GTAW Application for Additive Manufacturing and Cladding of Steel Alloys

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Abstract

Steel alloys are widely used in many industry sectors namely construction, automobile, and aerospace. With additive manufacturing (AM), complex and rare parts of steel alloys can be manufactured efficiently in days in an economical way. On the other hand, conventional manufacturing methods include time-consuming and cost-incurring die and mold preparation and postmachining of the parts. The other benefits associated with AM are low cost governed by low-energy input, low-material wastage, and automation with high strength. The gas tungsten arc welding (GTAW) process produces sound weld with high integrity with the parent metal. Therefore, GTAW has found the place as a method for AM. Additionally, the components in these industries are many times subjected to high wear, corrosion, and abrasion. Their durability at the work is increased by using the cladding process. GTAW is widely used in the cladding process for hard facing and corrosion resistance. With its increased deposition rate using advanced hotwire multi-cathode GTAW processes, high applicability to different metals, defect-free weld, and high strength of weld, among other welding processes like shielded metal arc welding (SMAW), gas metal arc welding (GMAW), plasma metal arc welding (PMAW), laser welding, and electron beam welding (EBW), GTAW is a promising process for AM and cladding process. The deposition rate can be further improved by optimization of weld parameters like type of current supply (DC supply, DC pulsed supply, and AC supply), mean voltage, wire feed rate, frequency, and hotwire current. In this chapter, the study of different advanced hotwire GTAW processes and optimization of weld parameters is explained.

Keywords

GTAW cladding · Single cathode GTAW · Additive manufacturing · Hotwire welding · Dual cathode GTAW

1 Introduction

In a global competitive environment, different industries are aiming for the least price for manufacturing of their products. This is closely related to lightweight manufacturing. Most of the time, the production cost is increased by the lightweight technologies due to the new processes and equipment needs (Tisza and Czinege 2018). Steel is the most popular among other materials used in different industries like construction, automobile, and aerospace. According to rankings released by the World Steel Association (WSA) in 2019, China was the world's largest crude steel producer followed by India, Japan, and the USA. As per the WSA report in 2018, 50 percent of the crude steel production was utilized by the construction industry. According to the American Iron and Steel Institute (AISI), as of now, more than 200 steel grades are available which are three to four times stronger than the latest aluminum alloys available in the market. Similarly, these steels perform better with safety benefits using an existing manufacturing infrastructure and eliminating the major manufacturing cost by the introduction of alternative materials.

With additive manufacturing (AM), complex and rare parts of steel alloys can be manufactured efficiently in days in an economical way. On the other hand, conventional manufacturing methods include time-consuming and cost-incurring die and mold preparation and postmachining of the parts. The other benefits associated with AM are low cost governed by low-energy input, low-material wastage, and automation with high strength. The gas tungsten arc welding (GTAW) process produces sound weld with high integrity with parent metal (Shah and Agrawal 2019). Therefore, GTAW has found the place as a method for AM.

GTAW is widely used in the cladding process where two metals are joined together by welding to the surface and adding a layer for hard facing and corrosion resistance. The mining components such as high-speed rotating components are subjected to high wear and abrasion. Their durability at the work can be increased by using the cladding process. Hence, GTAW cladding has an important application in the mining industry (Wang et al. 2016). GTAW use in the mining industry can be further extended to AM of tools and components. The other benefits associated with it are low cost governed by low-energy input, low-material wastage, and automation with high strength. However, traditional GTAW has a low deposition rate and travel speed. Recently, many improved variants of GTAW have been proposed to increase the efficiency of the welding process such as GTAW with powder, single cathode single hotwire, single cathode dual hotwire, dual cathode single hotwire, and dual cathode dual hotwire (Egerland et al. 2015).

In the hotwire-cladding process, a hotwire is fed into the puddle, where hotwire acts as a secondary source of heat into the plasma and hence increases the deposition rate by pouring more weld material into the clad. This process has better weld quality compared to GTAW and GTAW with a powder (Egerland et al. 2015).

Many variants of hotwire GTAW namely single cathode single hotwire, single cathode dual hotwire, dual cathode single hotwire, and dual cathode dual hotwire have increased deposition rate as well as low overspray. The low dilution rate achieved with these processes also improves weld quality by increasing corrosion resistance and hard facing. Also, proper chemistry is achieved with fewer layers of the weld. All these benefits are attractive when cladding applications are considered.

2 Current Trends

Recently, Twin-wire / Tandem GTA and other variants of cladding processes have been developed and researched by Fronius International GmbH, Austria. It is found that the arc pressure varies when two arcs coming from two cathodes are single arcs, overlapping arcs, and coupled arcs as shown in Fig. 1.

Figure 2 shows the elemental distribution when different combinations of the cathode and hotwire are used. Hence, it can be seen that the twin hotwire single cathode GTAW has better elemental distribution. Further, at the University of Alberta, Canada, the GTAW process has been utilized for wear-resistant overlays.

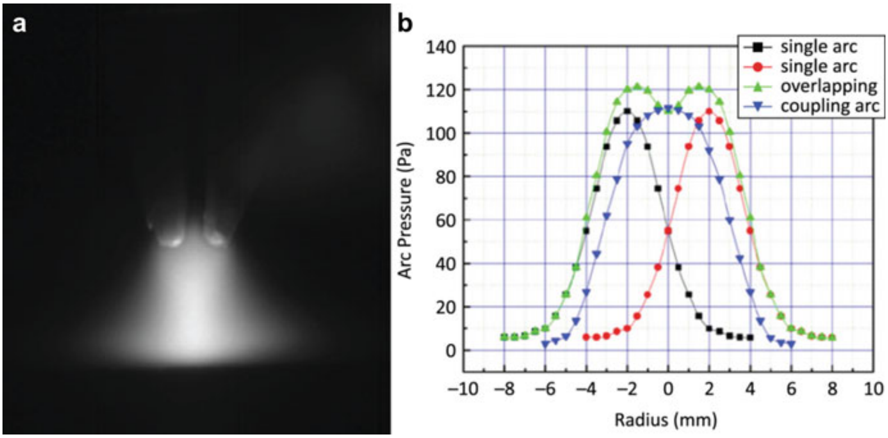

Fig. 1 Comparison of arc pressure for a different combination of arcs (Egerland et al. 2015)

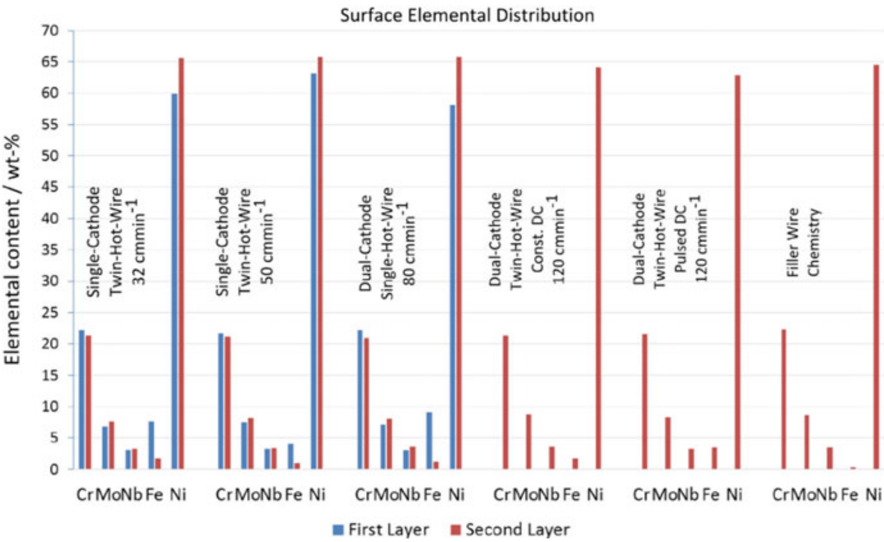

Fig. 2 Effect of various combinations of cladding on surfacial elemental distribution (Egerland et al. 2015)

When we talk about AM, there is phenomenal growth in engineering. The startups like Relativity and Desktop Metal are 3D printing even at higher speeds than the classical manufacturing methods. This shows the potential of AM in the digitalization of the industry.

In India primarily research in the field of GTAW has been done by the Welding Research Institute (WRI), Bharat Heavy Electrical Limited (BHEL). WRI has developed hotwire GTAW, narrow gap hotwire GTAW, orbital hotwire GTAW, activated

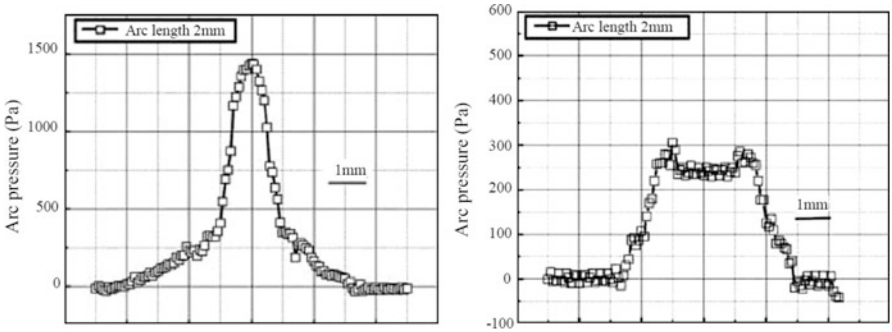

Fig. 3 Comparison of arc pressure for single cathode and two cathodes (Shah and Agrawal 2019)

TIG welding, automated wire feed GTAW, etc. Besides WRI, BHEL, Institute of Infrastructure Technology Research and Management (IITRAM), Ahmedabad, has researched twin TIG where two tungsten electrodes are used in one torch. Their research shows that there is a significant effect of many electrodes used on arc pressure. Welding Research laboratory of Pandit Deendayal Energy University (PDEU), Gandhinagar working extensively in the area of Activated- TIG welding and its variants like FB-TIG and FZ –TIG for ferrous, non-ferrous and dissimilar metal combinations. Recently researchers have also developed welding procedure for 16 mm thick plate of copper using hot wire GTAW. The arc pressure curve gets flattened when two cathodes are used as shown in Fig. 3.

3 Gas Tungsten Arc Welding

Fusion welding processes are divided into three types as flux-shielded welding processes, gas-shielded welding processes, and beam-welding processes. Each of these processes has unique features and finds a wide range of applications. The gas-shielded welding processes – GTAW, GMAW, and plasma metal arc welding (PMAW) – are extensively employed in almost all fabrication industries. Among these processes, GTAW is suitable to weld almost all metals and for uniform root penetration. Due to the development of newer materials, new variants of GTAW processes like hotwire GTAW activated TIG, continuous wire feed GTAW, etc. have been developed for improving productivity and enhancing its scope for diverse areas.

The traditional GTAW process has certain issues like the weld pool dynamics and slower manual wire feed rates. A highly skilled operator is required for the manual GTAW process. To enhance productivity, increase of current increases the arc pressure which results in defects and poor weld bead quality. But these processes can be further optimized based on the other parameters like type of current supply (DC supply, DC pulsed supply, and AC supply), mean voltage, wire feed rate, frequency, and hotwire current.

4 Progress in GTAW Process

4.1 Hotwire GTAW and Narrow Gap Hotwire GTAW

The hotwire GTAW method is able to produce high-quality welds with improved deposition rates and finds a feasible place in different applications where it was not before. It uses an additional power source for wire heating by which faster weld speed and improved wire feed rates are obtained that reduces the weld defects. A schematic diagram for hotwire GTAW is shown in Fig. 4.

The narrow gap hotwire GTAW process is an extension of the hotwire GTAW process aimed for productivity enhancement. Due care has been taken to achieve a constant sidewall fusion in a narrow gap with special accessories and techniques. Different metals and alloys with thick jobs can be welded using this process. This process gives high quality and efficient welds with excellent mechanical properties. A typical setup for narrow gap hotwire GTAW process is shown in Fig. 5.

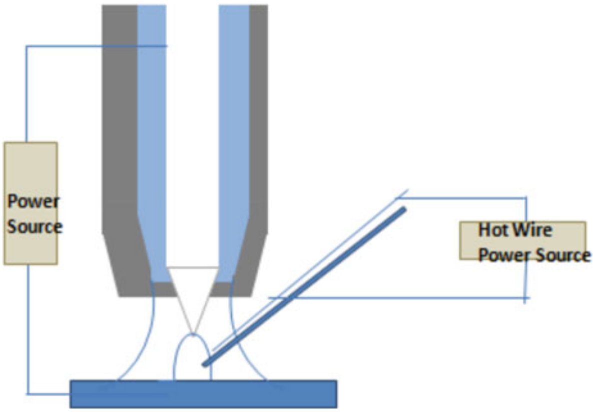

Fig. 4 Hotwire GTAW (Santhakumari 2018)

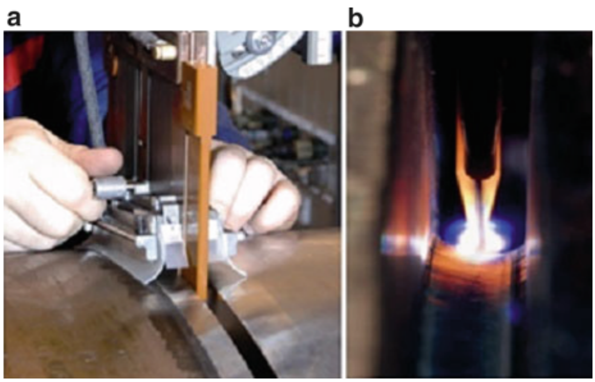

Fig. 5 (**a**) Narrow gap hotwire TIG; (**b**) welding in progress (Santhakumari 2018)

Fig. 6 Orbital hotwire GTAW (Santhakumari 2018)

4.2 Orbital Hotwire GTAW

Orbital hotwire GTAW is a hybrid process that combines the conventional orbital GTAW process and the hotwire method. The process has been developed to increase the productivity, weld quality, and its wider applications in aircraft, aerospace industry, nuclear, boiler, and high-pressure tubes. A typical setup of the orbital hotwire GTAW process for pipe welding is shown in Fig. 6.

4.3 Activated TIG Welding

Activated TIG or A-TIG Welding was developed in the middle of the 1960s by Paton Welding Institute (PWI), Ukraine. In this process to improve the weld penetration, a thin flux material coating is applied on top of the joint surface before welding. It is reported that the weld penetration is increased two to three times than the conventional GTAW process. It is presently used for steels and nickel base alloys and found useful in orbital pipe-welding applications. A typical setup for an activated TIG welding process is shown in Fig. 7.

4.4 Automated Wire Feeding in GTAW

It is a hybrid process that combines manual and automated GTAW wire feed control (Tip TIG / Top TIG) combined with a hotwire method. It is suitable in any position

Fig. 7 Activated TIG welding (Santhakumari 2018)

Fig. 8 Root pass welded by Tip TIG process (Santhakumari 2018)

of the weld of any thickness material. A typical setup of Tip TIG which enables to weld root is shown in Fig. 8.

4.5 Inter Pulse TIG Welding

Inter Pulse TIG patented by VBC Group, UK, is specially designed to give highly constricted and fine welding arc to weld "difficult-to-weld" materials. A comparison of the DC TIG arc and the inter-pulse arc is depicted in Fig. 9. It can be seen that the inter-pulse arc is finer with smaller heat-affected zone (HAZ).

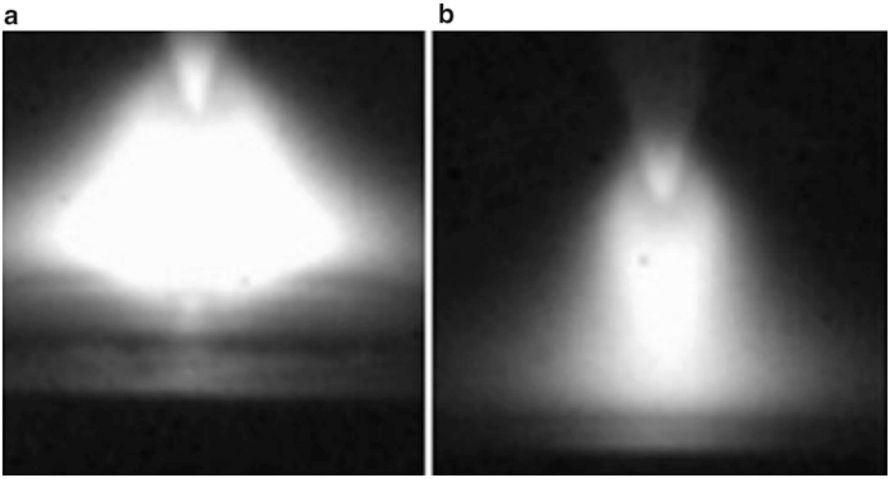

Fig. 9 (**a**) DC TIG arc 85 Amps; (**b**) inter-pulse arc 85 Amps average current (Santhakumari 2018)

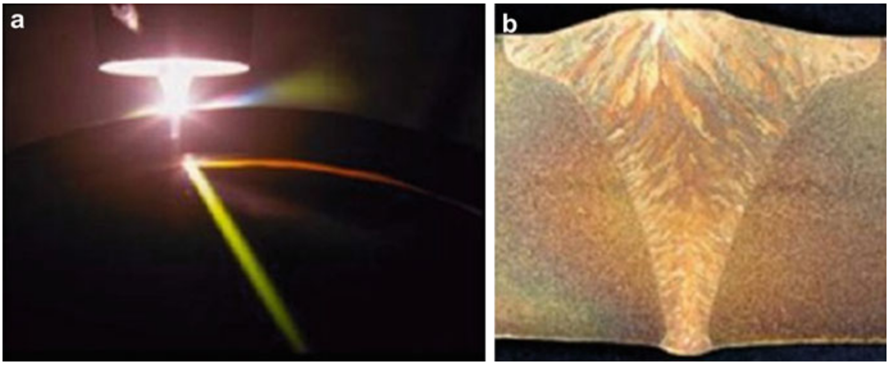

Fig. 10 (**a**) K-TIG welding process; (**b**) macro of the K-TIG weld (Santhakumari 2018)

4.6 K-TIG Welding

K-TIG (Keyhole TIG) welding technique was developed in 1990–1993 by Dr. Laurie Jarvis, Australia, which is a single-pass full-penetration keyhole method. In this process, the weld pool surface is fixed to the top and bottom surface making a stable arc that is moved along the weld path as a keyhole by increasing the arc pressure. A typical K-TIG welding technique is explained in Fig. 10.

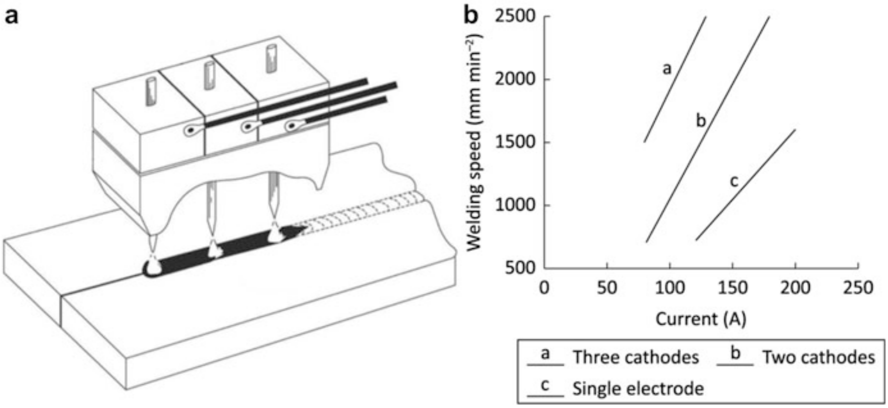

Fig. 11 (**a**) A schematic of multicathode GTAW process; (**b**) comparison of weld travel speed and current (Egerland et al. 2015)

4.7 Twin Wire/Tandem GTA Cladding Process

Conventional GTAW process is not recommended for cladding due to its slower production caused by lesser dilution which resulted in weld defects. To overcome these defects, in the late 1990s Yamada patented a novel high-efficiency GTAW method known as multicathode GTA for improving process efficiency and weld quality shown in Fig. 11a, where a welding torch contains the electrically insulated electrodes with independently operated power supplies. A plot of weld travel speed and current consisting of single and multicathode GTAW is shown in Fig. 11b (Egerland et al. 2015). This process is capable of increase in weld speed without weld defects.

The Tandem GTA cladding process is an extended version of the twin hotwire GTAW process where the two electrodes are combined with two independently controlled preheated welding wires which permit higher weld speeds with higher deposition rate. A typical Tandem GTAW process and torch setup are shown in Fig. 12.

4.8 Internal GTAW

Joining of stub tube to pipe known as internal GTAW system was developed by WRI and is depicted in Fig. 13. It has a servomotor drive which is controlled by a programmable logic controller (PLC) that handles all the inputs like voltage, current, and gas flow rate and outputs.

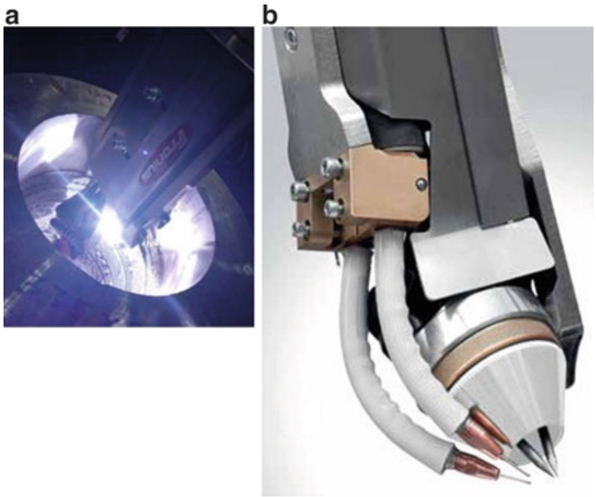

Fig. 12 (**a**) Tandem GTAW process setup; (**b**) Tandem GTAW torch setup (Santhakumari 2018)

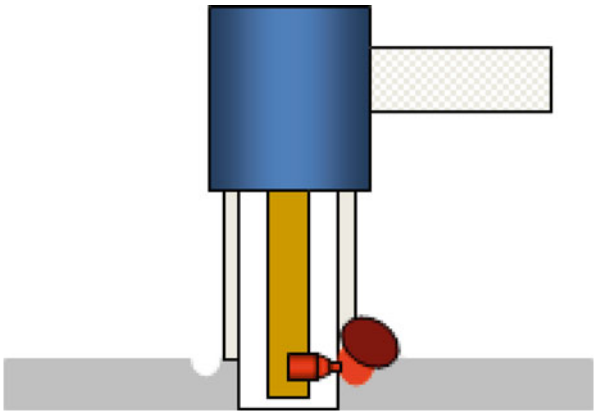

Fig. 13 Internal GTAW (Santhakumari 2018)

4.9 Multicathode GTAW

There are four variants of hotwire GTAW as single cathode single hotwire GTAW, single cathode double hotwire GTAW, double cathode single hotwire GTAW, and double cathode double hotwire GTAW. A schematic of single and twin hotwire GTAW is shown in Fig. 14.

The dissimilar material joining is recognized as a challenge where there are increasing demands for high strength and lightweight alloys in different industries. In such a case, the twin GTAW process can be beneficial to join by supplying less heat input to highly thermal conductive material and more heat input to low thermal conductive material (Shah and Agrawal 2019).

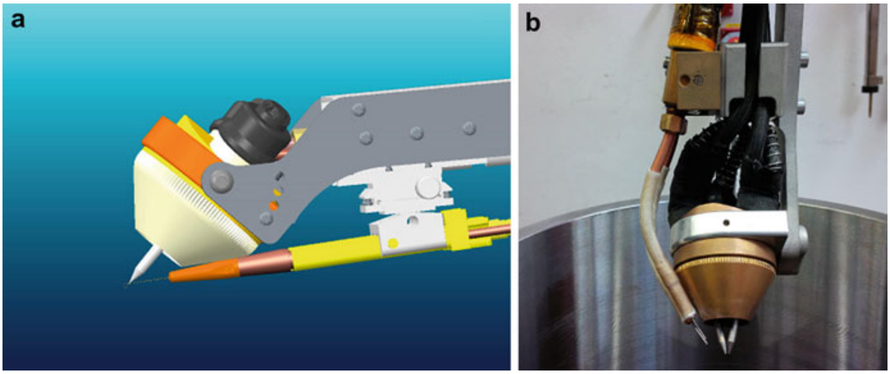

Fig. 14 A schematic of single and twin hotwire GTAW (Egerland et al. 2015)

5 Additive Manufacturing

AM processes have different variants which include vat photopolymerization, binder jetting, material extrusion, material jetting, sheet lamination, powder bed fusion, and directed energy deposition. The benefits of AM processes are less material waste and a minimum processing cycle. It is successfully applied to fabricate components for a variety of metals. In these processes, different sources of heat such as arc, laser beam, or electron beam are used.

The wire arc-additive manufacturing (WAAM) process was developed by Baker in the year 1925. The WAAM process belongs to the directed energy deposition method where the wire is heated then melted and transferred to the melt pool, and it continues to form a component by building layer by layer. The process can be employed using GMAW, GTAW, PAW, or cold metal transfer welding (CMT) as a heat source and build a component as depicted in Fig. 15 (Jin et al. 2020). Currently, WAAM is one of the popular fabrication processes applied for different materials like Ti, Al, Ni alloy, and steel. It is reported that directed energy deposition GMAW has deeper penetration, 5–10 times arc power than powder bed fusion with a laser heat source, and directed energy deposition with a laser heat source, and produces stainless steel (SS) 316 components with much higher speeds and least fusion defects (Jin et al. 2020; Mukherjee and DebRoy 2019).

Recently, the WAAM process has attracted the attention of many researchers in producing large-scale SS parts with high efficiency and low cost. Eagar (Eager 1995) opinioned that, "a new welding technology is often get commercialized before a fundamental science emphasizing the underlying physics and chemistry can be developed." It is truly agreed and applicable to the WAAM process as well. The different factors that affect the performance of the WAAM process are depicted in Fig. 16. The dimensional accuracy and surface quality are based on the WAAM process parameters. The thermal history, solidification behaviors, and phase transformations are closely related to each other and have a strong influence on

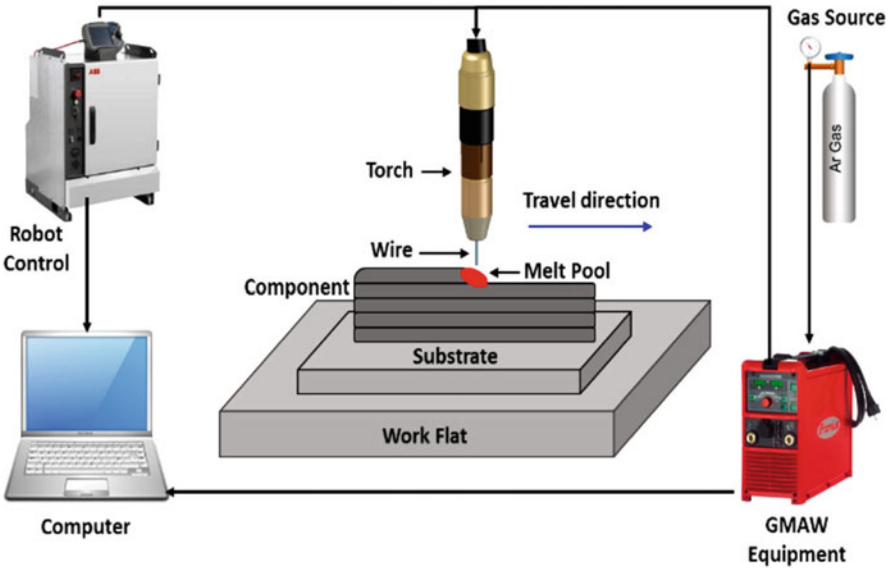

Fig. 15 Schematic diagram of the WAAM setup (Xia et al. 2020)

the microstructure. Anisotropy problems are frequently seen in WAAM-processed parts, and they can be overcome by in-process mechanical working like rolling followed by WAAM.

Abe and Sasahara (Abe and Sasahara 2016) successfully deposited first YS308L stainless steel weld bead on a SUS304 stainless steel substrate and then finally deposited Ni6082 weld bead onto the previous stainless steel weld bead using WAAM process. They have studied the structure-properties of the dissimilar metal deposition layers using a nickel-based alloy. Comparable bond strength was obtained at YS308L and Ni6082 bond area than the tensile strength of the YS308L and Ni6082 weld metals. It is argued that the bond produced has high heat resistance, and corrosion resistance along with low weight of the object due to its inside rib structure. Such kind of inside rib structure is difficult to fabricate using other traditional manufacturing processes.

Chen et al. (2017) fabricated 316 L austenitic SS using GMAW-AM and studied the mechanical properties and microstructure. They found that the microstructure has σ,δ, and γ phases which are differently orientated and have different morphologies. Also, the mechanical properties are similar to wrought 316 L with ductile mode of fracture. The increase of microhardness and tensile strength is attributed due to σ phase; however, there is reduction in tensile yield strength, and ductility. They have extended their work (Chen et al. 2018), to investigate the mechanical, corrosion properties, and analyzed the effect of heat treatment on the microstructure. The heat treatment causes improvement in corrosion resistance of the steel. However, due to σ phase formation, there is an increase in corrosion attack sensitivity.

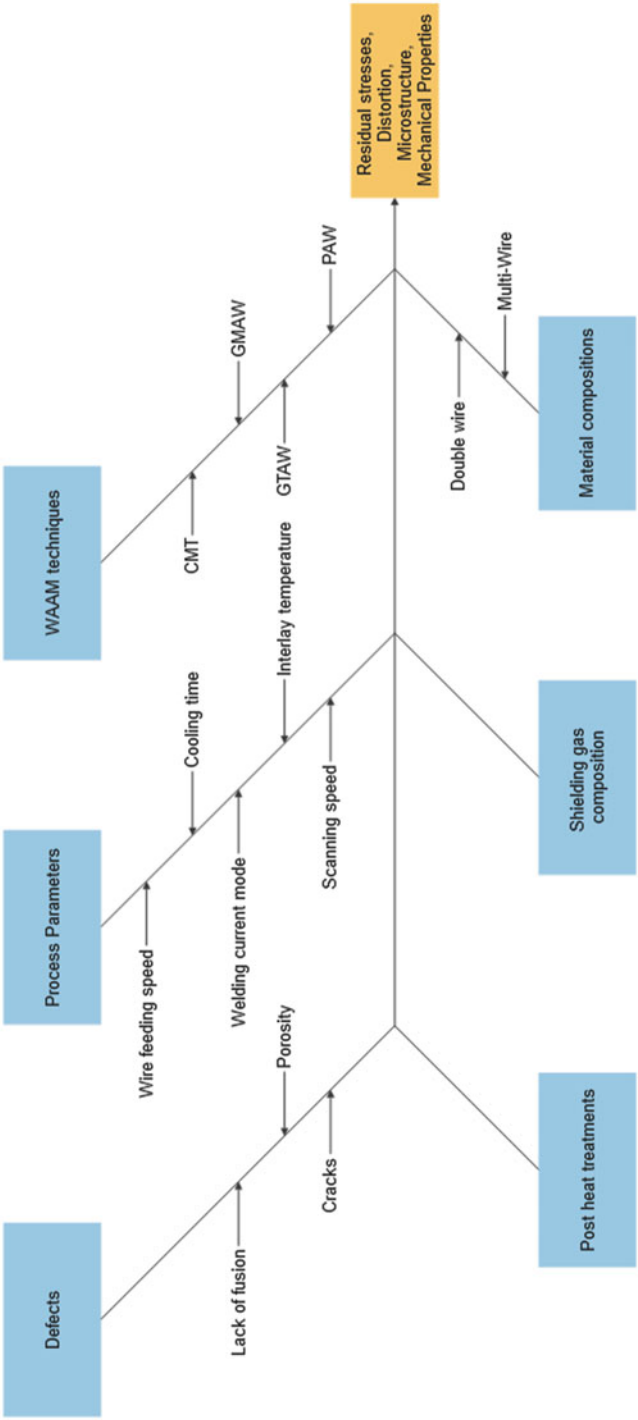

Fig. 16 Cause and effect diagram for WAAM process

Rodriguez et al. (2018) have employed CMT and Top TIG processes to deposit the 316 L SS and compared the mechanical properties and microstructures of deposit produced using these processes. Both of these processes are able to deposit thick walls with high accuracy and sound flatness. Higher material deposition rates were obtained for CMT (3.7 kg/h) than Top TIG process (2 kg/h).

Li et al. (2019) deposited H08Mn2Si steel filler wire onto Q235B low-carbon steel as a substrate using GMAW-AM process and investigated the molten pool stability at different wire feed speed, weld speed, and inclination angles, i.e., angle between the GMAW torch and substrate. It is found that the bead width increases with an increase in the inclination angle, with decrease in bead height and penetration depth. Similarly, the forward position of the GMAW torch gives a stable molten pool with superior quality than other positions.

Ge et al. (2019) studied microstructural evolution, defect distribution, and residual stresses developed in additively manufactured 2Cr13 SS thin wall parts created using robotic CMT technology and numerical simulations. The residual stress distribution grows frequently with the addition of the deposited layers and was found highest for the final deposited layer.

Rafieazad et al. (2019) deposited ER70S-6 low-carbon low-alloy steel wire onto ASTM A36 mild steel substrate using GMAW-AM process in advanced surface tension transfer mode. They have studied the microstructure and mechanical properties of the deposits. In the microstructure, the main phases observed were fine ferrite and laminar pearlite. The additively manufactured part of microstructure has found equiaxed grains with weak cubic texture. A similar kind of mechanical properties of deposits as that of substrate was found in both deposition and building direction. The mechanical properties of different steels produced using WAAM process are depicted in Table 1.

6 Cladding

In metal cladding, a thin layer of coating material is applied onto the base material or substrate. A variety of methods employed for cladding such as accumulative roll bonding (ARB) (Selvaraj et al. 2020), resistance welding, SMAW, submerged arc welding (SAW), overlay welding, electroslag welding (ESW), GTAW, flux-cored arc welding (FCAW), laser beam cladding, oxyacetylene welding, laser powder welding, pulsed GMAW, tubular core covered electrodes, hotwire plasma process, explosive cladding, plasma transferred arc (PTA) cladding, hybrid methods, etc. (Saha and Das 2016, 2018).

Chen et al. (2009) have successfully deposited multicomponent alloy fillers (Ni, Co, Cr, Al, and Mo with Si) on low-carbon steel substrates using GTAW cladding process. They evaluated the microstructure and wear properties of this multicomponent alloy. They observed that the FeMoSi as a principal dendritic and BCC interdendritic phases with both phases have multiple elements. The hardness and wear resistance of cladding layer are function of Si content. Both enhancement

Table 1 Mechanical properties of different steels produced using WAAM processes

Heat source	Filler metal wire	Substrate	Input process condition	Mechanical properties	Ref
GMAW	ER70S-6	A36	WD: 0.889 mm, horizontal	YS: 400 MPa; UTS: 500 MPa	Rafieazad et al. (2019)
			WD: 0.889 mm, vertical	YS: 385 MPa; UTS: 500 MPa	
GMAW	316L	–	WD: 1.2 mm, as deposited	YS: 235 MPa; UTS: 533 MPa; %El: 48	Abe and Sasahara (2016)
			WD: 1.2 mm, 1000°C/1 h, WQ	YS: 255 MPa; UTS: 549 MPa; %El: 41	
			WD: 1.2 mm, 1100°C/1 h, WQ	YS: 323 MPa; UTS: 498 MPa; %El: 56	
			WD: 1.2 mm, 1200°C/1 h, WQ	YS: 215 MPa; UTS: 474 MPa; %El: 57	
			WD: 1.2 mm, 1200°C/4 h, WQ	YS: 204 MPa; UTS: 494 MPa; %El: 70	
			WD: 1.2 mm, wrought 316L	YS: 222–265 MPa; UTS: 505 MPa; %El: 56–63	
GMAW	316L	–	WD: 1.2 mm, as deposited	YS: 235 MPa; UTS: 533 MPa; %El: 48	Chen et al. (2017)
			WD: 1.2 mm, cold worked	YS: 255–310 MPa; UTS: 525–632 MPa; %El: 30	
			WD: 1.2 mm, solution treated	YS: 222–265 MPa; UTS: 505–578 MPa; %El: 56–63	
GMAW	316L	316L	WD: 1.2 mm, SpeedPulse WAAM, mean current (I)-22.1 A; mean voltage (U)- 135 V; arc power P-2984W; Layer thickness (δ)-1.5 mm	YS: 418.0 MPa; UTS: 550 ± 6 MPa	Wang et al. (2019)
			WD: 1.2 mm, SpeedArc WAAM, I -19.5 A; U- 140 V; P-2730W; δ-1.8 mm	YS: 417.9 MPa; UTS: 553 ± 2 MPa	

GTAW	Al and LS422750/4 99.5% black annealed iron	DH36	WD: 0.9 mm, as deposited	YS: 847 MPa; UTS: 944 MPa; %El: 3.27	Shen et al. (2015)
CMT and TopTIG	316L	316L	WD: 1.2 mm, CMT-vertical- continuous mode (CM)	YS: 336 MPa; UTS: 574 MPa; %El: 42	Rodriguez et al. (2018)
			WD: 1.2 mm, vertical- pulsed mode (PM)	YS: 331 MPa; UTS: 536 MPa; %El: 45.6	
			WD: 1.2 mm, horizontal-CM	YS: 364 MPa; UTS: 577 MPa; %El: 43.4	
			WD: 1.2 mm, horizontal-PM	YS: 374 MPa; UTS: 588 MPa; %El: 45.1	
			WD: 1.2 mm, base material	YS: 346 MPa; UTS: 651 MPa; %El: 47	
			WD: 1.2 mm, top TIG -vertical	YS: 322 MPa; UTS: 539 MPa; %El: 43.1	
			WD: 1.2 mm, top TIG - horizontal	YS: 365 MPa; UTS: 590.3 MPa; %El: 42.3	

WD wire diameter (mm), *YS* yield strength (MPa), *UTS* ultimate tensile strength (MPa), and *%El* percentage elongation in the hardness and wear resistance of cladding layer are affected by FeMoSi dendrites, which have strong covalent bonds.

Chen and Lee (2016) have attempted to alter the surface properties like surface hardness, wear resistance, and heat dissipation of AISI 410 martensitic SS with an AlN clad layer by specific addition of Si, W, and Co using GTAW process. It is found that the surface properties of cladding material were better than the parent material.

Lv et al. (2008) investigated GTAW cladding of S201 copper (Cu) alloy under different processing conditions on carbon steel. Their work focuses on the influence of clad current on the concentration and morphology of Fe solute in the clad layer and the hardness of the Cu/Fe bond area. The Fe morphology in the Cu layer depends on its concentration. The Fe concentration is exponentially related with growth of clad current. The hardness of Cu layer is a function of clad current and its Fe content.

Silwal et al. (2019) employed low current GTAW cladding of hot-wire filler of IN625 Inconel alloy on the 347 austenitic SS substrate. It is found that the torch angle has significant effect on the bead formation. The low current resulted in minimum Fe dilution on the cladding whereas the high current (90–100 A) has resulted in liquation cracking formation in the HAZ of 347 SS.

Malhotra (2020) employed GTAW process for top clad layer remelting of austenitic stainless steel 316 L which was previously deposited on low-carbon steel substrate using GMAW. It has been found that the pitting corrosion resistance was higher than the GMAW cladding with comparatively smaller degree of sensitization and obtained depth of penetration around 2.34 mm.

Knerek et al. (2021) have successfully deposited 625 Inconel alloy on API 5L X65 carbon steel pipe as a substrate using hotwire TIG process. The cladding layer is free from defect or cracks during bend test, and the resulting cladding possesses enhanced mechanical properties. Moradi and Ketabchi (2015) have cladded 625 Inconel alloy on the A516 Grade 70 carbon steel plate using GTAW process. It is found that the shear strength of 232.5 MPa was obtained which is greater than regular standards. The microstructure shows mainly Niobium carbide (NbC) and Fe_2Nb precipitate phases.

In general, metal cladding provides high hardness, corrosion and/or erosion resistance, and good bonding where clad material of different thickness is deposited over the substrate surface (Saha and Das 2016). Recently, weld cladding processes find applications in numerous industries as a cost-effective engineering solution method.

7 Optimization of Welding Parameters

Much of the research work reported on the effect of welding parameters in GTAW-based metal deposition process. It is reported that the current, voltage, torch velocity, wire feed speed, and TIG welding torch with the substrate are vital weld parameter that affects the performance of the metal deposition process (Gokhale et al. 2019).

The WAAM deposition path, thermal history, and phase transformation control during WAAM can be optimized to reduce the residual stress and distortion of the parts (Jin et al. 2020). Still, other weld parameters like current supply (DC supply, DC pulsed supply, and AC supply), frequency, and hotwire current are not explored so far. It is reported that the heat input in the layer by layer deposition needs to be controlled for getting a high deposition rate and good forming appearance (Dadbakhsh et al. 2012). To date, researchers have employed response surface methodology (Srivastava et al. 2018; Youheng et al. 2017; Balasubramanian et al. 2009; Lakshminarayanan et al. 2008), mathematical modeling (Geng et al. 2017), and developed controllers (Bonaccorso et al. 2011; Xiong et al. 2016) for optimizing the weld parameters, genetic algorithm (GA) for weld bead geometry optimization in PTA hard-faced austenitic SS plates (Siva et al. 2009).

Traditional optimization methods give local optimal solutions and are not robust. The meta-heuristics (MH) is a global search technique which deals with all kinds of objective functions and design variables, and these are flexible as there is no need of data training (Saka et al. 2016). There is an ardent need to explore these MH and other machine learning algorithms for AM and cladding to optimize the weld parameter and predict the weld performances. Furthermore, for making state-of-the-art processes (Tutum and Hattel 2011), a clear understanding of the thermo-mechanics of these welding processes is essential by which the mathematical models can be developed. With these developed models as an input to the different efficient algorithms in which the process parameters can be optimized efficiently with multiple inputs to get commercially acceptable parts. The AM and cladding of metal parts with advanced properties have attracted great attention in various fields. Still, AM faces substantial techno-commercial logical and scientific issues like difficulty in microstructure control, properties and defects, lack of standards, slower rate of AM, and availability of filler materials for several commercial alloys and economy. Similarly, the effectiveness of digital twins is well recognized; however, it is not fully explored for AM. Efforts are needed to develop or modify the digital twin building blocks and their analysis for variety of alloys and AM processes (DebRoy et al. 2021).

8 Conclusion

This chapter elucidates the application of GTAW for the additive manufacturing and cladding process of steel alloys. It covers different techniques employed for additive manufacturing and cladding processes of steel alloys. Parametric optimization for GTAW-based additive manufacturing and cladding processes with multiple input weld parameters using meta-heuristic algorithms and machine learning algorithms are suggested for improving the weld performance.

9 Websites

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