An Insight into the Scope of Implementation of Intelligent Welding in Welding of Titanium

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Abstract. Traditionally welding is considered as an art rather than a science. The quality of the weld is dependent on the skill and intuition of the welder. The welding process is mostly not reliable and labor-intensive. The solution to the problems in welding lies in utilizing intelligent welding techniques where in the selection of weld parameters like voltage, current, speed etc and defect control is done intelligently by the automated welding system. The intelligent welding system shall comprise elements, viz., control system, sensing, design and modeling of process and application of artificial intelligence. The application of intelligent welding system has developed into a new field of automation called as ‘Integrated Computational Welding Engineering (ICWE)’. The welding of titanium and its alloys is predominantly dependent on the skill of the welder. Majority of research and industrial practice is based on the traditional manual welding process and hence it is prone to defects deterioration of metallurgical, mechanical and corrosion properties. There is scope in adopting ICWE in welding of titanium and its alloys.

1. Introduction

Titanium is a silvery grey metal, the fourth plentiful metal available in earth [1]. The reason for its use in critical applications is because it is 40 % lighter compared to steel and 60 % heavier compared to
aluminum, but has elevated strength to weight ratio even at temperatures ranging from 220 °C to 540 °C [2]. Titanium has tensile strength of around 1000 MPa, which is double that of aluminum and almost equal to the tensile strength of iron. Due to its high strength-to-weight ratio titanium is used in structures in temperature range from 425 °C to 595 °C [3]. Among the various types/grades of titanium alloys, the Ti6Al4V alloy (Grade 5/Defense Grade) is used in 45 percent industrial applications. Therefore, Ti6Al4V alloy is called the workhorse among the titanium alloys. It is used in military and aerospace applications. By virtue of its high strength-to weight ratio it’s one of the most important structural material. Due to its high corrosion resistance, it is used in marine, petrochemical, processing industry and medical prosthetics. The titanium is primarily associated with a single industry, i.e., aerospace. Around three-fourth of titanium production is used for aerospace and major portion of this goes to defense applications.

2. Applications of Titanium and its alloys
The commercial airplanes are becoming fuel-efficient; therefore, there is a demand for lightweight airplanes, which gives rise to the need for titanium. There is emerging need for titanium in the airframes, but the application of titanium in engines is limited due to constraints in service temperature. However, the military requirements are showing a steady demand. The advent of fiber composites will not affect the demand for titanium, but rather it will increase since titanium is used for fittings in composite structures.

In the marine, the titanium use is increasing due to its use in submarines and is reported in Titanium Information Group and Titanium Technology Forum [4]. There is an increased use of titanium for heat exchanger, condenser tubing in nuclear plants and power plant salt-water condenser tubing and binary cycle power plants. In geo thermal industry titanium is used due to its resistance to corrosion and moderate tolerance to high temperatures [5].

The Ocean Thermal Energy Conversion (OTEC) provides new market of around 900 million lbs (408.23 million kg) due to its long life in marine conditions [6]. The desalination plants built with titanium are likely to increase manifold due to the growing need for potable water. The use of titanium anodes in manufacture of chlorine and sodium chlorate and its use as cathode for electro winning of metals from sulphide and lateritic ores in acid solutions. Because of the high corrosion resistance of titanium, it has become a material in high demand for the construction of chemical process equipment’s. The automobile industry is an ideal candidate since it requires high strength, low-density material for components like springs, but its growth depends on the economics (see Figure 1).
3. Weldability of Titanium and Its Alloys

The high reactivity of titanium and titanium alloys at temperatures above 550°C requires additional precautions in shielding the weldment, maintaining the base metal and filler metal clean from contamination. Highly bet-stabilized alpha-beta alloys become embrittled during welding.

As described in Titanium Information Group and Titanium Welding Institute [7], the fusion welding processes generally applied for welding of titanium are Gas Tungsten arc Welding. Localized inert gas shielding is provided in the arc and laser welding processes. In the electron beam welding a complete enclosed vacuum chamber is required. Thus, yielding very good quality welds as described in Titanium Information Group and Titanium Welding Institute [7]. The fluxes are not used in these welding processes because they cause embrittlement and reduce the corrosion resistance of the weldment. Due to their inherent drawbacks and high cost of the fluoride-base fluxes these welding processes are used on a limited basis.

The LBW and EBW processes are used if volume of production is more and accurate welds are required. The high capital investment involved in the LBW and EBW processes are the limiting constraints.
The solid-state welding processes like Friction Welding (FRW) and Resistance Welding (RW) are used to join without using shielding gas. The FW process is used to join tubes, pipes and rods. The spot-welds or continuous seam welds of titanium sheets to dissimilar metals and cladding of titanium with stainless steel are achieved using RW process.

4. Precautions in Welding of Ti6Al4V

The titanium filler metal and base metal are to be cleaned in acetone-soaked, lint free cloth [8]. In some cases, pickling with nitric-hydrofluoric acid solution is done for cleaning the titanium metal surface. Argon gas of 99.985 percent purity is used for shielding. Rubber hose have a tendency to absorb air. Therefore, only hose made of Tygon or vinyl plastic are used for the shielding gas, since it is non porous and flexible. A non-turbulent flow of shielding gas is ensured. Suitable clamping arrangement is provided to prevent deformation of weldments, to ensure joint fit-up and full purging of the weld surface. The oxide layer may be cleaned using stainless steel wire brush or draw filing. The acid pickling is done after brushing to prevent contamination and loss of corrosion resistance.

5. Intelligent Weld Manufacturing

The objective of intelligent weld manufacturing comprises of integrated computational materials engineering (ICME) and integrated computational welding engineering (ICWE); is to optimize the welding process in real-time by sensing and control of weld position, heat source, defects control, microstructure and properties of the weldment [9]. The intelligent weld manufacturing offers solution to welding problems which are coupled to each other and variables are nonlinear in nature. Hence intelligent control of welding increases its productivity. The intelligent control of the weld necessitates the thorough understanding of the following components:

1. Process design, its mathematical modeling and simulation.
2. Effect on microstructure.
3. Achieving good weldment properties.
4. Control of weld process and its automation.

It was observed that the welding process requires good quality fixtures which could be customized to the components to be welded [10]. The fixtures must serve the functionalities such as manufacturability, reconfigurability, intelligent assembly and maintainability. The intelligent reconfigurable welding fixture (IRWF) can be the solution to any type of welding technique and weld component and it could be effectively generated using the commercial computer aided design software’s.

The friction stir welding is an ideal candidate to join the titanium and other hard to weld materials. It was concluded that, the prospects of implementing Industry 4.0 automation through sensor-based monitoring and achieving defect free weldments in FSW process is high [11].

The real time monitoring and control of FSW process over cloud based remote access method has evolved as a emerging technique to get defect free joints. The technique was proposed [12-14] wherein the data required by the model is acquired from the FSW setup, having multiple sensors and the processing of the required signals is done in real time using the cloud, through signal processing techniques and machine learning. The model proposed makes it possible to remotely access the FSW machine from any location in real time.

The control of the welding parameters and weld geometry could be made feasible through the application of artificial intelligence (AI) in welding domain [15]. It was observed that the erratic disturbing process parameters associated with the arc welding process could be controlled by appropriatley controlling the modes of arc welding through intelligent control which is an application of artificial intelligence [16-18]. Thus, deep learning-based data analytics is the ideal technology for achieving good quality welding of titanium-based materials [19]. It was observed that with the application of AI in welding leads to the continuous accumulation of knowledge storage and retrieval. The access and representation of the technical knowledge of the welding process gives arise to evolution of reliable expert system which can be operated across mobile platforms and internet [20].
It was proposed that the intelligent modeling of laser welding relies on the model database, which consists of heat source model database, material database and weld configuration database [21]. The heat source models are based on the heat energy distribution characteristics of the welding process [22-23]. The weld joint configuration database includes all the possible structural configurations in the weld joints. These models pave way for the welding in robotic welding facilities [24]. Different types of sensors are used in weld monitoring like an acoustic sensor, thermal imaging, real-time temperature measurements, digital image correlation, etc.

6. Conclusion
Generally, the gas tungsten arc welding (GTAW) is used to weld titanium and its alloys. The argon gas of 99.9% purity is used for shielding the weld pool from contamination and to prevent embrittlement. The high-energy intense welding techniques like laser beam welding (LBW) are also used to implement critical applications. Since the welding of titanium and its alloys are traditionally carried out through manual welding, it is highly dependent on the skill of the welder and hence has scope for implementation of intelligent welding technologies.

The intelligent welding system (IWS) involves the modern information technologies like industry 4.0, internet of things, artificial intelligence, big data, intelligent manufacturing, cloud computing, cyber-physical system (CPS), etc. The implementation of IWS shall deliver reliable automation in design of weld and fixtures, sequencing of tasks, planning of robotic weld path, robot planning, process modeling-diagnosis-simulation, process control, inspection, virtual welding and human-robot collaboration. Hence the IWS has vast potential to automate the welding of titanium and its alloys and optimize the properties of the weldment and their processing parameters with increased quality and reliability.

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