

A Study on The Effect of Welding Parameters in Gas Tungsten Arc Welding (GTAW) For Aerospace Applications

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Abstract—Gas Tungsten Arc Welding (GTAW), commonly known as Tungsten Inert Gas (TIG) welding, is one of the most precise and reliable fusion welding processes used in aerospace industries due to its superior weld quality, controlled heat input, and excellent arc stability. Aerospace materials such as titanium alloys, aluminium alloys, stainless steels, and nickel-based super-alloys require high-quality welds with excellent strength, corrosion resistance, and fatigue performance. The quality of GTAW weldments is strongly influenced by welding parameters such as welding current, voltage, travel speed, shielding gas flow rate, pulse frequency, and heat input, which directly affect weld penetration, bead geometry, microstructure, mechanical properties, residual stresses, and defect formation. This paper presents a critical review of research on the effect of GTAW process parameters on aerospace weld quality, covering parameter optimization, mechanical and metallurgical behaviour, weld defects, quality-control methods, and recent advancements such as pulsed GTAW, robotic welding, and AI-based monitoring. Current research gaps and future opportunities in aerospace GTAW applications are also highlighted.

Index Terms—GTAW, TIG Welding, Aerospace Materials, Heat Input, Pulsed GTAW, Weld Defects, Taguchi Method, ANOVA

I. INTRODUCTION

Welding is one of the most important joining processes in modern manufacturing, and it plays a major role in aerospace, automotive, shipbuilding, nuclear, railway, and defence industries. Aerospace welded joints must possess excellent fatigue resistance, dimensional accuracy, fracture toughness,

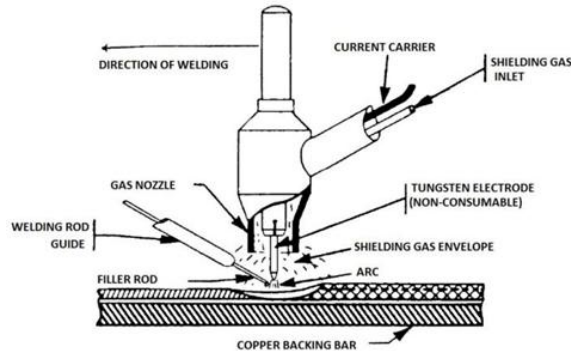
and structural integrity, since aircraft and spacecraft components are continuously subjected to cyclic loading, vibration, thermal stress, and high-temperature service environments.

Among the fusion welding processes available, Gas Tungsten Arc Welding (GTAW) is considered one of the most precise and reliable processes for aerospace applications. In GTAW, a non-consumable tungsten electrode produces an arc between the electrode and the workpiece; the intense heat melts the base metal and forms a weld pool, while inert shielding gases such as argon and helium protect the pool from atmospheric contamination.

The process may operate on Direct Current Electrode Negative (DCEN), Direct Current Electrode Positive (DCEP), or Alternating Current (AC). DCEN is mainly used for titanium and stainless-steel welding because it provides deeper penetration and stable arc characteristics, whereas AC is preferred for aluminium and magnesium alloys because it removes oxide layers through cathodic cleaning. The major advantages of GTAW include excellent weld quality, precise heat-input control, superior arc stability, ability to weld thin sections, low distortion, high corrosion resistance and better metallurgical properties, although the process suffers from lower deposition rate, slower welding speed, higher equipment cost, and the need for skilled operators.

Modern developments such as Pulsed GTAW, Hot-Wire GTAW, and Robotic GTAW have significantly improved productivity and process efficiency, and

GTAW is extensively used for aircraft fuselage structures, compressor blades, turbine components, cryogenic fuel tanks, rocket motor casings and thin-wall aerospace structures.



II. AEROSPACE MATERIALS AND WELDABILITY

Modern aerospace industries use advanced materials capable of operating under extreme thermal and mechanical conditions; these materials are highly sensitive to heat input and atmospheric contamination.

A. Titanium Alloys

Ti-6Al-4V is widely used for aircraft engine components, compressor blades, airframe structures and spacecraft components because of its excellent strength-to-weight ratio and fatigue properties. Titanium becomes highly reactive above 400 °C, and improper shielding may cause oxidation, embrittlement, and loss of mechanical strength.

B. Aluminium Alloys

AA2219 is used in fuselage panels, fuel tanks, wing structures and cryogenic vessels due to its excellent weldability and low density. Aluminium welding is associated with oxide-layer formation, porosity, hot cracking and distortion caused by high thermal conductivity.

C. Nickel-Based Super-alloys

Inconel 718 is used in turbine engines and high-temperature aerospace components because of its thermal stability and oxidation resistance. Careful parameter control is required to avoid grain-boundary liquation, hot cracking, residual-stress formation and heat-affected-zone (HAZ) failures.

TABLE I. PROPERTIES OF SELECTED AEROSPACE MATERIALS

Property	Ti-6Al-4V	AA2219	Inconel 718
Density	4.43 g/cm ³	2.84 g/cm ³	8.19 g/cm ³
Tensile Strength	900–1100 MPa	414 MPa	1240 MPa
Hardness	340 HV	120 HV	410 HV

III. GTAW PROCESS PARAMETERS AND HEAT INPUT

Weld quality is mainly governed by welding current, arc voltage, travel speed and shielding-gas flow rate. Higher current increases penetration but also increases heat input, grain growth and distortion; typical aerospace current ranges are 70–180 A for titanium, 90–250 A for aluminium and 60–160 A for stainless steel.

Arc voltage (typically 10–18 V) affects arc stability, bead width and heat distribution, while travel speed governs heat input, cooling rate, penetration depth and distortion — lower speed increases penetration but enlarges the HAZ. Shielding-gas flow rate (typically 8–18 L/min argon) prevents oxidation, porosity and tungsten contamination; both insufficient and excessive flow are detrimental.

Heat input, one of the most important parameters governing weld quality and microstructure, is expressed as:

$$Q = (V \times I \times 60) / (1000 \times S)$$

where Q is heating input (kJ/mm), V is voltage (V), I is current (A) and S is travelling speed (mm/min).

Excessive heat input causes grain coarsening, HAZ enlargement, reduced tensile strength and distortion, whereas insufficient heat input causes incomplete fusion and poor penetration. Proper optimization of these parameters is therefore essential for defect-free aerospace weldments.

IV. LITERATURE REVIEW

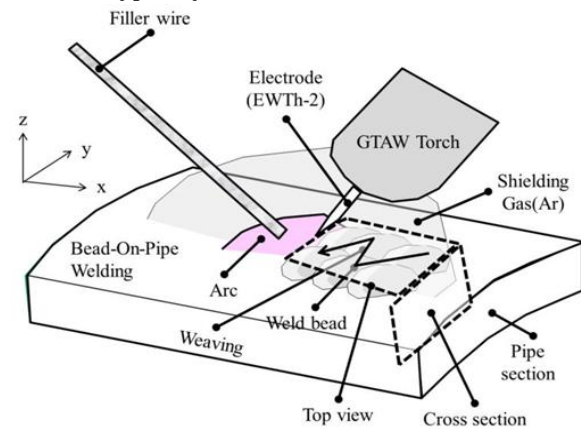
A summary of significant published studies relevant to GTAW parameter optimization for aerospace materials is presented in Table II.

Author(s)& Year	Focus/ Material	Key Findings
Balasubramanian & Kannan (2021)	Pulsed GTAW of Ti-6Al-4V	Optimum: 150 A peak / 75 A base / 6 Hz / 2.5 mm/s gave 930 MPa tensile strength, 96% weld efficiency, 25% reduction in HAZ width
Senthil Kumar & Ravikumar (2020)	Taguchi optimization, AA2219	140 A, 15 V, 3 mm/s gave 392 MPa tensile strength; current contributed 58% (ANOVA) to weld quality
Francis & Smith (2019)	Residual stress in Ti welds	Optimized heat input reduced residual stress by ~30%; peak stress 420 MPa near fusion zone
David & Vitek (2020)	Inconel 718 weldability	Controlled heat input gave 980–1180 MPa tensile strength and >92% weld efficiency; PWHT improved strength by 12%
Ramachandran & Balaji (2021)	Shielding gas on Ti alloys	Optimum flow 12–15 L/min; Ar-He blends raised penetration but excess He caused arc instability
Omiyale & Loto (2022)	GTAW-based WAAM	Optimized deposition raised tensile strength by 15%; low heat input improved dimensional stability
Zhang & Liu (2023)	AI defect monitoring	Neural-network monitoring achieved >94% defect-detection accuracy with real-time adaptive control
Palani & Murugan (2021)	Pulsed GTAW, stainless steel fatigue	150 A / 70 A / 6 Hz / 3 mm/s improved fatigue life by ~35% and raised hardness to 265 HV
Biswas & De (2022)	Thermal FE modelling, thin sheet	Heat input above 2 kJ/mm sharply increased distortion; optimized conditions cut distortion by 28%
Cao & Jahazi (2023)	Hybrid laser-GTAW, Al alloys	40% higher welding speed, 18% higher tensile strength and narrower HAZ versus conventional GTAW

V. EFFECT OF GTAW PARAMETERS ON WELD QUALITY

Welding current is the primary determinant of arc energy and penetration; increasing current from 90 A to 150 A raised measured penetration depth from 2.1 mm to 4.8 mm, but excessive current promotes grain coarsening, HAZ enlargement and burn-through in thin aerospace sections. Short arc length improves arc stability, heat concentration and penetration, while long arc length causes heat dispersion, arc instability and oxidation.

Lower travel speed increases heat input and penetration but enlarges the HAZ and increases distortion and residual stress; heat input above roughly 2 kJ/mm significantly increases residual stress, grain coarsening, HAZ width and distortion. Pulsed GTAW alternating between a peak current of 120–180 A and a base current of 60–90 A at 2–10 Hz — reduces average heat input, narrows the HAZ and has been reported to improve fatigue life by up to 35%. Shielding-gas selection also plays a critical role: pure argon gives stable arc characteristics and a smooth weld surface, while argon-helium mixtures increase heat transfer and penetration depth, with an optimum flow rate typically identified around 12–15 L/min.



VI. WELD DEFECTS AND QUALITY CONTROL

The principal defects encountered in aerospace GTAW are porosity (gas entrapment from poor shielding, moisture or surface impurities), hot cracking (from excessive heat input and rapid solidification), lack of fusion (from low current or excessive travel speed), undercut, distortion (angular, longitudinal, transverse shrinkage and buckling) and

tungsten inclusion or oxidation. These defects reduce tensile strength, fatigue resistance and structural reliability, and can act as crack-initiation sites under cyclic aerospace loading.

Quality is verified through visual inspection, radiographic testing (RT), ultrasonic testing (UT), dye-penetrant testing (DPT) for titanium alloys, and magnetic-particle testing (MPT) for ferromagnetic materials. Modern aerospace manufacturing increasingly employs AI-based monitoring using infrared sensing, acoustic-emission monitoring and weld-pool imaging, achieving defect-detection accuracy exceeding 94%, together with robotic GTAW systems that improve precision, productivity and repeatability.

VII. OPTIMIZATION TECHNIQUES AND RECENT ADVANCEMENTS

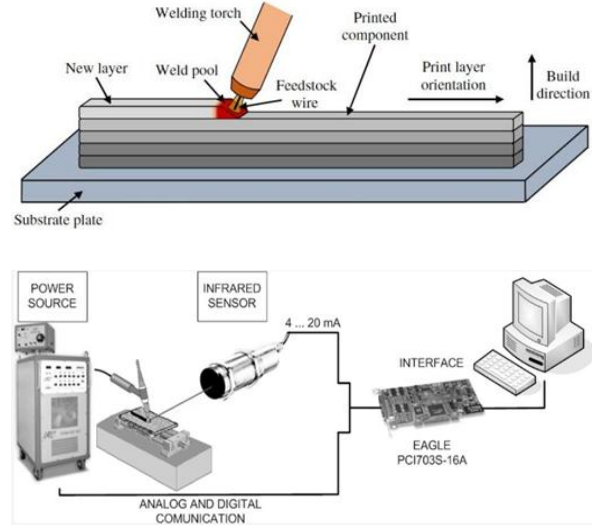
Statistical and computational optimization techniques are widely applied to identify optimum GTAW conditions.

The Taguchi method reduces experimental cost through orthogonal-array design; ANOVA quantifies each parameter's contribution to a response; Response Surface Methodology (RSM) develops predictive mathematical models; and Grey Relational Analysis supports multi-objective optimization involving strength, hardness and penetration simultaneously.

TABLE III. ANOVA CONTRIBUTION OF WELDING PARAMETERS

Parameter	Contribution (%)
Welding Current	58
Travel Speed	21
Gas Flow Rate	12
Voltage	9

Recent advancements Pulsed GTAW, Hot-Wire GTAW, Robotic GTAW, AI-based process monitoring, and GTAW-based Wire Arc Additive Manufacturing (WAAM) have collectively improved weld quality, automation, productivity and dimensional stability, and are increasingly applied to turbine-blade repair, aircraft structural repair and near-net-shape aerospace component fabrication.



VIII. RESEARCH GAP AND FUTURE SCOPE

Most existing studies optimize individual welding parameters rather than performing simultaneous multi-parameter optimization, and detailed work on residual-stress prediction, distortion minimization, real-time defect prediction and adaptive process control remains limited. Welding of dissimilar aerospace materials, and industrial-scale validation of pulsed, hybrid-laser and additive-manufacturing GTAW variants, also require further investigation.

Future aerospace welding research is expected to increasingly employ artificial intelligence, robotics, additive manufacturing, digital-twin modelling and intelligent monitoring for real-time defect prediction, adaptive parameter optimization and consistent weld quality, alongside sustainable welding technologies, multi-material joining, residual-stress minimization, hybrid welding systems and cryogenic aerospace welding.

IX. CONCLUSION

This review confirms that GTAW remains one of the most reliable precision-welding processes for aerospace materials because of its controlled heat input, superior arc stability and excellent shielding. Welding current, voltage, travel speed, shielding-gas flow rate, heat input and pulse frequency strongly influence penetration depth, weld-bead geometry, residual-stress formation, fatigue resistance and microstructural evolution; excessive heat input causes distortion, grain coarsening and residual-stress

accumulation, while insufficient heat input causes lack of fusion and poor penetration. Advanced optimization techniques and modern GTAW technologies — pulsed GTAW, robotic welding, AI-based monitoring and additive manufacturing — significantly improve weld quality, productivity, automation and reliability. Proper understanding and optimization of GTAW process parameters therefore remains essential for producing reliable, high-strength, defect-free aerospace weldments with superior dimensional accuracy and fatigue performance.

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