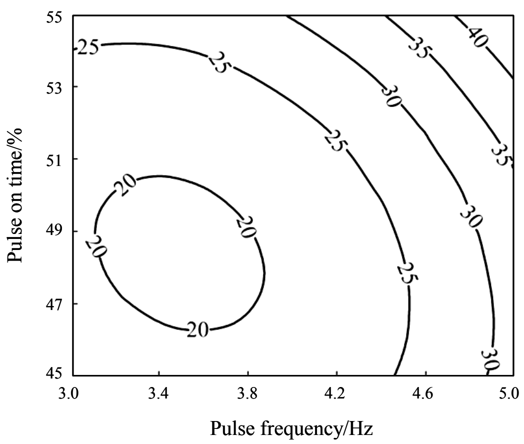

Fig. 6 Contour plot for tensile strength of AA6061[49]

that when peak current was increased by keeping the same mean current, the width of the weld bead will increase and no effect on weld penetration. But when peak current was increased by decreasing the mean current it reduced the weld bead penetration but no change in weld bead width[42]. It is also found that when peak current is used at higher side it increases both weld bead ripple formation and penetration[42-44]. It is also observed that at extreme low and high frequency, peak current has less significance on aspect ratio (weld bead width to penetration ratio)[45]. For Ti-6Al-4V, it is found that for achieving optimum results of weld bead and height, the peak current should not be operated at extreme high and low value[46]. Fig. 7. explains the all aspect of weld bead geometry affected by peak current while other welding parameters are constant[47].

Fig. 8 represents the ripple height and pitch value of weld bead for different values of pulse frequency. It can be inferred that for higher value of pulse frequency the lower pitch length and height is obtained[54]. For low frequency (6-10Hz) the depth of penetration is lower as

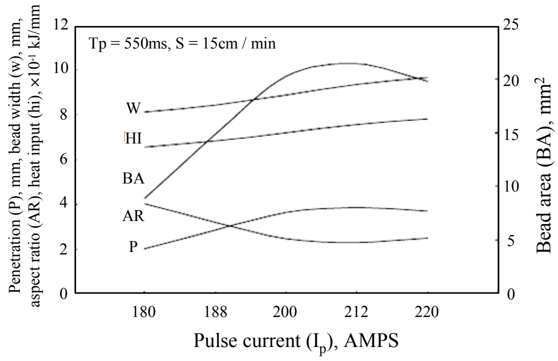

Fig. 7 Effect of peak current on various components of weld bead geometry for AISI304L[48]

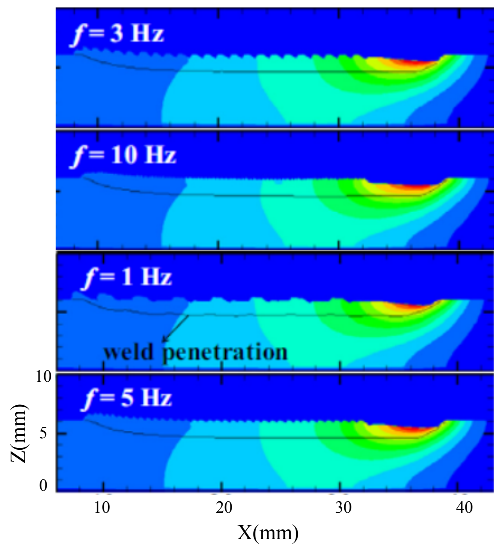

Fig. 8 3D weld bead shape for different pulse frequency[54]

compared to high frequency (150-250Hz) for AISI304L[45]. For higher frequency, large weld region was found as compared to low frequency[50].

For Ti-6Al-4V material it has been observed that if the frequency is increased from 1 to 5 Hz grain refinement occurs speedily from prior beta phase and for the same material it also influences impact strength greatly[55,47]. It was investigated that there should be an optimum level for which the grain size is fine. At very small frequency, the mechanical and thermal disturbance is very small and it will not break the grain boundary[50].

Duty cycle is defined as the ratio of time duration for peak current and background current. It is also represented by pulse on time i.e. the duration of time for which peak current is supplied. For large duty cycle it is observed weld bead with large ripple width and depth[4].

The value of background current should be chosen appropriately so that the arc does not extinct when the pulse off time is active. A little research has been found which focuses only background current as prime study. Certainly, the ratio of I_p/I_b is essential for predicting weld bead geometry[54].

So, from above studies it can be concluded that peak current is a prime factor contributing heat input. The role of background current is to prevent the extinction of arc. Other important interactive effect of peak and background current are the ratio of it which decides the amount of thermal fluctuation. Pulse frequency decides the microstructure and consequently mechanical properties such as impact strength, tensile strength. Duty cycle also has interactive effect with pulse frequency to control the grain size by varying the cooling time.

4.2 Hot wire welding parameters influencing weld bead properties

The filler material is heated outside the weld pool before it comes into contact with arc plasma. This reduces the amount of heat required to melt the material from arc plasma. Little research was found to analyze the effect of hot wire welding parameters on responses. However, Table 6 represents the effect of influencing parameters of hot wire (HW) welding by extractive and intensive literature survey. In hot wire welding the additional heat is provided by resistance heating. As per equation (2) the value of resistance heating can be calculated.

$$H_{resistance} = (I^2 \times R \times t) \tag{2}$$

Here I is the wire current, R is the resistance of wire and t is the time for which current is passed.

$$R = \rho \times \frac{L}{A} \tag{3}$$

Here ρ is the specific resistance or resistivity of wire, L is the stick-out-length and A is cross sectional area of filler wire. So, to increase the resistance heat the value of L and d (diameter of filler wire) should be chosen accordingly. Longer stick-out-length increases the heat input but simultaneously creates more corrosion tendency due to increased temperature. Again, the lower diameter wire reduces the deposition rate. So, the value of stick-out-length and wire diameter should be optimum.

Hot wire current, arc current and wire feed rate are strongly interactive. Fig. 9. shows that increment in wire feed rate has to be compensated by increasing arc and hot wire current. It is also investigated that when the hot wire applied at rear of arc it decreases embrittlement of weldment due to low cooling rate and reheating reduces temperature gradient[57,58].

4.3 T-TIG welding parameters and its effects on welding

As discussed, a little research has been done experimentally for T-TIG welding. However, some numerical and analytical models have been developed to understand the effects of T-TIG welding process parameters on welding qualities. To investigate the effect of process parameters on welding, the literature survey has been done as per table 1. On the basis of it following are the important process parameters for T-TIG welding process.

Table 6 Hot wire process parameter effects on welding

HW welding parameter \ Effect on welding	Weld bead geometry	Microstructure	Impact strength	Deposition rate
Increment in wire temperature[31,56]	Weld bead increases and reinforcement decreases	Coarse grain	Deceases	Increases
Increment in wire stickout and decrement in wire diameter[31]	NA	Coarse grain	Decrease	Increase
Increment in wire feed rate at constant arc current and hot wire current[57]	Bead width and depth of penetration decreases	NA	NA	Increases

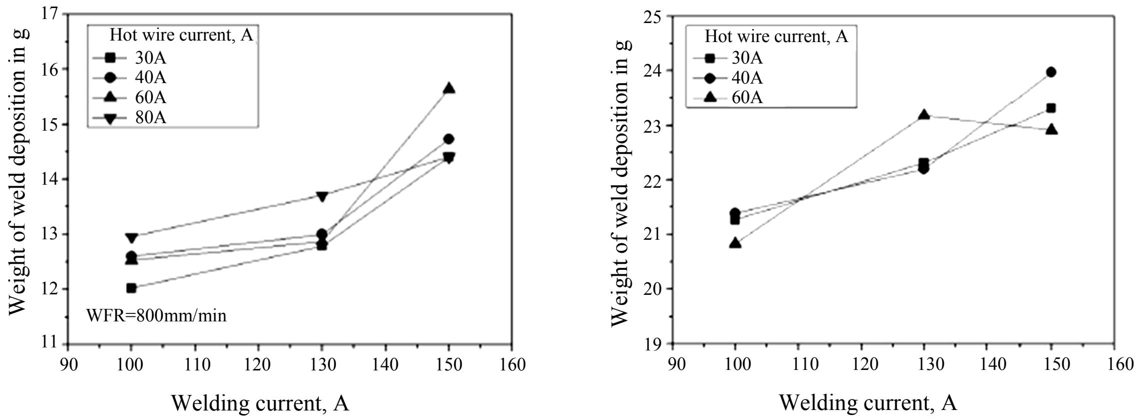

Fig. 9 Effect of deposition rate due to variation in arc current, hot wire current and wire feed rate[58)]

(a) Leading and trailing arc current
(b) Distance between two arcs
(c) Polarity of two arcs.

4.3.1 Effect of leading and trailing arc current

The leading arc current is more sensitive to penetration than trailing arc current. The ripple formation and surface appearance of weld bead is controlled by trailing current.

4.3.2 Effect of distance between two arcs

The separation between two electrodes has a significant effect on temperature and arc plasma flow field but a non-significant effect on peak temperature. As shown in Fig. 10. if the distance between two electrodes increases, the humping of weld bead and molten metal decreases for slower speed. But when simultaneously the speed is increased, the amount of molten metal increases. The effect of metal vapor due to electrode separation is analyzed and it is found that having 9 mm separation between electrodes creates intensive constriction of arc and temperature profile[9)].

4.3.3 Effect of polarity of two electrodes

If the two electrodes are having opposite polarity then it is observed that the arc is constricted and controlled as per Lorentz effect. The arc force is also higher as compared to similar polarity[2)].

It has been also observed that increasing in wire extension value leads to increase in melting rate[13)].

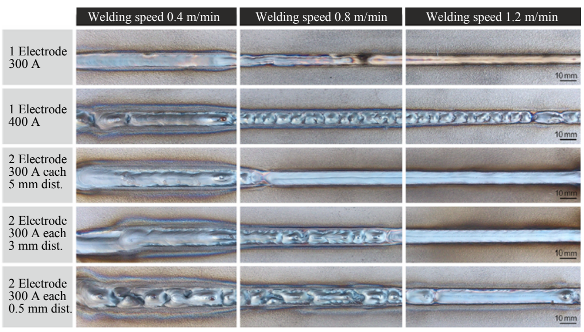

Fig. 10 Variation of weld bead profile for different electrode spacing of dual electrode GTAW[13)]

Conclusions

From the literature survey, it can be concluded that little research is available that combines the three unique characteristics namely twin electrode, usage of hot filler wire and pulsed power source of TIG welding process. Hence following conclusive remarks can be made which identifies the special features of individual and then in combined form.

- T-TIG welding is developed to increase the current capacity of electrode and thus to increase the metal deposition rate. In single electrode TIG welding process as current increases, arc pressure increases. This unstable arc causes welding defects like undercut and burn through. But T-TIG welding process reduces arc pressure drastically when appropriate distance is kept between two electrodes. As this process is used at high speed, maximum advantage can be achieved in automated welding.
- It is observed that most of the heat from TIG arc plasma is utilized to heat the filler metal as well as base material from room temperature to melting point temperature. By using hot filler wire, requirement of heat from plasma can be reduced and deposition rate can be increased.
- In pulsed welding the net heat input is lesser than constant current welding process. This reduces the grain size and increases impact strength. From literature review it is observed that it also increases the depth of penetration, provides good strength for dissimilar material by thermal pulsing at high frequency.
- So, there is a high potential that deposition rate can be

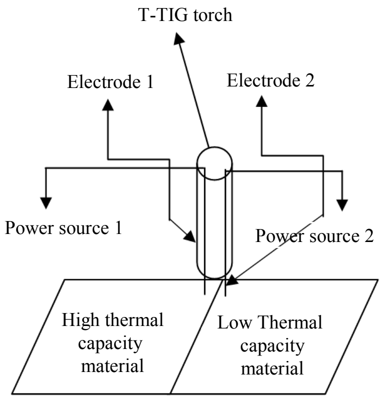

Fig. 11 Block diagram for proposal of dissimilar material

increased drastically by combining hot wire with T-TIG welding process. And if pulsed power source adds into it then there is a good potential to weld dissimilar materials, to obtain control on grain size and weld bead productively. Automated T-TIG can be an attractive option to replace SAW welding process for cladding due to lower dilution, optimized bead height and highly control on parameter resulting an exceptional weld quality

- However, the limitation of integration of above three processes is high capital cost and large number of influencing process parameters involved. So, large numbers of experiments are required to identify the relationship between process parameters and on output response like mechanical properties, weld bead geometry, etc.

Proposed T-TIG Process for dissimilar thermal capacity material either due to dissimilar thickness or thermal conductivity

As in T-TIG welding process, two independent power sources are there and that can operate at different current. So, with this unique characteristic, it is possible to supply lower current to high thermal capacity and higher current to low thermal capacity as shown in Fig. 11.This combination can meet the stringent requirement of dissimilar welding.

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