A Comprehensive Review of Gas Tungsten Arc Welding (GTAW) with a Focus on Weld Parameters

G.Pugalvendhan[1], D.Noorullah[2], and K.Venkatesan[3]
[1]PG Student, Department of Metallurgical Engineering, Government College of Engineering, Salem-11
[2]Head of the Department, Department of Metallurgical Engineering, Government College of Engineering, Salem-11
[3]Professor, Department of Metallurgical Engineering, Government College of Engineering, Salem-11

Abstract: **This study reviews the critical parameters influencing Gas Tungsten Arc Welding (GTAW) and their impact on weld quality and performance. Welding current is identified as the most crucial factor affecting electrode burn-off, fusion depth, and weld geometry, with direct current electrode negative (DCEN) providing superior penetration and travel speed. Welding voltage, speed, and heat input play significant roles in controlling arc stability, heat transfer, and weld pool formation, ultimately shaping the weld's mechanical and metallurgical properties. The selection and composition of shielding gases such as argon, helium, and their mixtures notably affect arc temperature, plasma characteristics, and penetration through phenomena like current constriction and Marangoni convection. Electrode tip geometry influences arc concentration and heat flux distribution, impacting arc velocity and welding efficiency. The use of filler metals tailored to the base material's chemical and mechanical requirements ensures adequate strength, corrosion resistance, and crack prevention, particularly in thicker sections and specialized alloys. Understanding and optimizing these parameters enables the production of high-quality, defect-free welds with desired structural integrity and service performance.**

keywords: **GTAW, HAZ, Welding Speed, Voltage, Current, Heat Input, Shielding Gas, Filler Metal.**

I. INTRODUCTION

Gas Tungsten Arc Welding (GTAW), also known as Tungsten Inert Gas (TIG) welding, is a precision arc welding process widely used in industries requiring high-quality and clean welds. It utilizes a non-consumable tungsten electrode to produce the weld, while an inert shielding gas commonly argon or helium—protects the weld pool from atmospheric contamination. GTAW is especially suitable for welding thin sections of stainless steel, aluminum, magnesium, and other non-ferrous metals where excellent control over weld penetration and bead shape is essential.

The process offers superior weld quality with minimal spatter, allowing for strong, aesthetically clean joints with excellent corrosion resistance and mechanical properties. GTAW operates by establishing an electric arc between the tungsten electrode and the workpiece, generating localized heat sufficient to melt the base metal and, when necessary, a filler metal. The inert gas shield prevents oxidation and contamination of the weld area, which is critical in maintaining the integrity of the weld.

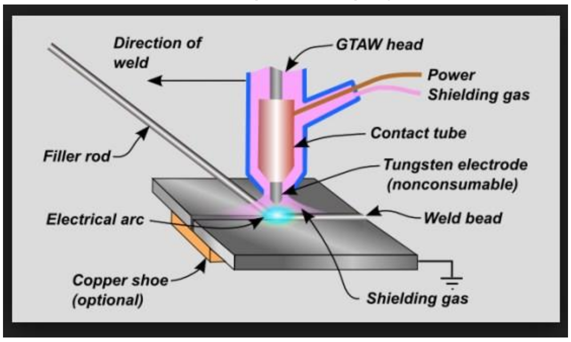

Fig. 1 GTAW Process

Key parameters in GTAW, such as welding current, voltage, welding speed, shielding gas composition, and electrode geometry, greatly influence the weld's characteristics, including penetration depth, bead shape, and microstructure. Due to its precision and control, GTAW is extensively employed in aerospace, nuclear, chemical, and automotive industries, where high weld quality and reliability are paramount.

II. GTAW PROCESS PARAMETERS

WELDING CURRENT:

Welding current is the most critical parameter in the arc welding process, influencing the electrode burn-off rate, fusion depth, and weld geometry. It directly affects the weld bead shape, welding speed, and overall weld quality. In Gas Tungsten Arc Welding (GTAW), direct current with electrode negative (DCEN), also known as straight polarity, is commonly used because it provides deeper weld penetration and higher travel speed compared to electrode positive (DCEP), or reverse polarity.

Reverse polarity causes rapid heating and deterioration of the electrode tip, as the anode experiences greater heat than the cathode in a gas tungsten arc. Excessive welding current can result in spatter and damage to the workpiece, while insufficient current may cause the filler wire to stick.

Additionally, using a lower welding current can lead to a larger heat-affected zone, since the same amount of filler material requires prolonged exposure to high temperatures. In fixed current mode, the voltage adjusts automatically to maintain a constant arc current [1 & 2].

WELDING VOLTAGE:

Welding voltage refers to the electrical potential difference between the tip of the welding wire and the surface of the molten weld pool. Depending on the GTAW equipment, this voltage can be either fixed or adjustable. It plays a key role in shaping the fusion zone and determining weld reinforcement.

A higher initial voltage facilitates easier arc initiation and allows for a greater range of working distances between the electrode and the workpiece. However, high voltage tends to produce wider, flatter welds with reduced penetration compared to lower voltages. Maximum penetration is achieved at an optimal arc voltage, while excessively high voltage can cause significant variations in weld quality [3]

WELDING SPEED:

Welding speed is defined as the rate at which the electrode travels along the seam, or alternatively, the rate at which the workpiece moves under the electrode along the seam [4]. It is calculated using the formula:
Weld Travel Speed = Distance traveled by the electrode / Arc time (mm/min). [5]

In Gas Tungsten Arc Welding (GTAW), welding speed is a key parameter. Increasing the welding speed while keeping current and voltage constant results in reduced heat input. Since electromagnetic forces and arc pressure are determined by the current, welding speed has no effect on them. As welding speed increases, the weld cross-sectional area decreases, leading to reductions in both penetration depth (D) and weld width (W). However, the depth-to-width (D/W) ratio is only slightly affected by travel speed.

These findings indicate that welding speed does not impact the underlying mechanisms of weld pool formation, but rather influences the volume of molten material. Typical welding speeds range from 100 to 500 mm/min, depending on factors such as current, material type, and plate thickness.

HEAT INPUT

Heat input is a relative measure of the energy delivered per unit length of the weld. It plays a crucial role in determining the cooling rate higher heat input leads to slower cooling, while lower heat input results in faster cooling. Similar to preheat and interpass temperature, heat input significantly influences the cooling rate, which in turn can affect the mechanical properties and metallurgical structure of both the weld and the heat-affected zone (HAZ).

In arc welding, energy is transferred from the welding electrode to the base metal through an electric arc. When the arc is initiated, a sufficient amount of power (energy per unit time) and energy density is delivered to the electrode. This energy melts both the base metal and the filler metal, forming the weld.

Heat input is typically calculated using the following formula:

$$H = (\eta \times I \times V) / s$$

Where:
- H = Heat input (kJ/mm)
- η = Process efficiency (0.60 for GTAW)
- I = Current (Amps)
- V = Voltage (Volts)
- s = Welding speed (mm/sec)

This equation helps quantify the energy applied to the workpiece, aiding in controlling weld quality and structural characteristics.

SHIELDING GASES:

Helium has lower electrical conductivity compared to argon, which reduces the diameter of the current channel and leads to current constriction. This constriction causes a higher peak in heat intensity. As a result, the temperature on the anode surface can be nearly twice as high when using helium compared to argon. Consequently, heat transfer by electrons becomes more concentrated along the arc axis.

CO_2 welding produces even higher anode surface temperatures than helium. This is due to CO_2's greater molecular weight and molar specific heat, which increase current constriction near the cathode and raise the plasma temperature.

The thermal conductivity of argon-shielded arc plasma can be improved by adding hydrogen and introducing 10% hydrogen into argon leads to a more constricted arc plasma.

Argon also has a significantly lower ionization energy than helium, allowing easier arc ignition at greater electrode-to-workpiece distances up to 13 mm. When a helium-argon gas mixture is used, increasing the argon content improves arc ignition over larger distances.

Further found that adding a small amount of oxygen (around 0.2%) to a helium-argon mixture increases the weld penetration depth and the depth-to-width ratio. This improvement is attributed to a change in Marangoni convection behavior. Normally, surface tension in the weld pool is higher at the cooler pool edges than at the hotter center under the arc, causing fluid to flow outward from the center. This outward flow distributes heat toward the edges, resulting in a wider, shallower weld. However, adding trace elements like oxygen reverses the direction of fluid flow from the edges to the center thereby enhancing penetration and producing a deeper, narrower weld. Additionally, adding hydrogen to argon increases the arc plasma's melting efficiency, leading to improved welding performance.

ELECTRODE TIP GEOMETRY:

During their experiments, Abid et al. [7] observed that the arc temperature near the electrode tip is highest when the tip is sharp and gradually decreases as the electrode tip angle increases. This occurs because sharper tips have a smaller cross-sectional area, resulting in higher localized heating compared to blunter tips. However, the electrode tip angle has little to no significant effect on the arc temperature just above the surface of the workpiece.

The electrode tip angle does influence arc velocity, which was found to decrease as the tip angle increases. Similarly, current density exhibits an inverse relationship with the tip angle—current density at the cathode decreases as the tip angle becomes larger. This reduction is attributed to the lower electrical potential in the arc associated with wider tip angles. Interestingly, the distribution of current density on the anode surface remains largely unaffected by changes in the tip angle.

Heat flux resulting from conduction and convection is more sensitive to changes in tip angle and tends to decrease as the angle increases. However, the heat flux due to electron transfer—which constitutes the majority of the total heat flux—remains largely unchanged regardless of the electrode tip angle.

FILLER METAL

Filler metals are typically used when welding plates thicker than 2 mm and are selected to have a chemical composition similar to that of the base material. The diameter of filler metals generally ranges from 1.6 to 3.2 mm, and in automated systems, they are usually fed cold from a roll or coil.

Many austenitic stainless steels can be welded without the use of filler metal or post-weld heat treatment. However, most super austenitic alloys require filler metals to ensure the weld achieves adequate corrosion resistance. In general, the weld metal meets or exceeds the minimum yield and tensile strength of the annealed base metal. Although the ductility of the weld is typically lower than that of the base metal, it remains sufficiently high for most applications.

For corrosion-resistant applications, low-carbon filler metals (L-grades) are preferred. In contrast, for high-temperature applications, higher carbon filler metals may provide superior strength at elevated temperatures.

The compositions of many filler metals, particularly those in the 300 series, are modified to promote the

formation of a controlled amount of ferrite during solidification. This helps prevent hot cracking, allowing for the use of higher heat inputs and faster welding speeds. However, the presence of ferrite also makes these welds slightly ferromagnetic.
Alloys that solidify as fully or nearly fully austenitic must be welded using lower heat inputs to avoid cracking. In certain cases, low-ferrite weld metal is preferred, and specific filler metals are designed for this purpose. For most 300 series stainless steels, a nominally matching filler metal is commonly used [6].

III. CONCLUSIONS

WELDING CURRENT:

Welding current is the most influential parameter, directly affecting penetration depth, bead geometry, and electrode behavior. In GTAW, DCEN is typically preferred for deeper penetration and better control. An optimal current setting is critical, as excessive current can damage the workpiece while insufficient current may lead to poor fusion and filler wire issues.

WELDING VOLTAGE:

Voltage controls arc stability and fusion zone geometry. While a higher voltage facilitates arc initiation and tolerance in tip-to-work distance, it can also lead to shallow and wider welds. Optimum voltage ensures proper penetration and consistent weld quality.

WELDING SPEED:

Speed affects the heat input and consequently the size and shape of the weld pool. Higher welding speeds reduce heat input, leading to narrower and shallower welds. While it does not impact electromagnetic forces or arc pressure, it controls the amount of molten metal and weld profile consistency.

HEAT INPUT:

Heat input is a critical factor determining cooling rates, which influence microstructure and mechanical properties of both the weld and HAZ. Proper calculation and control of heat input ensure adequate fusion, minimized residual stresses, and optimized structural integrity.

SHIELDING GASES:

The choice and composition of shielding gases affect arc characteristics, heat intensity, and weld pool behavior. Helium and CO_2 create high plasma temperatures due to current constriction, while additions like hydrogen and oxygen influence arc constriction, penetration, and Marangoni convection. These adjustments enhance weld depth, efficiency, and shape based on application needs.

ELECTRODE TIP GEOMETRY:

The tip angle significantly affects arc concentration, velocity, and current density. Sharper tips produce more intense arcs and higher heat localization, whereas larger angles distribute energy more broadly. Although electron heat flux remains consistent, conduction and convection heat fluxes decrease with increasing tip angles, influencing arc stability and efficiency.

FILLER METALS:

Filler metals ensure mechanical strength and corrosion resistance in thicker sections. Proper selection—based on carbon content, composition, and intended service conditions—is essential to avoid hot cracking and achieve desired weld performance. Controlled ferrite formation helps prevent cracking and supports higher heat inputs, while specific low- or high-ferrite fillers serve niche requirements.

Overall, achieving optimal GTAW weld quality involves a careful balance of these interrelated parameters. Each must be tailored to the material, thickness, and intended application to ensure a structurally sound, durable, and defect-free weld.

REFERENCES

[1] SEO, D.W., JEON, Y.B. AND LIM, J.K. (2003) Effect of Electric Weld Current on Spatter Reduction in Spot Welding Process. Key Engineering Materials, 261-263, 1623-1628.

[2] ATMA, R.M.R. AND JOY, V.V.M. (2014) Determination of Distortion Development during TIG Welding of Low Carbon Steel Plate. International Journal of Engineering Research, 1, 23-29.

[3] TEWARI, S.P., GUPTA, A. AND PRAKASH, J. (2010) Effect of Welding Parameters on the Weldability of Materials. International Journal of Engineering Science and Technology, 2, 512-516.
[4] ABIOYE, T.E. (2017) The Effect of Heat Input on the Mechanical and Corrosion Properties of AISI 304 Electric Arc Weldments. British Journal of Applied Science and Technology, 20, 1-10.
[5] CHUAIPHAN, SRIJAROENPRAMONG L. (2013) Effect of Welding Speed on Microstructures, Mechanical Properties and Corrosion Behavior of GTA Welded AISI 201 Stainless Steel Sheets. Journal of Materials Processing Technology, 214, 402-408.
[6] ARUN, N., CIJO, M., VINOD, Y.B. AND JOBY, J. (2013) Influence of Gas Tungsten Arc Welding Parameters on Aluminum 5083 Alloy. International Journal of Engineering Science and Innovative Technology, 2, 113-118.
[7] M. ABID, S. PARVEZ, D. H. NASH, "Effect of different electrode tip angles with tilted torch in stationary gas tungsten arc welding: A 3D simulation," International journal of Pressure vessels and Piping, pp. 51-60, 2013.
[8] W. ZHOU, Q. LE, Q. LIAO, Y. SHI, T. WANG, AND W. HU (2025). Study of GTA-Welded Joints of ZW61 Magnesium Alloy — Effect of Welding Current on the Microstructure and Mechanical Properties, Welding Journal: 17-s -27-s.
[9] 2. N. NOGUEIRA DA SILVA AND W. SADE (2024). The Effects of Preheating the Shielding Gas Used in Gas Tungsten Arc Welding, Welding Journal: 298-s -307-s.
[10] H. JIANG, G. QIN, C. FENG, AND X. MENG (2019). High-Speed Tandem Pulsed GTAW of Thin Stainless-Steel Plate, Welding Journal: VOL.98, 215-s – 226-s.