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A Review: Parametric effect on mechanical properties and weld bead geometry of Aluminium alloy in GTAW

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Abstract: *Gas tungsten arc welding (GTAW) is high quality and high precision welding process which are suitable for welding thin metals. Inert gas as helium and argon are used as a shielding gas to prevent the weld bead from air, dust and other contaminations in welding. There are so many welding process parameter affect the weld quality in GTAW. Important process parameter which mainly affect the weld quality are welding current, arc voltage, welding speed, gas flow rate, heat input, gun angle, stand of distance and specimen thickness. Important quality parameters in GTAW process are depth of penetration and weld bead geometry. Depth of penetration and weld bead width both are affected by welding speed. As welding speed increases, depth of penetration increases but weld bead width decreases. The weld joint quality can be assessed in terms of weld bead geometry, mechanical properties and distortion. Post weld heat treatment is done to improve the weld quality by solutioning and aging which results in refinement of grain size and thus, mechanical properties of weld joint improved. Heat input effects the filler rod deposition rate in the form of droplets in weld bead. This paper covers review of process parameters of GTAW and their effect on weld quality.*

Keywords: *Depth of penetration, GTAW, Heat affected zone, mechanical properties, Parametric effect, Weld bead geometry.*

Contents

I. Introduction

Welding is fabrication process for joining materials, usually metals or thermoplastics, by the application of heat due to an electric arc produced between electrode and base metal. Significant impact of welding has made on large number of industries due to their raising operational efficiency & productivity of plant. Welding has capability to use in any position such as horizontal, flat, vertical (up and down) and overhead. [1]. Generally, constant current and constant voltage power supplies are available to use for welding the materials. An electric arc directly related to voltage and amount of heat generated related to current [2]. Gas tungsten arc welding is manual welding process in which non- consumable tungsten electrode, an inert gas and a filler rod used. GTAW process is specially preferred for thin materials due to characterizing a stable arc, high weld quality, better reliability, smooth finishing and high productivity [3]. Many factors influence the strength of weld joint and material around them are heat input, weld ability of base material, filler material, arc voltage and design of joint [4]. Aluminium is most abundant metal of low density and corrosion resistant property due to phenomenon of passivation. GTAW is preferred to weld aluminium alloy at low voltage. Aluminium and its alloys has applications to make structural components of aerospace industry, ship building, vehicle bodies, mine skips and pressure vessels [5]. Aluminium has another property of recycling without any loss of its natural qualities. Recycling involves melting the scrap, A Process require only 5% of energy used to produce aluminium from ore. Recycled aluminium is known as secondary aluminium that is produced in a wide range of alloys [6].

II. Gas tungsten arc welding process

Gas tungsten arc welding is high quality, high precision and economic process that produces an electric arc between non-consumable tungsten electrode and base material that to be welded with the use of argon inert gas as a blanket to protect heat affected zone (HAZ), molten metal and electrode from atmospheric contaminations. The heat produced by the arc is used to melt the base material and high quality weld of desired composition is obtained by GTAW process without the application of pressure. GTAW is also known as Tungsten Inert Gas Welding. Fig. 1 shows schematic diagram of gas tungsten arc welding. Fig. 2 employs complete working of gas tungsten arc welding. Helium and Argon shielding gases are preferred to use for better welding and also does not chemically react or combine with each other [7]. The inert gas : i) shield the welding area from air, preventing oxidation, ii) transfer the heat from electrode to metal and iii) helps to start and maintain a stable arc (due to low ionization potential) [8].

During second world war in 1930's, Russell Meredith demonstrated GTAW process first for welding magnesium and aluminium in American aircraft industry with the use of tungsten electrode and helium shielding gas and investigate the effect of welding process parameters as welding current, arc voltage, welding speed, shielding gas flow rate, stand of distance between electrode & work piece on micro-structure and mechanical properties of weld joint [9]. Hydrogen cracking occurred in Gas Tungsten Arc (GTA) welded duplex stainless steel joint where hydrogen content and ferrite level relatively high due to moisture present in shielding gas and sufficient stress produced. The present trend is to substitute traditional quenched and tempered steels which require surface protection and use the corrosion resistant materials, such as stainless steel or titanium alloys [10].

Many delicate components in aircraft and nuclear reactors are GTA welded due to its reliability. Basically, GTA weld quality is strongly characterized by the weld pool geometry because the weld pool geometry plays an important role in determining the mechanical properties of the weld [11]. Maximum weld quality can be achieved by maintaining all equipments and material used must be free from oil, moisture, dust and other impurities that cause porosity which results as feeble weld joint [12]. Due to developments, a number of variations exists now these days such as pulsed current, manual programmed, hot-wire, dabber and increased penetration GTAW methods[13].

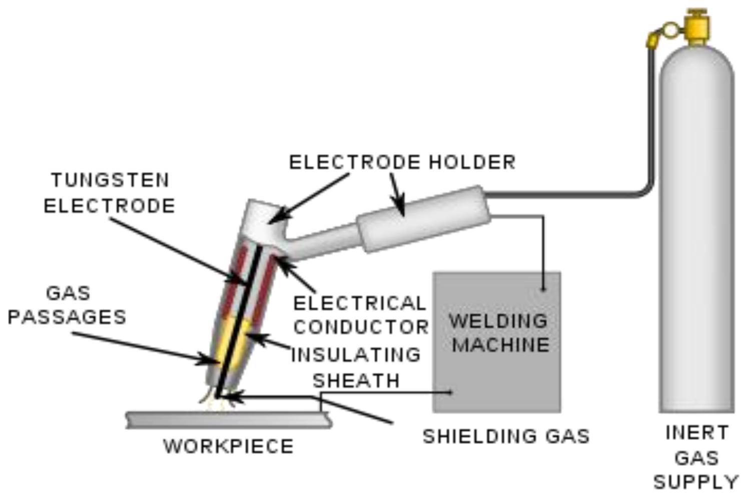


Figure 1: Schematic arrangement of gas tungsten arc welding

2.1 Gas tungsten arc welding process parameters

The selection of parameters plays an important role which influence the weld joint quality. Welding input parameters has significant influence on the weld bead quality that may be constant or variable. Parameters of GTAW process are discussed below:-

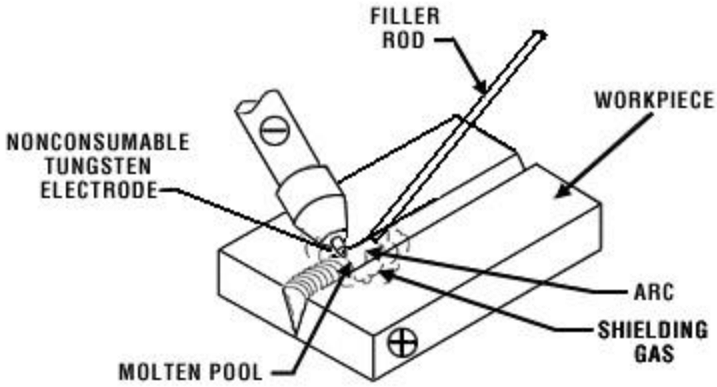


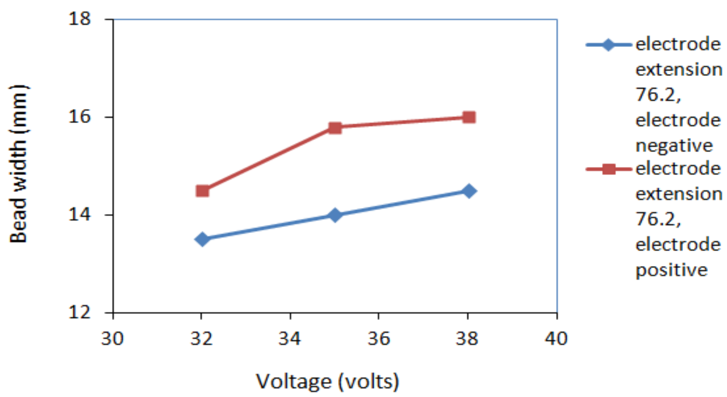
Figure 2: Working of gas tungsten arc welding (after Casanueva et al.[29])

2.1.1 Welding power polarity

Power polarity is the indication of current flow direction. The power polarity influences the heat generated between non-consumable tungsten electrode and base material in welding process which depends on the type of polarity such as DCEN or DCEP [14]. One third of total heat is generated in negative electrode (straight) polarity and two third of total heat is generated in positive electrode (reverse) polarity. An electric arc is more spread in electrode negative polarity than in positive electrode polarity which results as more weld bead width and less penetration because of more electrode melting rate in DCEN as compare to DCEP [15].

2.1.2 Arc voltage and stand of distance

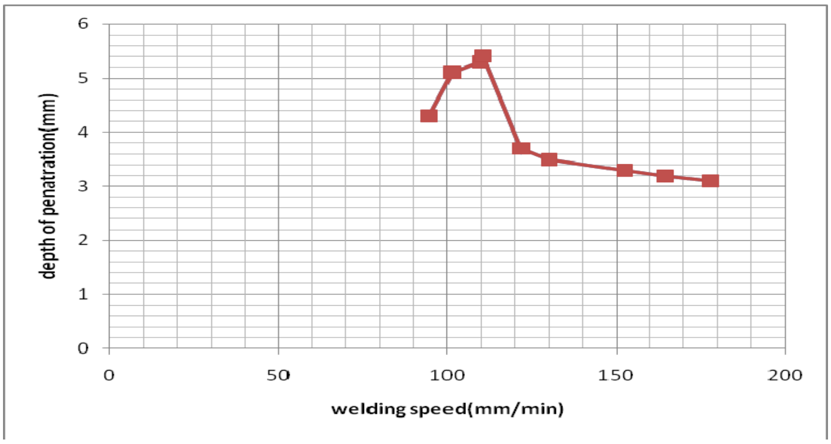
Arc voltage and stand of distance are efficient parameters which help to control and generate continuous electric arc between non-consumable tungsten electrode and base material in welding process. The arc is electrically characterized by low voltage about 10 volt and high current value [16]. Increased arc voltage increases the arc length which results in wider bead width [17]. As increased arc voltage increases arc length, more heat is generated on base material surface which results in melting of filler rod and base material. A graph 1 shows that weld bead width increases with increased arc voltage for a particular power polarity of DCEN or DCEP.



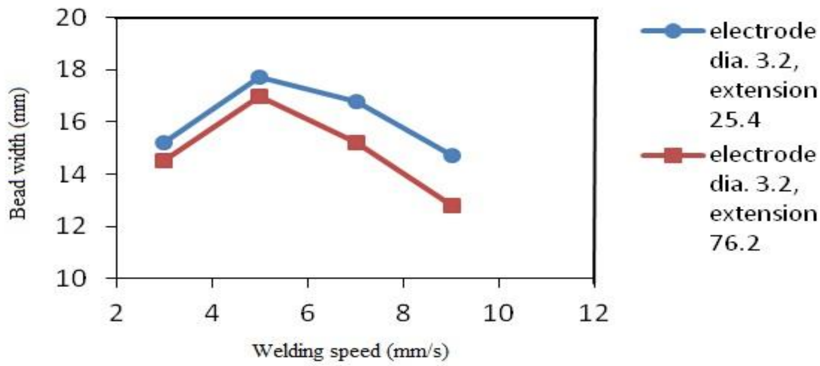
Graph 1: Effect of arc voltage on bead width (after Yang et al. [18])

2.1.3 Welding speed

Welding speed/travel speed is another parameter which controls the depth of penetration with its variation. Depth of penetration is more in slow welding speed as compare to fast welding speed shown in graph 2. So as increased welding speed results in decreasing weld bead width [19]. It is clear from graph 3 that the weld bead increases till optimum value but it decreases with further increase in welding speed.



Graph 2: Effect of welding speed on Depth of penetration (after Tewari et al. [27])



Graph 3: Effect of welding speed on bead width (after Yang et al. [18])

2.1.4 Electrode

The electrode used in GTAW is made of tungsten or a tungsten alloy, because tungsten has the highest melting temperature among pure metals, at 3,422 °C. The diameter of the electrode can vary between 0.5 and 6.4 mm and their length can range from 75 to 610 mm. Filler rod is used similar in composition as the welded base material. Filler rods are generally available in various different grades such as 1100, 4043, 5154, 5183 and 5356 of aluminium alloys with standard diameters. Changed filler rod diameter in gas tungsten arc welding changes the current density for given current. Current density decreases as changing the filler rod diameter in increasing order. Pure tungsten electrodes are preferred to use in welding process because of low cost. They have poor heat resistance and electron emission. They find limited use in AC welding of e.g. magnesium and aluminium [20].

2.1.5 Shielding gas

The inert gases are used as a shielding gas in the form of blankets in gas tungsten arc welding. The main purpose of the use of inert gas in welding : i) To shield the welding area from air, preventing oxidation, ii) to transfer the heat from electrode to base material and iii) to helps to start and maintain a stable arc between electrode to base material (due to low ionization potential). There are various types of inert gas available as helium, neon, argon and mixture of gases. Shielding gas used for stainless steel as a backing. But argon and helium are used for aluminium, magnesium and other metals that oxidise readily [8]. Argon-helium mixtures are also frequently utilized in GTAW. But normally, the mixtures are made with primarily helium (often about 75% or higher) and a balance of argon. These mixtures increase the speed and quality of the AC welding of aluminium, and also make it easier to strike an arc. Another shielding gas as a mixture of argon-hydrogen, is used in the welding of stainless steel, but its use is limited because hydrogen can cause porosity [21].

III. Results for weld bead quality

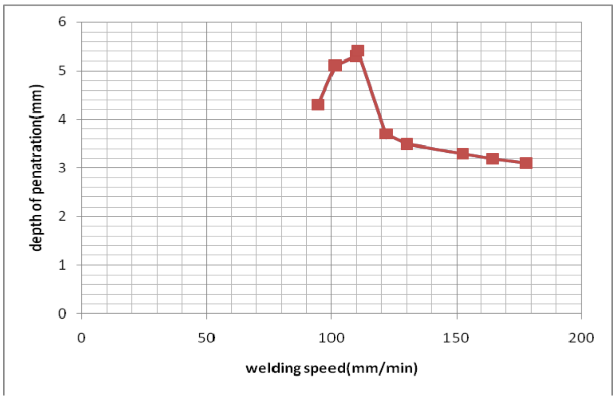
Gas tungsten arc welding is an arc welding process which has capability to weld thin materials with high productivity. This process is suitable for welding various kind of materials such as aluminium, magnesium, stainless steel, low alloy steel, high alloy steel, mild steel, monel, brass, bronze, tungsten, silver, molybdenum, and wide range of other metals. Review of parametric effect on weld joint quality in gas tungsten arc welding has been discussed below:-

3.1 Parametric effect on heat affected zone (HAZ)

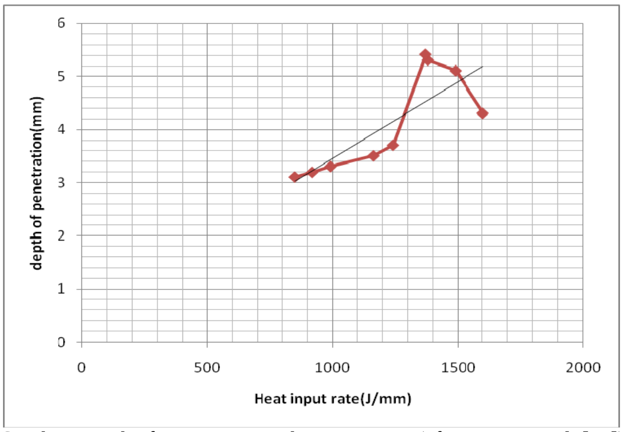
Weld bead size and quality can be controlled by selecting the process variables in gas tungsten arc welding process. Welding process parameters has made effect on heat affected zone of welded specimen of high strength low alloy metal found that thermal cycles of welding has a significant effect on grain size of martensite and austenite constituents. Investigation of micro-structure of welded alloy joints predict the existence of coarse grain in weld metal and heat affected zone due to increase in heat input. The heat affected zone is influenced with increase in heat input due to increase of current. The width of heat affected zone increased due to low heat input and no pre-heating of base metal [23].

3.2 Parametric effect on weld bead geometry

Productivity and weld bead geometry both are important in a welding process. Zhang et al. [22] had observed that the current variation has made influence on weld bead geometry as weld bead width, grain size and depth of penetration of three aluminium alloy specimens of different thickness (3.2 mm, 6.4 mm and 9.5 mm). As increased current value, weld bead width and depth of penetration increases with increase of heat generated. Micro-structure is improved by post weld heat treatment as solutioning and aging. Weld bead geometry influences the mechanical properties of weld joint but welding parameters influences the weld bead geometry. Ghosh et al. [23] had found that the affect of input parameters on weld bead geometry. There is negative effect of increased welding speed on weld bead geometry. The depth of penetration increases but weld bead width decreases with increase in current. Wide and flat weld bead produced with increase in arc voltage which results in decrease in depth of penetration. Li et al. [24] investigated that the weld bead geometry of weld repaired aluminium alloy is almost similar as cast aluminium alloy in appearance different in micro-structure. Olabi and Benyounis [25] had developed the mathematical relationship between welding input process parameters and weld joint output parameters using statistical and numerical approaches and suggested that these approaches are useful to determine the welding input parameters which lead to desired weld quality. Datta et al. [26] had observed that Taguchi method used for optimizing the weld bead geometry and heat affected zone in welding also revealed that the positive effect of current on the features of weld bead geometry and heat affected zone. Balaji et al. [7] had observed that In micro-structure of welded joint, austenitic coarse grain and fine grain are the present which results as fine grained area shows maximum tensile strength. Tewari et al. [27] had carried out As the welding speed increases, width of weld bead reduces but depth of penetration increases until an optimum welding speed values shown in graph 4. Increased welding speed results as decreasing heat input and electrode burn-off rate but maximum the depth of penetration occurs at greater heat input value shown in graph 5.



Graph 4: Depth of penetration Vs welding speed (after Tewari et al. [27])



Graph 5: Depth of penetration Vs heat input rate (after Tewari et al. [27])

3.3 Parametric effect on mechanical properties

The process parameters are arc voltage, current, filler rod feed rate and travel speed which are necessary to control because they influence the mechanical properties of welded joint. Balaji et al. [7] had observed the various effects of welding parameters like welding current, bevel angle and shielding gas flow rate on weld joint of similar graded material as (i) High tensile strength achieved at optimum values of current of 110 amp, bevel angle of 60 deg. and shielding gas flow rate of 0.7 Lt/min. (ii) hardness of weld joint found in order as Weldment > HAZ > Base metal. Zhang et al. [22] had observed that the strength property of thin plate of 3.2mm is efficient than other two plates of thickness 6.4mm and 9.5mm because of low HAZ present in weld bead. Li et al. [24] had found that Fatigue strength of cast aluminium alloy is affected by the existence of defects as cracks, pores and inclusions in the welded joint which results in decrease in fatigue life of aluminium alloy. Heat input parameter influences the cooling rate, weld bead size and mechanical properties of the weld [28].

IV. Discussion

Weld bead geometry and micro-structure of the welded joints is strongly influenced by process input variables in gas tungsten arc welding. Composition of base metal and filler rod have significant effect on micro-structure of weld metal. Mechanical properties of the welded joint depend on composition of base metal as well as on weld bead parameters and shape relationships which are mainly affected by the welding input parameters. The findings of researchers revealed that the affect of welding current, arc voltage, welding speed, filler rod and shielding gas on the weld bead geometry. Statistical and numerical approaches are useful to determine the optimum values of welding input parameters which lead to desired weld quality.

Quality of GTA welded joint depends on various process parameters. There may be less or more effect of welding parameters on weld quality are like welding current, arc voltage, gas flow rate, bevel angle, heat input, work piece thickness, stand of distance b/w electrode and work piece. The weld quality is measured in the form of microstructure’s grain size and mechanical properties of weld joint, which has requirement to find optimum condition for process parameters to give better quality of GTA weld joint.

So many investigations had done on GTAW process, weld bead quality and mechanical properties are improved with the use of optimum welding process parameters. But major problem with increase in welding speed is that weld bead width decreases and depth of penetration increases. Type of shielding gas and its flow rate also affect the weld bead quality by protect it from atmospheric contaminations. The following gaps in literature review have been revealed.

1. Very less work on metal transfer has been seen in gas tungsten arc welding. The metal is transferred uniformly in the form of small droplets from filler rod at given current. The material is transferred across the arc gap which influences the chemical composition and metallurgy of weld metal, arc stability, weld bead geometry as well as strength of the weld.
2. The study of the effect of changing the power polarity on metal transfer behaviour is scarce in gas tungsten arc welding. The effect of changing power polarity on the amount of heat generated between welding filler rod and base material and hence influences the metal deposition rate, weld bead geometry and mechanical properties of the weld metal.

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