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Techniques to improveweld penetration in TIG welding (A review)

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Abstract

Tungsten Inert Gas (TIG) welding is also known as Gas Tungsten Arc Welding (GTAW) process which is an arc based welding process that uses the arc between a non-consumable tungsten electrode and a work piece with the help of a shielding gas [1-6]. The TIG welding is used to produce high quality welds and isone of the most popular technologies for welding in manufacturing industries [7-12]. The main disadvantage of TIG welding process is low weld penetration. The purpose of this review was to look into various techniques that may improve the weld penetration and weld quality in a TIG welding. In this review we discuss the influence of various types methods such as ATIG (Activated Flux TIG), FBTIG (Flux Bounded TIG), PCTIG (Pulsed Current Tungsten Inert Gas) Welding.It was observed during the review that use of flux or fluxes and pulsed current method improve the weld penetration with weld quality.

*Keywords:*TIG welding, ATIG welding, FBTIG welding, PCGTIG welding, weld penetration depth, TIG welding penetration profile, TIG welding variations and versions

1. Introduction

TIG welding is a process where parts are joined together by application of heat generated due to an arc struck between a non-consumable Tungsten electrode and the job in presence of a shielding gas. TIG welding is applied to weld sheet, tube, pipe, plate, and castings. Such fabricated products are used in shipbuilding, power generation, aerospace, and other industries [13-18]. TIG welding process may use a filler material. There is a variant in the process which does not require filler material. Such process is known an Autogenous TIG welding.Generally, a single pass autogenous TIG welding is used to weld materials upto 3mm thick. For welding thicker material multi-

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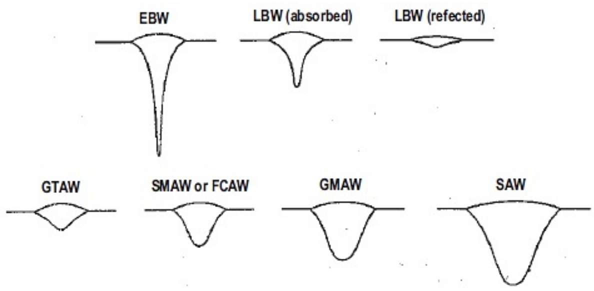
pass weld is required. This is time consuming. Unlike few other welding processes, the penetration of TIG process is not impressive. The depth of penetration in various types of welding is schematically shown in Fig. 1. It can be seen clearly that the penetration is least in case of TIG welding. Due to the lack of penetration capability of TIG welding, but owing to the fact that the welded surface of this process is free from slag and any other inclusion, TIG welding in many cases is used only to weld root passes [19-23]To enhance productivity during fabrication in any industry, penetration during weldinghas to improve.This is the main focus of this review. Thispaper also summarizes the improvements achieved in terms of penetration during TIG welding.



EBM: Electron Beam Welding
LBW: Laser Beam Welding
SAW: Submerged Arc Welding
GMAW: Gas Metal Arc Welding
SMAW: Shielded Metal Arc Welding
FCAW: Flux Cored Arc Welding
GTAW: Gas Tungsten Arc Welding

Where:
Fig.1. Comparison of penetration depth in various welding process [18]

A proper selection of parameters during TIG welding like current, torch speed, arc voltage, arc gap, electrode diameter, electrode tip angle, shielding gas and flux improve penetration as well as weld quality [24-32]. Several modifications on TIG welding have been developed which increase the penetration. These are activated flux tungsten inert gas welding (ATIG), flux bound tungsten inert gas welding (FBTIG), pulsed current tungsten inert gas welding (PCTIG). Fig.2. shows several techniques to increase the penetration in TIG welding.

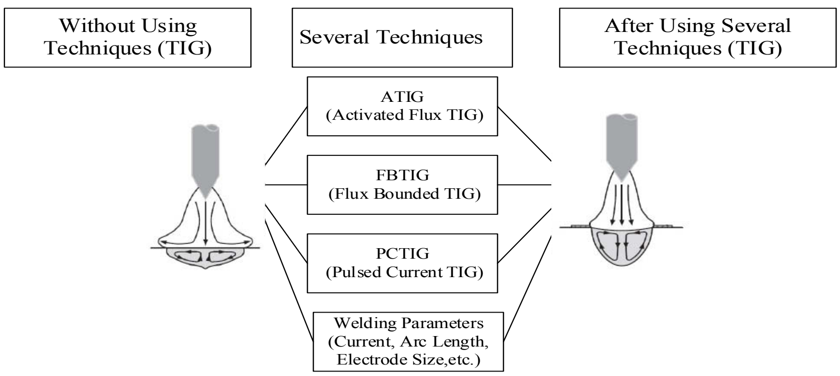
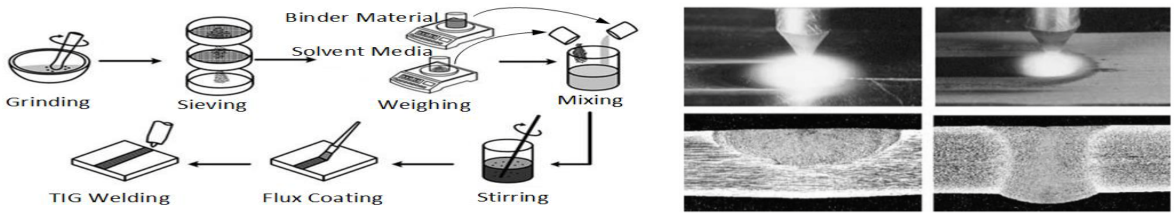


Fig.2. shows several methods to increase the penetration in TIG welding

2. Welding Mechanisms: ATIG (Activated Flux TIG)

Activated Flux TIG welding is a unique joining process, invented at Paton Institute of electric welding in 1960. ATIG welding process is also called flux zoned TIG (FZTIG) [33-36]. In this process a thin layer of activating flux is covered on weld surface of the joint, a brief explanation and preparation procedures of activating flux is shown in Fig.3.(a). A comparison of the penetration of TIG and ATIG are shown in Fig.3.(b) in this the left side of the figure showsconventional TIG welding whereas the right side shows an ATIG processes. The photographs of the cross section of the welds show that deep penetration is achieved in the ATIG compared to TIG. Table 1 show the numbers of activated flux which are used in TIG welding to improve the weld penetration [37-42]. The flux is mixedwith a binder (sodium silicate) and a solvent (acetone or methanol). These bind the flux paste on the metal surface in the form of coated layer. Flux playsan important role to enhance the penetration with the help of convection flow of liquid metal. The weld pool is governed by various types of forces namely Buoyancy force, Marangoni convection (surface tension) and Lorentz force (electro-magnetic)[6, 9, 18, 28]. The ATIG process aids to increase the weld penetration in thick materialssuch as plates or pipes by single pass without any edge preparation or use of filler metal. The weld penetration in ATIG processimproves twice or thrice to that of the conventional TIG welding process. The microstructure, shape and mechanical properties of the weld are also improved when welded by this process [13-17, 43-45].



(a) (b)

Fig.3. (a) Preparation procedures of activated flux (A-TIG) welding [33]; (b) Schematic of (Left Side) TIG and (Right Side) ATIG Welding [34]

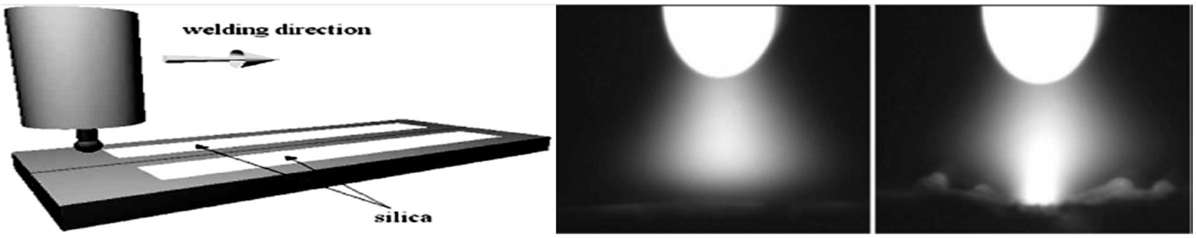
Tables1. Physical Characteristics of oxide fluxes [1-45, 77,78]

S.No.	IUPAC*Name of Flux	Molecular formula of flux	Density ρ (g/cm^3)	Flux Appearance
1	Aluminium oxide	Al_2O_3	3.95	White solid, odourless
2	Calcium chloride	$CaCl_2$	2.15	White powder, hygroscopic, odourless
3	Magnesium chloride	$MgCl_2$	2.32	White or colourless crystalline solid
4	Lithium fluoride	LiF	2.635	White powder or transparent crystals,non-hygroscopic
5	Chromium Fluoride	CrF_2	3.79	Blue-green iridescent crystals and hygroscopic, turns to cr2o3 when heated in air
6	Titanium (IV) oxide	TiO_2	4.23	White solid, odourless
7	Potassium Chloride	KCl	1.98	White crystalline solid, odourless
8	Silicon dioxide	SiO_2	2.65	Transparent crystals
9	Sodium sulfate	Na_2SO_4	2.66	White crystalline solid hygroscopic, odourless
10	Calcium oxide powder	CaO	3.35	White to pale yellow/brown powder, odourless
11	Chromium(III) Chloride	$CrCl_3$	2.87	Purple when anhydrous, dark green when hexahydrate
12	Fluorite	CaF_2	-	Colourless
13	Ferric oxide red	Fe_2O_3	5.24	Red-brown solid, odourless
14	Zinc oxide Pure	ZnO	5.61	White solid, odourless
15	Manganese dioxide powder technical	MnO_2	5.03	Brown-black solid, odourless
16	Chromium (VI) oxide purified	Cr_2O_3	2.70	Dark purple solid, odourless

*IUPAC: International Union of Pure and Applied Chemistry

3. Welding Mechanisms: FBTIG (Flux Bounded TIG)

In flux bounded TIG process welding mechanism it was initially developed to improve deep weld penetration in aluminum alloys [46-54,18]. A flux-bounded coating (FBTIG technique), gave very favorable results in the penetration during welding. Flux was pre-placed before welding [55-56]. This FBTIG process is similar to ATIG welding except that the flux coating is applied on the top surface, slightly away from the center of joint, of the two plates in such a way that a small clearance remains between the pieces to be joined.The penetration decreases when thisgap between the bounded fluxes increases or not properly coated. The weld penetration decreases with an increase inthe flux coating gap [57]. Fig.4. shows the schematic diagram of FBTIG welding [18].



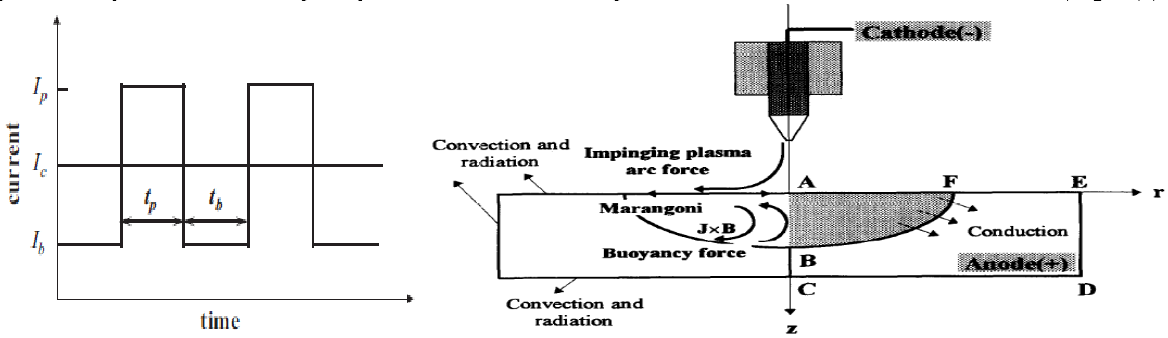
(a) (b)

Fig.4. (a) Show the schematic diagram of FBTIG welding; (b) Arc flow of (Left Side) TIG and (Right Side) FBTIG Welding process.

The same (ATIG) flux is also used in FBTIG process which is shown in Table 1.Not only are single fluxes used but research was carried out on mixture of these. A New multi-component flux AF305 was developed by the researchers to weld aluminum alloy to improve weld penetration in TIG welding [57-59].

4. Welding Mechanisms: PCTIG (Pulsed Current TIG)

This is another type of TIG welding mechanism where current pulses based on pulse parameters are utilized instead of steady current. Several researchers have worked and are still working to improve these pulse parameters to maximize the weld penetration. There are four important parameters in Pulse current TIG welding i.e. peak current, background current, pulse-on-time and pulse frequency [60-65]. The weld penetration, here, is thus dependent on the workpiece,its thermal properties and plate thickness [66]. In pulsed TIG welding, the magnitude of the pulsed current is that which interchanges between high (peak) current, Ip, and low (base) current, Ib. This varies periodically at a definite frequency. The schematic of the process, as mentioned above, is shown in (Fig.5.(a) & (b)).



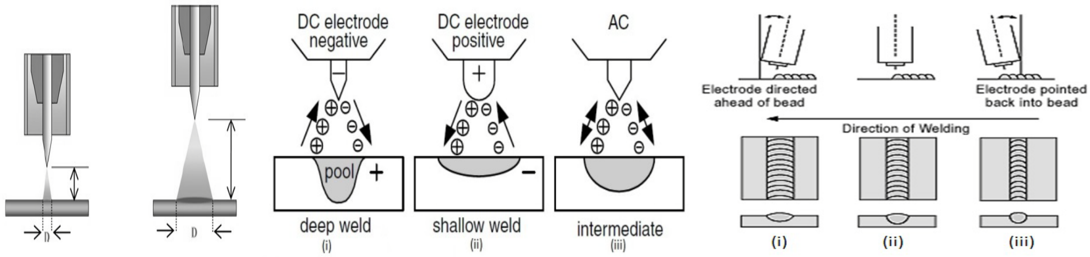
(a) (b)

Fig.5. (a) Schematic sketch of continuous current and pulsed current waveform [65]; (b) Schematic representation of TIG welding pool with driving forces [68]

Each pulse in weld pool, the peak current heat and melt the work specimen and the base current maintains the arc burning. It is also used in different industrial applications for its excellent weld quality [67-68].

5. Welding Parameter and process helps to improve the weld bead penetration in TIG welding

The first step to welding after selectinga material for welding is to know their chemical composition, thermo-physical properties of material (i.e. Density, Thermal conductivity, Specific heat, Thermal expansion coefficient, Latent heat, etc.) and thermal diffusivity[69-71]. Before TIG welding, all rust, grease, dirt, oil, paint, and other contaminations must be removed from the welded surface. Weld bead penetration is also depended on the arc length and electrode condition, current polarity on weld shape, travel speed, angle of the torch and shielding gas coverage [72-76].Fig.6 (a)shows how arc length influencesthe melting pool (D) where "D" is weld pool shape. It shows, the way in which the arc length influences the melting pool (D). It also shows the way in which the arc turn out to be wider with consequent rise of the heat output on the base material which is subjected to overheating [31, 44].



(a) (b) (c)

Fig.6. (a) Arc length on weld shape; (b) Effect of current polarity on weld shape; (c)Angle of the torch with welding direction

Fig.6. (b)-(i) shows Direct Current Electrode Negative(DCEN) in which electrons flow (cathode (-)) towards workpiece (anode i.e. Ions (+) flow), it is also known as Straight Polarity. Flow directionaid to form deeper penetration and narrow weld pool area at a range of approximate 30% heat in electrode and 70% heat in base metal. (ii) Direct Current Electrode Positive (DCEP) in which electrons flow just opposite direction toward electrode (+) to workpiece (-), it is also known as Reverse Polarity.Flow direction form shallow weld with less weld penetration in weld pool area at a range of approximate 70% heat in electrode and 30% heat in base metal [2, 17-18]. (iii) Alternating Current(AC) TIG welding, the duration of alternating current can be sub divided into DCEN and DCEP durations that means 50% heat in electrode and 50% heat in workpiece (base metal) [31, 44, 65-66]. Fig.6. (c) shows the angle of torch/electrode and welding directions which also effect weld pool shape and size of the weld bead geometries [2, 31, 44, 66].

6. Conclusion

This paper shows an overview of different methods used to increase the penetration of weld penetration as well as improvement in TIG welding process has been described properly. According to literature review, Most of the experimental studies are reviewed to improveTIG welding process and their mechanical properties.

The following conclusions may be drawn from the literature review-

- ATIG(Activated flux TIG) welding achieves significant improvement in penetration compared to conventional TIG. Flux used in the process probably make arc narrow in the molten weld pool and thus reduce the weld bead width by half compared to that ofconventional TIG welding and thereby increase the weld penetration.
- FBTIG (Flux Bounded TIG) welding also generatesfull penetration. The drawback of this process is that if distance between the flux paints on top of the plates across the weld joint increase, then the weld penetration decreases vice-versa.
- PCTIG (Pulsed Current TIG) welding, it is found that if peak current is high, then higher ripplesoccur which results adeeper weld penetration. When pulsed current is larger, the frequency leads to form more uniform thermal energy distributions on the workpiece and thus, it tends to decrease the solidification rate. The penetration is more uniform and the pitch, height of the ripples, is reduced. A slow travel speed is helpful to reduce the pitch of the ripples but this reduces effective penetration. The performance of pulsed current TIG welding is better than non -pulsed current welding
- Proper selection of Welding Parameter also play an important role to improve the weld quality and increase the weld bead penetration in TIG welding

7. Future Scope

- This all techniques give an idea to welder, how to weld the specimen with proper selection and control initial welding parameter which play an important role to improve the weld quality in TIG welding to increase the weld bead penetration and weld quality.
- Using mixture oftwo fluxestogether according to their chemical composition, thermo-physical properties and thermal diffusivity of material it willincrease more weld penetration in thick material while using single flux.

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