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Comparative Study of Different Welding Processes and Optimization Methods: A Review

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Abstract- In the present paper, an attempt has been made to review the literature available on comparison of different welding processes and optimization methods. The principal objective of this review paper is to figure out all the ways in which comparison between different welding processes and optimization methods can be made. In the end, the important findings of the researches have been summarized in a tabular format. From the literature surveyed, it was observed that different welding processes can be evaluated and compared in terms of use of different filler materials in a welding process, different optimization methods and on the basis of microstructure, mechanical properties, residual stresses and corrosion resistance etc. of weld joints. Also, fusion welding processes have several problems associated with them such as high heat input, slow cooling rate, wider and softened HAZ, phase transformation, multiple thermal cycles etc. which are known for decreasing the mechanical properties of weldments. Solid state welding processes provide joint properties comparable to base material and can be used to join advanced materials easily. Interestingly, the concept of hybrid welding processes is gaining popularity now due to additional process capabilities providing better weld properties.

Keywords -* *Comparison, hybrid, mechanical properties, microstructure, optimization, welding.

ABBREVIATIONS

AISI	American Iron and Steel Institute	GHGs	Green House Gases
ANN	Artificial Neural Network	GMAW	Gas Metal Arc Welding
ANOVA	Analysis of Variance	GRA	Grey Relational Analysis
ASS	Austenitic Stainless Steel	GTAW	Gas Tungsten Arc Welding
ASTM	American Society for Testing and Materials	HAZ	Heat Affected Zone
AWS	American Welding Society	HSLA	High Strength Low Alloy
BPNN	Back Propagation Neural Network	LBW	Laser Beam Welding
CCD	Central Composite Design	LOM	Light Optical Microscope
CCGTAW	Constant Current Gas Tungsten Arc Welding	MRA	Multiple Regression Analysis
CMT	Cold Metal Transfer	NGLW	Narrow Gap Laser Welding
CPN	Counter Propagation Network	OM	Optical Microscopy
DCEP	Direct Current Electrode Positive	PCA	Principal Component Analysis
DoE	Design of Experiment	PCGTAW	Pulsed Current Gas Tungsten Arc Welding
DSS	Duplex Stainless Steel	P-GMAW	Pulsed Gas Metal Arc Welding
EBSD	Electron Back-scattered Diffraction	PWHT	Post Weld Heat Treatment
EBW	Electron Beam Welding	RSM	Response Surface Methodology
EDS	Energy Dispersive Spectrometry	SEM	Scanning Electron Microscope
EDAX	Energy Dispersive X-Ray Analysis	SMAW	Shielded Metal Arc Welding
EDX	Energy Dispersive X-ray Detector	SS	Stainless Steel
EPMA	Electron Probe Microanalysis	TEM	Transmission Electron Microscopy
FCAW	Flux Cored Arc Welding	TIG	Tungsten Inert Gas
FE	Finite Element	ToFD	Time of Flight Diffraction
FSS	Ferritic Stainless Steel	UTS	Ultimate Tensile Strength
FSW	Friction Stir Welding	XRD	X-ray Diffractometer
GA	Genetic Algorithm	XRF	X-ray Fluorescence

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I. INTRODUCTION

Welding can be defined as the joining of similar or dissimilar metal pieces to make them one. It is a quick and cost-effective process to join two materials permanently. It provides flexibility in design [1] and simplifies the construction of large structures. It plays a key role in metal fabrication industry. Today, virtually all the metal products are welded [1]. Products like jet engines, pipelines, automobiles, building construction, airplanes etc. could not have materialized without welding [1], [2]. Welding has been classified into different types as shown in Fig. 1 below.

The concept of hybrid welding processes such as laser-GMAW, laser-GTAW, laser-FSW, laser-plasma welding, GMAW-plasma welding, GTAW-FSW etc. is gaining popularity these days as hybrid welding provides additional and enhanced process capabilities thereby improving weld properties [3]. Fusion welding uses large amount of heat to fuse the metal for welding which results in slow cooling rate, wider and softened HAZ, phase transformation, multiple thermal cycles and consequently decrease in mechanical properties of welds [4], [5]. In comparison to fusion welding process, solid state welding processes use less heat energy and welding takes place in solid state. As a result, the weld joint properties are comparable to that of base metal. Also, advanced metals and dissimilar metal pairs can be welded using solid state processes which are usually difficult or impossible to join using fusion welding processes [6]. The choice of filler metal also has a decisive role in improving the weld joint properties. In case of dissimilar welds, filler metal should be selected such that the joint properties are at least similar to metal having lower properties [7]. Hydrogen induced porosity is generally attributed to filler metal [8]. Defect free welds are obtained in solid state welding processes since no filler metal is used and it can have economic benefits as well.

The weld quality can be evaluated on the basis of bead geometry such as bead height, bead width, depth of penetration; mechanical properties such as UTS, elongation, yield strength, hardness, impact toughness and microstructure, corrosion resistance and fatigue strength etc. These weld characteristics are affected by several input process parameters. These parameters can be optimized to get a sound joint with superior properties using different methods available. Optimization of welding process is generally expensive and time-consuming exercise [9].

The weldability of a material ensures that material is used frequently in the industry and is a deciding factor in selecting the manufacturing process of a machine component [5]. Today, there are over 90 welding processes in use. The shipbuilding, space and nuclear industries conduct constant research for new metals, which in turn spurs research in welding [10]. Due to so many welding options available, it becomes difficult for one to select the best welding process for a particular material. Therefore, it is necessary to compare different welding processes and optimize their process parameters to select the best process and input parameters to get the defect free welds having optimum weld properties. Various researchers have compared different optimization methods, filler metals and welding processes on the basis of mechanical properties, microstructure, residual stresses and corrosion resistance etc. of weld joints. In this paper, literature available on the comparison of different filler metals, optimization methods and welding processes has been reviewed.

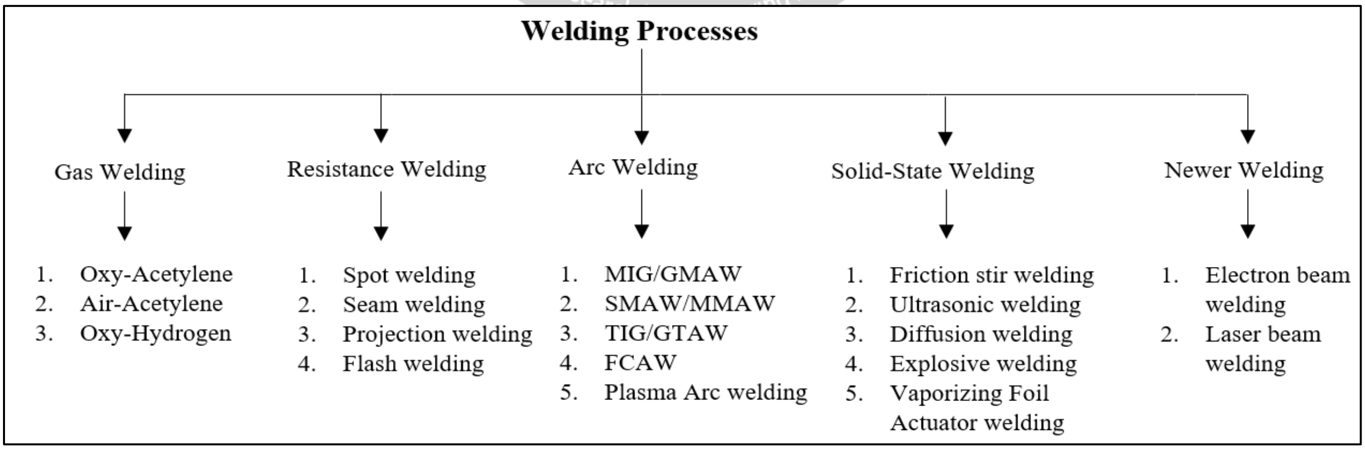

Fig. 1. Classification of Welding Processes

II. LITERATURE REVIEW

2.1 Comparison of different welding processes

A. K. Lakshminarayanan et. al. compared the GMAW, GTAW and FSW processes on the basis of tensile strength of AA6061 aluminium alloy weldments. The filler material for GMAW and GTAW is AA4043 grade aluminium alloy wire and rod respectively. Single pass square butt joints were obtained using pure argon as shielding gas. The parameters considered for GMAW and GTAW processes were gas flow rate (l/min), current (A), welding speed

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(mm/min.), heat input (kJ/mm), voltage (V) while parameters considered for FSW were welding speed (mm/min), pin diameter (mm), heat input (kJ/mm), tool rotational speed (rpm), pin length (mm), axial force (kN). Various tensile properties were studied using UTM and the mean behaviour of the considered samples was compared. The experiment concluded that FSW weldments exhibited higher strength as compared to MIG and TIG weldments. The research also proves the fact that two or more welding techniques can be compared on basis of tensile strength of weldments, irrespective of their symmetrical parametric behaviour [11].

K. Shanmugam et al. compared the influence of SMAW, GMAW and GTAW process parameters on tensile properties, impact, hardness and microstructure of AISI 409M FSS weldments. Single pass square butt joints were made by using AISI 308L ASS as filler metal. Ultrasonic testing of weldments was done to check the defects. All the tensile and impact test specimens were prepared based on ASTM E8M-04 and ASTM E23-04 guidelines respectively. SEM was used to study the fractured surface morphology of impact and tensile tested specimens. Experimental results showed that GTAW weldments exhibited superior mechanical properties than SMAW and GMAW weldments. Microstructural analysis by LOM revealed that the joints by all the three processes predominantly contained solidified dendritic structures of austenite [12].

V. Balasubramanian et al. compared the effect of SMAW, GMAW and GTAW processes on the fatigue crack growth behaviour. The base material used is AISI 409M FSS and filler metal used is AISI 2209 grade DSS. The input process parameters used are arc voltage (V), welding speed (mm/s), heat input (J/mm), current (A), electrode diameter (mm), polarity and shielding gas. Shielding gas used was pure argon. Weldments were examined using ultrasonic testing to check the defects. The experimental results showed that GTAW weldments have higher fatigue strength than SMAW and GMAW weldments [13].

Dhananjay Kumar et. al. examined the effects of various welding parameters of SMAW and TIG welding on distortion of weld joints in different configurations. Various types of joint configurations were studied and welded using above welding techniques. The approach used is statistical analysis of angle distortions of different specimens at predefined parameters and joint configurations. The base material used for the experiment is AISI 304L SS. The various parameters considered for SMAW were welding current (A), voltage (V), torch speed (mm/s), arc gap (mm) and for TIG welding were gas flow rate (l/min.), welding voltage (V), arc gap (mm), torch speed (mm/s), current (A). It was observed that TIG weld joints showed lower angular distortion while SMAW weld joints showed maximum angular distortion [14].

M. Ericsson et. al. studied the effect of welding speed on fatigue strength of FSW welds and compared it with that of TIG and MIG welds. The process used to analyze the experiment proceeded with series of fatigue tests carried out on a hydraulic testing machine. Al-Mg-Si 6082 alloy was used as the base material. The parameters used for the experiment were welding speed (mm/min) and depth of penetration (mm) in different types of joints. The experiment concluded that fatigue strength of FSW welds is greater than TIG and MIG welds of same material [15].

T. Mohandas et al. compared the SMAW and GTAW weldments of 17 Cr FSS in terms of microstructure and mechanical properties. The input process parameters used for both the welding processes were electrode diameter (mm), welding speed (mm/min), arc voltage (V), current (A) and arc gap (mm). Gas flow rate was taken for GTAW only. Optical microscopy and ISI 100 SEM were used for microstructural and fractographic studies respectively. The experimental results showed that GTAW weldments having equi-axed grain structure possessed better tensile and yield strength than SMAW weldments. Base metal in general showed higher ductility than weldments [16].

S. M. Tabatabaeipour et al. compared the SMAW and GTAW weldments of AISI 316L using ToFD technique of ultrasonic testing. The parameters used for both the processes were heat input (kJ/mm), voltage (V), welding speed (mm/s), current (A), and electrode diameter (mm). ER316L and ER316L-16 electrodes have been used as filler metal for GTAW and SMAW. The experiment concludes that GTAW weldments are more isotropic than SMAW weldments and positioning of probe is very crucial to detect diffracted echoes in using time-of-flight-diffraction technique [17].

G. Karthik et al. compared the TIG and SMAW processes on the basis of microstructure and mechanical properties of weldments such as tensile property, toughness and microhardness. The base material used was AISI 304 SS and electrode used in SMAW was SS E308L. The input process parameters used were welding current, arc voltage. The experimental results showed that TIG weldments have higher tensile strength than SMAW weldments [18].

Radha Raman Mishra et al. compared the MIG and TIG welding on the basis of tensile strength of dissimilar joints of different stainless-steel grades and mild steel. The stainless-steel grades used were 202, 304, 310 and 316. Filler material used in both the processes was E309L rod having 2 mm diameter. The input process parameters considered were shielding gas, current (A), voltage (V), electrode type and filler rod. Pure CO_2 and 98%Ar-2%CO_2 mixture were used as shielding gas in TIG and MIG welding process respectively. The experimental results showed that dissimilar weldments of TIG welding have higher strength than that of MIG welding [19].

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G. R. C. Pradeep et al. compared the three welding processes namely TIG welding, gas and arc welding processes by studying the hard facing of AISI 1020 steel. The samples were prepared using the ASTM standards. To study the nature of wear surface of weldments, SEM was used. The results indicated that at low sliding velocities, TIG weldment has better wear properties than the weldments of gas and arc welding but at higher sliding velocities, gas and arc welding processes weldments have better wear properties than TIG weldments [20].

Weiwei Yu et al. compared the SMAW and GTAW weldments on the basis of their fracture toughness at base metal, weld metal, HAZs and fusion zones. The base material used was Z3CN20.09M primary coolant pipes. OK Tigrod 316L + OK 63.25N and ER316L/ER316LSi were used as welding material for SMAW and GTAW respectively. The pipes in both the processes were narrow gap multipass welded in butt joint configuration around the circumference. In order to study the strain evolution in each area and draw a comparison between tensile properties of SMAW and GTAW weldments, uniaxial tensile tests coupled with a 3D DIC system were performed. The experiments conclude that in both the welding processes, worst fracture toughness is seen at fusion zones as compared to other locations. Also, weld metal was wider in SMAW welds with more asymmetrical micro-hardness distribution than in GTAW welds. Overall, GTAW weldments performed better than SMAW weldments [21].

A. Benoit et al. studied and compared four welding processes namely MIG, pulsed MIG, cold metal transfer MIG and TIG. The base material used was 6061 aluminium alloy and 5356 wire was used as filler metal. Shielding gas used was pure argon. Before welding, plates were cleaned using acetone. Infrared thermography was used to study the characteristics of welding operations. Neutron diffraction and X-ray radiography were used to detect residual stress and defects respectively. Experimental results showed that weld beads produced by puls-mix CMT process were better than other processes. Also, mechanical properties were damaged by TIG process the most [22].

Humberto N. Farneze et al. compared the SMAW and FCAW processes on the basis of microstructure and mechanical properties of ASTM A-36 steel weldments with and without PWHT. AWS E 110C-G and AWS E 11018M electrodes were used as filler metal in FCAW and SMAW respectively. Specimens were multipass welded in flat position. The input process parameters considered were current (A), heat support (kJ/mm), voltage (V), arc time (sec), electrode diameter (mm) and number of passes. Optical microscope and electron scan microscope were used for metallographic analysis. Experimental analysis showed that lower impact resistance was observed in tubular wire process weldments as compared to clad electrode process. Also, it was observed that columnar region is 30% and 50% in clad electrode and tubular wire respectively [23].

V. Balasubramanian et al. compared the SMAW and FCAW processes on the basis of fatigue crack growth behaviour of ASTM 517 ‘F’ grade steel weldments. The input process parameters considered were heat input (kJ/mm), voltage (V), welding speed (mm/s), current (A) and electrode diameter (mm). Cruciform joints having improper penetration were formed with AWS E11018-M and AWS E100T5K5 electrodes using SMAW and FCAW processes respectively. Results indicated that SMAW welded joints have better resistance to fatigue crack growth than FCAW welded joints [24].

S. Raghu Nathan et al. compared the microstructure and mechanical properties of GMAW, SMAW and FSW welded naval grade DMR-249 A HSLA steel joints. The filler metal used in GMAW and SMAW processes was E-8018-C1. FSW joints were prepared using tungsten based alloy as a non-consumable rotating tool. The input process parameters considered in GMAW and SMAW processes were current (A), voltage (V), filler diameter (mm), welding speed (mm/min), heat input (kJ/mm) while rotational speed (rpm), heat input (kJ/mm), welding speed (mm/min), tool shoulder diameter (mm), pin length (mm) and axial force (kN) were considered for FSW. ASTM guidelines were adhered to for preparing the test specimens. SEM and optical microscopy were used for fractographic and microstructural analysis of impact and tensile tested specimens. The experimental results showed that FSW joints have superior mechanical properties than GMAW and SMAW joints. Also, use of FSW resulted in removal of problems generally associated with fusion welding processes [25].

Jorge Carlos Ferreira Jorge et al. studied the effect of GMAW and SMAW method and PWHT on HSLA steel joints and compared their mechanical properties. Specimens were multipass welded at 200 °C preheat temperature. The input process parameters considered in both the processes were current (A), deposition rate (kg/h), voltage (V), welding energy (kJ/mm) and number of passes. Ar-CO_2 mixture in 4:1 was used as shielding gas in GMAW. ER120S-G wire rods and E12018-M rods were used as filler metal for GMAW and SMAW respectively. Magnetic particle and ultra sound inspection tests were carried out to check the soundness of welded specimens. Optical microscopy, SEM and EBSD were used for metallographic and microstructural analysis. Thermo-calc software was used to gauge the presence of carbides due to PWHT. PWHT usually results in reduction in mechanical properties especially UTS. The results showed that GMAW has higher deposition rate as compared to SMAW. Thus, GMAW can provide significant gain in productivity of HSLA steel welds [26].

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R. Bendikiene et al. compared the GMAW and SMAW processes on the basis of microstructure and strength of non-alloy S235JR structural steel weld joints. Shielding gas used in GMAW was 82% Ar and 18% CO_2 mixture. Two passes were used to weld the specimens. LOM was used for microstructural analysis. The experiment concludes that GMAW joints have 4-5 times more grains per cm as compared to SMAW joints. Also, more the temperature, coarser the grains and in turn, less is the ductility. Joints having finer grains are identified as possessing superior mechanical properties [27].

Ramkishor Anant et al. compared the P-GMAW, SMAW and GTAW processes on the basis of thermal behaviour and microstructure of dissimilar weld joints between AISI 304LN ASS and SAILMA- 350HI/SA-543 HSLA steel. The common input process parameters used were mean current (A), arc voltage (V), welding speed (cm/min) and heat input (kJ/cm). The pulsed input parameters used in P-GMAW were base current, base current duration (sec), frequency (Hz), pulsed current and pulse current duration (sec). Shielding gas used in P-GMAW and GTAW processes was commercial argon. Optical microscope was used for microstructural analysis. ASTM guidelines were adhered to for preparing the test specimens. The experimental results showed that P-GMAW process can provide joints with better mechanical properties and finer weld grain microstructure than SMAW and GTAW processes [28].

Andrés R. Galvis E et al. compared the GMAW, SMAW and FCAW on the basis of mechanical properties, microstructure and failure mechanisms of AISI 304 SS joints. Optical emission spectroscopy was used to study the chemical compositions and identify the ferrite numbers of the welds. E308L-16, E308LT-1 and E308L-Si electrodes were used in SMAW, FCAW and GMAW respectively. The input process parameters considered were number of passes, current (A), velocity (mm/s), voltage (V) and average heat input (kJ/mm). Pure CO_2 and 98% Ar with 2% O_2 were used as shielding gas in FCAW and GMAW respectively. Fractographic analysis showed three types of fracture modes in the weldments. Also, FCAW joints were better than SMAW and GMAW joints in terms of fatigue life performance [29].

Giedrius Janušas et al. analysed the quality of GMAW and SMAW welded structural steel S235JR joints using destructive as well as non-destructive testing. Tensile tests and holographic interferometry method were used for studying tensile strength and fractures of small seams respectively. Two passes were used in making welds. Shielding gas used in GMAW was 82% Ar and 18% CO_2 mixture. The experiment concludes that GMAW joints have no or very few weld defects and showed superior mechanical properties while opposite was seen in case of SMAW joints [2].

Shrirang Kulkarni et al. compared the P-GMAW, GMAW and SMAW processes on the basis of mechanical, metallurgical, fracture mechanics, corrosion properties and residual stresses of thick wall and 304LN SS pipe joints in V-groove configuration. ER308-L ASS wire was used as filler metal in GMAW and P-GMAW processes with DCEP and 99.98% commercial argon gas while E 308L-15 electrode was used as filler metal in SMAW process with DCEP. The input process parameters used in GMAW and SMAW were electrode diameter (mm), welding current (A), arc voltage (V) and welding speed (cm/min) while pulsed current (A), mean current (A), base current (A), pulse time (ms), pulse off time (ms) and pulse frequency (Hz) were used as input parameters for P-GMAW process. ASTM guidelines were followed to prepare the test specimens. X-ray radiographic tests were performed to check the surface or sub-surface weld defects. The experimental results showed that use of P-GMAW process resulted in improvement in tensile properties, reduction in inclusion and porosity, residual stresses and increase in initiation fracture toughness as compared to that of SMAW and GMAW processes [30].

A. K. Lakshminarayanan et al. compared the GMAW, SMAW and GTAW processes on the basis of tensile and impact properties, microstructure and microhardness of AISI 409M grade steel joints. Specimens were single pass welded using AISI 2209 DSS consumables in square butt joint configuration. Ultrasonic testing of specimens was done to check their soundness. The common input process parameters used were arc voltage (V), heat input (J/mm), welding current (A), welding speed (mm/s) and electrode diameter (mm). Shielding gas used in GMAW and GTAW was pure argon. The results showed that joints made using GTAW process have better tensile and impact properties than joints made using SMAW and GMAW processes [31]

Amber Shrivastava et al. compared GMAW and FSW processes on the basis of energy consumption and their effect on environment. Aluminium 6061-T6 was used as base material. Al 4043 and argon were used as filler metal and shielding gas in GMAW. Environmental impact was measured using life cycle assessment approach. Results showed that FSW process uses 42% less energy, 10% less material for specimens having similar tensile strength and emits 31% less GHGs than GMAW process. FSW process uses less energy than any fusion welding as it is a solid state process. In other words, workpiece does not melt and welding takes place in solid state which results in low distortion, few welding defects, excellent weld properties and better health as compared to fusion welding processes [32].

C. Yeni et al. compared MIG, TIG and FSW processes in terms of microstructure and mechanical properties of 6 mm thick 7075 aluminium alloy welds. AA 5356 (Al-5% Mg) and AA 4043 (Al-5%Si) were used as filler metal in MIG and TIG welding respectively. Current (A), shielding gas

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(argon), voltage (V), welding speed (mm/min) and gas flow rate (l/min) were used as input process parameters in both MIG and TIG processes. MIG and TIG specimens were preheated at approximately 150°C for better penetration. Microstructural examination by optical microscope revealed recrystallized fine equiaxed grains in nugget zone of FSW welds whereas coarse grains were observed in weld and heat affected zone of MIG and TIG welds due to high heat input. Also, FSW joints possessed superior mechanical properties than MIG and TIG joints [33].

E. Taban et al. compared MIG, TIG and FSW processes in terms of microstructure and mechanical properties of 6.5 mm thick 5086-H32 Al-Mg alloy welds. ER5356 AlMg5Cr (A) wire was used with 99.999% pure argon to weld MIG and TIG specimens. All specimens were double sided butt welded. Microstructural examination was carried out using LOM, TEM and EDX. Experimental results showed that FSW joints have lower distortion rate and better tensile properties than MIG and TIG joints [34].

Stefano Maggiolino et al. compared MIG and FSW processes on the basis of corrosion resistance of aluminium alloys AA6082T6 and AA6060T5. Morphological analysis of welds surface with the help of LOM was used for studying the corrosion behaviour. Results showed that FSW welds were more resistant to corrosion than MIG welds [35].

Stephane Godin et al. compared the residual stresses in MCAW (a variant of GMAW) and FCAW welds of UNS S41500 using three different filler metals namely E410NiMo, 309L and 13%Cr-6%Ni. Specimens were multipass welded which generally results in subsurface residual stresses. Contour method was used to measure the residual stresses. All the specimens were preheated at 100°C and then with an interpass temperature of 160°C. Current (A), voltage (V), welding speed (mm/min), shielding gas and heat input (kJ/mm) were used as input process parameters. Experimental results showed that the selection of proper filler material was not clear for all loading and welding conditions; therefore, further research was needed. Also, all the weldments had same HAZ [36].

Wei Guo et al. compared GMAW and NGLW processes in terms of microstructure and mechanical properties of multipass butt welded S960 HSLA joints. Union X96 (ER120S-G) was used as filler metal. Argon and CO_2 were used as shielding gas in 4:1 in GMAW. LOM and SEM were used for macro- and micro-structural characterisation of welds while fractographic analysis was carried out using SEM coupled with EDX detector. Heat input (kJ/mm), welding speed (m/min), wire feed rate (m/min), shielding gas flow rate (l/min) and number of passes were common input parameters for both the welding processes. Input process parameters current (A), voltage (V) were used in GMAW only while power (kW) and focal position (mm) were used in NGLW only. Experimental results revealed that GMAW welds have slow cooling rate as compared to NGLW welds because the arc in GMAW process introduces more heat into the weld due to broader heating area than laser. Also, tensile properties of NGLW joint are superior than that of GMAW joint but opposite is true for impact toughness. Fractographic analysis of base metal and welds showed dimples which confirmed that all the specimens failed in a ductile manner [4].

A. Sik et al. compared the TIG and FSW processes in terms of microstructure and mechanical properties of AZ31 Mg alloy weldments. Specimens were butt welded using AZ31D electrodes in TIG welding. Experimental results showed that weld bead by FSW was much smoother than by TIG process but tensile strength of TIG welds was higher than that of FSW welds. Distortion was observed in TIG welds due to high heat input as TIG welding is a fusion welding. In FSW process, increasing the revolutions resulted in high heat input being introduced into the material and slow cooling rate thereby decreasing the hardness [5].

A. S. Elmesalamy et al. compared TIG and NGLW processes on the basis of residual stresses and plastic strain in multipass welds of AISI 316L SS. Shielding gas used was pure argon. Contour method was used to measure the residual stresses and results were confirmed using X-ray diffraction in some cases. Results showed that NGLW welds have lower longitudinal tensile residual stresses and plastic strain than GTAW welds. Also, distribution of residual stresses about the weld centreline was almost symmetrical [37]

HE Zhen-bo et al. compared TIG and FSW processes on the basis of microstructure and mechanical properties of Al-Mg-Mn-Sc-Zr alloy plates in hot rolled and cold rolled annealed condition. Al-Mg-Sc-Zr alloy wire along with argon shielding gas was used in TIG welding. TEM was used for microstructural characterization. Experimental results showed that FSW joints have better tensile properties and welding coefficient than TIG joints. Weld nugget zone of FSW welds has finer grains and more hardness than TIG welds seam [38].

A. Cabello Munoz et al. compared TIG and FSW processes on the basis of microstructure and mechanical properties of Al-4.5Mg-0.26Sc alloy joints and examined the effect of PWHT on them. OM and TEM were used for microstructural characterization. Current (A), welding speed (mm/s), arc length (mm), shielding gas (argon), gas flow rate (l/min) and SiO_2 coating were used as input parameters in TIG welding. Experimental analysis showed that mechanical properties of FSW welds were superior than TIG welds. Also, PWHT improved the strength of TIG joints but it had no material effect on FSW joints properties [39].

Jau-Wen Lin et al. compared the TIG and FSW processes on the basis of mechanical properties of pure copper joints.

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Copper plates were preheated in arc welding to avoid distortion and fast cooling due to its high thermal diffusivity. V-notched specimens were two passes TIG welded. Current (A), voltage (V), welding speed (mm/min), shielding gas (argon), gas flow rate (l/min), electrode diameter, preheat and post-weld temperature (°C) were used as input process parameters in TIG welding. LOM and SEM were used for microstructural and fractographic analysis respectively. Surface structure was observed using XRD. Experimental results concluded that tensile strength and hardness of FSW welds is higher than TIG welds. Microstructural examination showed that base metal has coarse grains whereas FSW welds have fine and isometric stir zone and elongated grains were observed in TIG welds [40].

Liang Zhang et al. compared the TIG and laser welding processes on the basis of microstructure and mechanical properties of Al-Zn-Mg-Cu alloy joints. Al-Mg alloy filler wire was used in TIG welding. Specimens were butt welded. Welding speed (mm/min), argon gas flow rate (l/min) were common input parameters in both the welding processes, Current (A), voltage (V), wire feed rate (mm/min) were used as input parameters in TIG welding only whereas laser power (kW) was used in laser welding only. XRF was used for analysing chemical composition. X-ray radiography followed by analysis using stereoscopic microscope was used to check the weld defects. Grain structure was analysed using EBSD while distribution of alloying element was analysed using back scatter electron imaging of SEM and EPMA. Experimental analysis showed that laser welds have higher UTS and lower elongation than TIG welds. Grain structure in fusion zone of both welds is equiaxed dendritic but laser welds have finer grains than TIG welds. Also, fusion zone of laser welds is narrower than TIG welds due to lower heat input and higher energy density [41].

T. Pasang et al. compared the LBW, EBW and GTAW processes on the basis of microstructure and mechanical properties of Ti-5Al-5V5Mo-3Cr welds. Specimens were full penetration butt welded without any filler metal. Microstructural analysis was carried out using an optical microscope. Fracture surface morphological analysis studied using SEM revealed that all the specimens failed in the weld metal region in a ductile manner. All welds had lower strength than base metal. GTAW welds had wider weld zones as compared to EBW and LBW welds due to high heat input supplied to specimens during GTAW process [42].

The main points of above discussion on comparison of different welding processes have also been summarized in Table 1.

Table 1. Studies on comparison with hybrid welding process

Sr. No.	Researchers	Base Material	Description	Important Remarks
1.	A. K. Lakshminarayanan et al. (2009) [11]	AA6061 aluminium alloy	Compared the GMAW, GTAW and FSW processes on the basis of tensile strength of weldments	FSW weldments exhibited higher strength as compared to MIG and TIG weldments.
2.	K. Shanmugam et al. (2009) [12]	AISI 409M FSS	Compared the SMAW, GMAW and GTAW processes on the basis of microstructure and mechanical properties of weldments	GTAW weldments exhibited superior mechanical properties than SMAW and GMAW weldments.
3.	S. M. Tabatabaeipour et al. (2010) [17]	AISI 316L wrought ASS	Compared the SMAW and GTAW weldments using time of-flight-diffraction technique of ultrasonic testing	GTAW weldments were more isotropic than SMAW weldments.
4.	Radha Raman Mishra et al. (2014) [19]	202, 304, 310 and 316 grades SS, mild steel	Compared the MIG and TIG welding processes on the basis of tensile strength of dissimilar joints	Dissimilar weldments of TIG welding exhibited higher strength than that of MIG welding
5.	G. R. C. Pradeep et al. (2013) [20]	AISI 1020 steel	Compared the TIG welding, gas and arc welding processes by studying the hard facing of AISI 1020 steel	At low sliding velocities, TIG weldments exhibited better wear properties than weldments of gas and arc welding but opposite was true at high sliding velocities.
6.	Weiwei Yu et al. (2018) [21]	Z3CN20.09M primary coolant pipes	Compared the SMAW and GTAW weldments on the basis of their fracture toughness	Overall performance of GTAW weldments was better than SMAW weldments.
7.	A. Benoit et al. (2015) [22]	6061 aluminium Alloy	Compared four welding processes namely MIG, pulsed MIG, cold metal transfer MIG and TIG	Weld beads produced by puls-mix cold metal transfer process were better than other MIG processes.
8.	Humberto N. Farneze et al. (2010) [23]	ASTM A-36 steel	Compared the SMAW and FCAW processes on the basis of microstructure and mechanical properties of weldments with and without PWHT	Lower impact resistance was observed in tubular wire process weldments as compared to clad electrode process.
9.	V. Balasubramanian et al. (1999) [24]	ASTM 517 'F' grade steel	Compared the SMAW and FCAW processes in terms of fatigue crack growth behaviour of weldments	SMAW welded joints had better resistance to fatigue crack growth than FCAW welded joints.

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10.	S. Raghu Nathan et al. (2015) [25]	Naval grade DMR-249 A HSLA Steel	Compared the GMAW, SMAW and FSW processes on the basis of microstructure and mechanical properties of weld joints	FSW joints had better mechanical properties than GMAW and SMAW joints.
11.	Jorge Carlos Ferreira Jorge et al. (2018) [26]	ASTM A 36 HSLA steel plates	Studied the effect of GMAW. SMAW processes and PWHT on weld joints and compared their mechanical properties	GMAW process had higher deposition rate as compared to SMAW process.
12.	R. Bendikiene et al. (2015) [27]	Non-alloy S235JR structural steel	Compared the GMAW and SMAW processes on the basis of microstructure and strength of weld joints	GMAW joints had 4-5 times more grains per cm as compared to SMAW joints.
13.	Ramkishor Anant et al. (2018) [28]	AISI 304LN ASS and SAILMA-350HI/SA-543 HSLA steel	Compared the P-GMAW, SMAW and GTAW processes on the basis of thermal behaviour and microstructure of dissimilar weld joints	P-GMAW process can provide joints with better mechanical properties and finer weld grain microstructure than SMAW and GTAW processes.
14.	Andrés R. Galvis E et al. (2011) [29]	AISI 304 SS	Compared the GMAW, SMAW and FCAW process in terms of microstructure, mechanical properties and failure mechanisms of weld joints	FCAW joints were better than SMAW and GMAW joints in terms of fatigue life performance.
15.	Giedrius Janušas et al. (2012) [2]	Structural steel S235JR	Compared the quality of GMAW and SMAW joints using destructive as well as non-destructive testing	GMAW joints had superior mechanical properties than SMAW joints.
16.	Shrirang Kulkarni et al. (2008) [30]	304LN SS pipe	Compared the GMAW, P-GMAW and SMAW processes on the basis of mechanical, metallurgical, fracture mechanics, corrosion properties and residual stresses of welds joints	P-GMAW process resulted in improvement in tensile properties, reduction in inclusion and porosity, residual stresses and increase in initiation fracture toughness as compared to that of GMAW and SMAW processes
17.	Stefano Maggiolino et al. (2008) [35]	AA6082T6 and AA6060T5	Compared MIG and FSW processes on the basis of corrosion resistance	FSW welds were more resistant to corrosion than MIG welds.
18.	Stephane Godin et al. (2014) [36]	UNS S41500	Compared the residual stresses in MCAW and FCAW welds using three different filler metals	The selection of proper filler material was not clear for all loading and welding conditions. Hence further research is needed.
19.	Wei Guo et al. (1999) [4]	S960 HSLA	Compared GMAW and NGLW in terms of microstructure and mechanical properties of joints	Tensile properties of NGLW joint were superior than that of GMAW joint but opposite was true for impact toughness.
20.	A. Sik et al. (2017) [5]	AZ31 Mg alloy	Compared the TIG and FSW processes on the basis of microstructure and mechanical properties of joints	Weld bead by FSW was much smoother than by TIG process but tensile strength of TIG welds was higher than FSW welds.
21.	A. S. Elmesalamy et al. (2014) [37]	AISI 316L SS	Compared TIG and NGLW processes on the basis of residual stresses and plastic strain	NGLW welds had lower longitudinal tensile residual stresses and plastic strain than GTAW welds.
22.	A. Cabello Munoz et al. (2008) [39]	Al-4.5Mg-0.26Sc alloy	Compared TIG and FSW processes on the basis of microstructure and mechanical properties of joints and examined the effect of PWHT on them	Mechanical properties of FSW welds were superior than TIG welds. PWHT improved the strength of TIG joints but it had no material effect on FSW joints properties.
23.	Jau-Wen Lin et al. (2013) [40]	Pure copper	Compared the TIG and FSW processes in terms of mechanical properties of joints	Copper plates need to preheated in arc welding to avoid distortion and fast cooling due to its high thermal diffusivity. Tensile strength and hardness of FSW welds were higher than TIG welds.
24.	Liang Zhang et al. (2016) [41]	Al–Zn–Mg–Cu alloy	Compared the TIG and laser welding processes on the basis of microstructure and mechanical properties of joints	Laser welds showed higher UTS and lower elongation than TIG welds. Laser welds had finer grains in fusion zone than TIG welds but grain structure in fusion zone of both welds was equiaxed dendritic.
25.	T. Pasang et al. (2013) [42]	Ti-5Al-5V-5Mo-3Cr	Compared the LBW, EBW and GTAW processes on the basis of microstructure and mechanical properties of welds	GTAW welds had wider weld zones as compared to EBW and LBW welds due to high heat input supplied to specimens during GTAW process. All welds had lower strength than base metal.

2.2 Comparison of a welding with its hybrid welding

Zhao Jiang et. al. studied double sided hybrid laser-MIG welding and MIG welding. The base material used is 30 mm thick Al 5083 alloy and ER5183 is used as filler wire. The laser beam parameters used were wavelength (mm), focal radius (mm), beam parameter product (mm-rad). Groove angle was kept constant during the experiments. The experiment concludes that hybrid laser-MIG welding process is better than conventional MIG welding [43].

Ruifeng Li et al. compared the LBW with hybrid laser-MIG welding on the basis of microstructure and mechanical

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properties of Ti-Al-Zr-Fe titanium alloy weldments made using TA-10 filler wire. For this, optical microscope observations were taken, microhardness and mechanical tests were performed. The input process parameters used for LBW were side assist gas flow rate (l/min), welding speed (m/min), power (kW) and focal position (mm) while parameters used for hybrid laser-MIG welding were laser arc distance (mm), welding speed (m/min), wire feed rate (m/min), arc voltage (V), power (kW), clearance (mm), MIG gas flow rate (l/min), side assist gas flow rate (l/min) and focal position (mm). The experiment concluded that out of both the welding processes, laser-MIG hybrid welding was better in terms of both strength and ductility and thus feasible for joining joints Ti- Al-Zr-Fe sheets [44].

Xiaohong Zhan et al. compared the MIG and laser-MIG hybrid welding considering welding efficiency, deformation and welding material consumption in Invar36 alloy joints. Current (A), welding speed (mm/s) and number of passes were common input process parameters in both the welding processes. Voltage (V) and laser power (W) were also considered as input parameters in MIG and hybrid laser-MIG welding respectively. FE software MSC. Marc was used for simulation purpose in hybrid welding. Experimental analysis concluded that laser-MIG hybrid welding is way better than MIG welding in all the aspects considered for the comparison purpose. Also, laser-MIG welds have higher penetration depth to weld width ratio than MIG welds. Weld seam was affected appreciably by laser-MIG hybrid welding as heat input in hybrid welding is more concentrated than that of MIG welding [45].

G. Li et al. compared laser and laser-arc hybrid welding on the basis of microstructure, coefficient of thermal expansion and mechanical properties of Invar36 alloy joints. The chemical composition, phases and microstructure were observed using XRF, XRD and LOM respectively while fracture surface morphology and chemical composition of precipitates were studied using SEM and EDS respectively. The common input process parameters used are laser power (kW), welding speed (m/min), focal length (mm) and defocused length (mm) while current (A) and voltage (V) were used in hybrid welding only. Experimental analysis concluded that laser-arc hybrid welds have better tensile properties and higher coefficient of thermal expansion than laser welds. The average grain size of hybrid welds is smaller than that of laser welds despite the high heat input involved in hybrid welding as compared to laser welding [46].

Pritesh Prajapati et al. compared the FCAW-GMAW hybrid welding with conventional GMAW and FCAW welding processes on the basis of microstructure, hardness, impact and tensile properties of SA516 Gr70 carbon steel welds. The V-grooved specimens were welded in flat position using current (A), shielding gas, shielding gas flow rate (l/min), voltage (V), travel speed (mm/min) and electrode extension (mm) as input process parameters. Ar-CO_2 mixture in 9:1 was used as shielding gas. Experimental results showed that GMAW-FCAW hybrid welds have superior tensile properties while FCAW-FCAW welds have highest hardness [3].

The above discussion given on comparison of a welding with its hybrid welding process has also been summarized in Table 2.

Table 2. Studies on comparison with hybrid welding process

Sr. No.	Researchers	Base Material	Description	Important Remarks
1.	Zhao Jiang et al. (2018) [43]	5083 aluminium alloy	Compared double sided laser-MIG hybrid welding and MIG welding	Hybrid laser-MIG welding process was better than conventional MIG welding.
2.	Ruifeng Li et al. (2011) [44]	Ti-Al-Zr-Fe titanium alloy	Compared the laser beam welding with the laser-MIG hybrid welding on the basis of microstructure and mechanical properties of welds	Hybrid laser-MIG welds had better tensile properties than laser beam welds.
3.	Xiaohong Zhan et al. (2016) [45]	Invar 36 alloy	Compared the MIG and laser-MIG hybrid welding on the basis of welding efficiency, deformation and welding material consumption	Hybrid laser-MIG welding was better than MIG welding in all the aspects considered for the comparison purpose.
4.	G. Li et al. (2014) [46]	Invar36 alloy	Compared laser and laser-arc hybrid welding on the basis of microstructure, coefficient of thermal expansion and mechanical properties of joints	Laser-arc hybrid welds had better tensile properties and higher coefficient of thermal expansion than laser welds.
5.	Pritesh Prajapati et al. (2018) [3]	SA516 Gr70 carbon steel	Compared the FCAW and GMAW hybrid welds with that of conventional FCAW and GMAW welds in terms of microstructure and mechanical properties	GMAW-FCAW hybrid welds had superior tensile properties while FCAW-FCAW welds had highest hardness.

2.3 Comparison of two variants of a welding process

Xiaohong Zhan et al. compared the continuous and pulsed MIG welding process in terms of morphology, microstructure of weld seam and mechanical properties of

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Invar36 alloy weld joints. The filler wire used was M39. The input process parameters used in both the processes were current (A), welding speed (mm/s) and voltage (V). The experimental result concluded that for Invar36 alloy, pulsed MIG is superior than continuous MIG welding within the rational parameters. Pulsed MIG weldments have more microhardness and tensile strength as compared to continuous MIG weldments. Also, the size of weld seam differs significantly in weldments of both the welding processes [47].

A. Mathivanan et al. compared the pulsed current and dual pulse GMAW processes on the basis of mechanical and metallurgical properties of AA6061 aluminium alloy sheet weldments. Square butt joints were obtained using ER 4043 filler wire. The input parameters used were travel speed (cm/min), wire feed rate (m/min), arc voltage (V), mean current (A) and heat input (kJ/cm). Shielding gas used was pure argon. ASTM E8M and ASTM EA370 standards were followed to prepare the tensile and microhardness test specimens. X-ray radiographic tests were carried out to check the soundness of weld joints. Microstructural analysis by LOM showed finer dendrites in both the weldments. Experimental analysis showed that superior mechanical and metallurgical properties were obtained in dual pulsed GMAW process than in pulsed current GMAW process [48].

Z. Bingul et al. compared the pulsed and constant current GMAW process using mild steel as base material. The input parameters considered were peak current (A), contact tube work distance (mm) and duty cycle (%). A mixture of 98% Ar and 2% O_2 was used as shielding gas. The filler metal used was ER70S-6 wire. High speed videography was used to measure the arc length and images were analyzed using LabVIEW software. Experimental data revealed that at the same energy input, resistivity remains the same in both the welding processes [49].

R. Garcia et.al. conducted experiments on the comparative analysis of MIG welding on composites using different electric arc processes. The process used for comparative analysis can be achieved by both direct electric arc (DEA) and indirect electric arc (IEA) with micro structure exploration of weld with the help of optical microscopy and scanning electron microscopy attached to an energy dispersive X-ray spectroscopy system. The parameter used for analysis in both IEA and DEA were argon flow rate (l/min), current (A), preheated temp (^{0}C), voltage (V), travel speed (mm/sec.), heat input (kJ/s). The material used is a metal matrix composite (MMC) of aluminium fabricated by use of capillary infiltration technique with chemical composition of Al-1010 with TiC and data acquisition technique is used to monitor process parameters. The experiment concludes that indirect electric arc yields uniform welds while broadening was observed in the upper parts in direct electric arc. Mechanical strength in indirect electric arc welds was uniform irrespective of the presumed pre-heating condition and depends only on consumable. Also, they concluded that use of IEA is much more beneficial than DEA for joining Al-based composites, independent of reinforcement content [50].

The above discussion given on comparison of two variants of a welding process has also been summarized in Table 3.

Table 3. Studies on comparison of two variants of a welding process

Sr. No.	Researchers	Base Material	Description	Important Remarks
1.	Xiaohong Zhan et al. (2017) [47]	Invar36 alloy	Compared pulsed and continuous MIG welding processes on the basis of microstructure and mechanical properties of joints	Pulsed MIG weldments exhibited better mechanical properties compared to continuous MIG weldments.
2.	A. Mathivanan et al. (2014) [48]	AA6061 aluminium alloy sheet	Compared the pulsed current and dual pulse GMAW processes in terms of mechanical and metallurgical properties of weldments	Superior mechanical and metallurgical properties were obtained in dual pulsed GMAW process than in pulsed current GMAW process.
3.	Z. Bingul et al. (2003) [49]	Mild steel	Compared the constant current and pulsed GMAW process	At the same energy input, resistivity remained the same in both the welding processes.
4.	R. Garcia et al. (2003) [50]	Metal matrix composite of Al-1010 with TiC	Compared the MIG welding using direct and indirect electric arcs	Use of indirect electric arc was much more beneficial than direct electric arc for joining Al-based composites, independent of reinforcement content.

2.4 Comparison of different filler metals in a welding

Jaime Casanova Soeiro Junior et al. compared the deposition rate and deposition efficiency of ER70S-6 and E71T-1C filler wires in MIG-MAG and FCAW processes respectively. ASTM A36 steel plates were welded in flat position. The input process parameters considered were current (A), contact tip workpiece distance (mm), shielding gas, arc voltage (V), arc power (W), wire feed rate (m/min). Shielding gases used were pure CO_2 and Ar-CO_2 mixture in 3:1. Experimental results showed that drop diameter and frequency of detachment depend on the type of shielding

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gas used. Also, electric current is the most influential parameter responsible for increasing the deposition rate. Deposition rate and deposition efficiency of ER70S-6 filler wire is more than that of E71T-1C filler wire [51].

Jiang Qinglei et al. studied the effect of three different filler wires namely ER50-6, MK-G60 and MK-G60-1 on microstructure and mechanical properties of gas shielded arc weld joints of Q550 steel. Current (A), voltage (V), welding speed (cm/min) and gas flow rate (l/min) were used as input process parameters. Argon and CO_2 were used as shielding gas in 4:1. Microstructural examination was carried out using LOM, TEM and EDS while EPMA was used for fracture surface morphology. The experimental data reveal that joints produced by MK-G60-1 filler wire showed better tensile properties than joints produced by ER50-6 and MK-G60 filler wires. Fractographic analysis and microstructural examination showed that fine acicular ferrite structure is helpful to keep crack propagation in check and increase toughness of weld joints [52].

L. H. Shah et al. compared the influence of aluminium filler ER5356 and SS filler E308LSi on the basis of microstructure and mechanical properties of MIG welded dissimilar joints of aluminium alloy AA6061 and SS SUS304. The choice of filler metal has a decisive role in improving the weld joint properties. Welding and microstructural examination of dissimilar metals is difficult due to different physical properties and requirement of different etching solutions for dissimilar metals. Experimental results showed that welds made using aluminium filler wire have superior tensile strength but lower hardness than SS filler welds [1].

M. T. Liao et al. compared the use of ER308L solid wire and E308LT-1 flux cored filler wire with different composition of shielding gases on the basis of spatter rate, tensile properties and chemical composition in GMAW process. AISI 304 SS plates having V-shaped groove were multipass GMA welded using a constant voltage power source. Fractographic and chemical analysis were carried out using SEM and SEM coupled with EDAX detector respectively. Results showed that spatter rates are less in case of flux cored filler wire welds as compared to solid wire welds because flux changes the mode of metal transfer, reduces the size of droplets thereby causing the spatters to reduce. Also, composition of shielding gas has no effect on spatters. Solid wire welds had higher UTS but lower oxygen content than flux cored filler wire welds [53].

H. T. Lee et al. compared the two filler metals namely I-82 and I-52 on the basis of microstructure and mechanical properties of GTA welded Inconel alloy 690 joints. LOM was used for microstructural characterization of fusion and heat affected zone while SEM was used for fracture surface morphology. Surface and sub-surface defects were checked using radiography. Current (A), voltage (V), welding speed (mm/s), heat input (kJ/mm), total heat input (kJ/mm) and number of passes were considered as input process parameters. Results showed that I-52 filler metal has better weldability as compared to I-82 filler metal. Also, welds by I-52 filler metal have greater impact toughness but lower tensile strength and elongation than welds by I-82 filler metal. Microstructural analysis showed that fusion zone centreline of I-52 welds have columnar dendrite structure whereas that of I-82 welds have equiaxed dendritic structure [54].

K. Devendranath Ramkumar et al. investigated the effect of different filler metals namely ER2553, ERNiCu-7 and different welding processes CCGTAW and PCGTAW on microstructure and mechanical properties of dissimilar joints of Inconel 718 and AISI 316L ASS. Specimens were welded in single V-groove butt joint configuration. Peak current (A), voltage (V), filler wire diameter (mm), shielding gas flow rate (l/min) and number of passes were common input process parameters in both the processes while back ground current (A), pulse time, frequency (Hz) and duty cycle were used as input parameters in PCGTAW only. Gamma ray radiography was used to check the micro- and macro- weld defects. LOM and SEM were used for microstructural characterization of welds. Experimental analysis concluded that PCGTAW joints using ERNiCu-7 filler metal showed superior mechanical and metallurgical properties. ERNiCu-7 welds fractured in a ductile manner while ER2553 welds fractured in a brittle manner. Also, different metals in dissimilar welds make PWHT of dissimilar welds difficult due to different chemical composition of base materials [55].

The above discussion given on comparison of different filler metals in a welding process has also been summarized in Table 4.

Table 4. Studies on comparison of different filler metals

Sr. No.	Researchers	Base Material	Description	Important Remarks
1.	Jaime Casanova Soeiro Junior et al. (2017) [51]	ASTM A36 steel	Compared the deposition rate and deposition efficiency of ER70S-6 and E71T-1C filler wires in MIG-MAG and FCAW processes respectively	Deposition rate and deposition efficiency of ER70S-6 filler wire was more than that of E71T-1C filler wire.
2.	Jiang Qinglei et al. (2011) [52]	Q550 steel	Studied the effect of three different filler wires on microstructure and mechanical properties of gas shielded arc weld joints	Joints produced by MK-G60-1 filler wire showed better tensile properties than joints produced by ER50-6 and MK-G60 filler wires.

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3.	L. H. Shah et al. (2013) [1]	Aluminium alloy AA6061 and SS SUS304	Compared the influence of aluminium and SS fillers on microstructure and mechanical properties of MIG welded joints	Aluminium filler 5356 joints showed better tensile properties than SS filler ER308LSi joints.
4.	M. T. Liao et al. (1999) [53]	AISI 304 SS	Compared the use of ER308L and E308LT-1 filler wires with different composition of shielding gases in GMAW process	Composition of shielding gases affected the weld properties remarkably in case of ER308L wire but slighty in case of E308LT-1 wire. Spatter rates were less in E308LT-1 wire joints as compared to ER308L wire joints.
5.	H. T. Lee et al. (1999) [54]	Inconel alloy 690	Compared the two filler metals in terms of microstructure and mechanical properties of GTAW joints	I-52 filler metal had better weldability as compared to I-82 filler metal. Welds by I-52 filler metal had greater impact toughness but lower tensile strength and elongation than welds by I-82 filler metal.
6.	K. Devendranath Ramkumar et al. (2014) [55]	Inconel 718 and AISI 316L ASS	Investigated the effect of different filler metals and different welding processes CCGTAW and PCGTAW on microstructure and mechanical properties of dissimilar joints	PCGTAW joints using ERNiCu-7 filler metal showed superior mechanical and metallurgical properties.

2.5 Comparison of different optimization methods

Abhijit Sarkar et al. compared the mathematical models developed for predicting the weld bead geometry and HAZ width using MRA and BPNN. AISI 1015 mild steel plates were submerged arc welded using copper coated mild steel electrode with wire feed rate (mm/min), stick out (mm) and traverse speed (m/min) as input process parameters. Voltage was kept constant. Taguchi's orthogonal array was used for DoE purpose. Experimental analysis showed that BPNN model is better than MRA since BPNN model is non-linear while MRA model is linear [56].

Davi Sampaio Correia et al. compared the GA and RSM optimization methods. Mild steel plates having square groove butt joint were GMAW welded using ER 70S-6 filler wire with voltage (V), wire feed rate (m/min) and welding speed (cm/min) as input parameters. Pure CO_2 was used as shielding gas. In RSM, design matrix is based on CCD. Deposition efficiency (%) and bead geometry i.e. reinforcement (mm), bead width (mm), and penetration depth (mm) were considered as output parameters. Experimental analysis showed that RSM is better than GA [9].

I. S. Kim et al. compared the MRA and BPNN models correlating the GMAW input parameters and top bead height. MATLAB and SAS statistical software were used for developing BPNN and MRA models respectively. Current (A), voltage (V) welding speed (cm/min) and number of passes were selected as input parameters. BV-AH32 steel plates were used as base material. Ar and CO_2 mixture in 4:1 as used as shielding gas. Experimental analysis showed that BPNN model is better than MRA model in predicting the top bead height of welds [57].

Nitin Kumar Sahu et al. compared the hybrid PCA and GRA based Taguchi optimization methods. IS 2062 mild steel plates were MIG welded using copper coated ER 70S-6 wire with current (A), voltage (V) and plate thickness (mm) as input parameters. Ar and CO_2 mixture in 3:1 was used as shielding gas. Tensile strength and bead geometry were considered as output parameters. Taguchi's orthogonal array was used for DoE purpose. Optimum parameters were same using both the optimization methods. Both the methods are easy to apply and do not need special skills. ANOVA showed that plate thickness is the most significant factor affecting the welds quality [58].

S. C. Juang et al. compared the two variants of ANN methods namely back propagation and counter propagation. BPN is the widely used ANN whereas CPN is a relatively new ANN. Pure 1100 aluminium plates were single pass TIG welded using AWS A5-10 wire and argon shielding gas. Welding speed (cm/min), wire feed rate (mm/min), cleaning (%), arc gap (mm) and current (A) were used as input parameters whereas front and back width (mm) and height (mm) of weld beads were taken as output parameters. Experimental results showed that generalization ability of BPN is better while learning ability of CPN is better [59].

The above discussion given on comparison of different optimization methods has also been summarized in Table 5.

Table 5. Studies on comparison of different optimization methods

Sr. No.	Researchers	Base Material	Description	Important Remarks
1.	Abhijit Sarkar et al. (2016)	AISI 1015 mild steel	Compared the MRA and BPNN mathematical models developed for	BPNN model is better than MRA since BPNN model is non-linear while MRA

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	[56]		predicting the weld bead geometry and HAZ width	model is linear.
2.	Davi Sampaio Correia et al. (2005) [9]	Mild steel	Compared the GA and RSM optimization methods	RSM is better than GA.
3.	I. S. Kim et al. (2003) [57]	BV-AH32 steel	Compared the MRA and BPNN models correlating the GMAW input parameters and top bead height	BPNN model is better than MRA model in predicting the top bead height of welds.
4.	Nitin Kumar Sahu et al. (2017) [58]	IS 2062 mild steel	Compared the hybrid PCA and GRA based Taguchi optimization methods	Optimum parameters were same using both the optimization methods. ANOVA showed that plate thickness is the most significant factor affecting the welds quality.
5.	S. C. Juang et al. (1998) [59]	Pure 1100 aluminium	Compared the two variants of ANN methods namely back propagation and counter propagation	Generalization ability of BPN is better while learning ability of CPN is better.

III. CONCLUSION

Today, due to the development of advanced materials and so many welding options available, comparison of different welding processes has become a necessity. Various optimization methods are available to get the optimum process parameters for better and efficient output results. From the above literature survey, following conclusions have been drawn:

1.Different welding processes can be evaluated and compared on the basis of microstructure, mechanical properties, residual stresses and corrosion resistance etc. of weldments.

2. Same welding process can be compared in terms of use of different filler materials and changing the nature of input parameter(s) like pulsed or continuous.

3. A welding process can be compared with its hybrid welding using some other process.

4. Different optimization methods can be compared on the basis of prediction of output parameters.

5. Fusion welding processes have several problems associated with them such as high heat input, slow cooling rate, wider and softened HAZ, phase transformation, multiple thermal cycles etc. responsible for decrease in mechanical properties of welds.

6. Solid state welding processes provide joint properties comparable to base material and can be used to join advanced materials easily.

7. The concept of hybrid welding processes is gaining popularity now due to additional process capabilities providing better weld properties.

REFERENCES

[1] L. H. Shah, Z. Akhtar, M. Ishak. Investigation of aluminium-stainless steel dissimilar weld quality using different filler metals. International Journal of Automotive and Mechanical Engineering (IJAME). 2013; 8:1121-1131. http://dx.doi.org/10.15282/ijame.8.2013.3.0091

[2] Giedrius Janušas, Audrius Jutas, Arvydas Palevičius, Darius Žižys, Arvydas Barila. Static and vibrational analysis of the GMAW and SMAW joints quality. Journal of Vibroengineering. 2012; 14:1220-1226. https://www.jvejournals.com/article/10677/pdf

[3] Pritesh Prajapati, Vishvesh J Badheka, Kush Mehta. An outlook on comparison of hybrid welds of different root pass and filler pass of FCAW and GMAW with classical welds of similar root pass and filler pass. Sādhanā. 2018 ; 43 : 75. https://doi.org/10.1007/s12046-018-0869-z

[4] Wei Guo, Lin Li, Shiyun Dong, Dave Crowther, Alan Thompson. Comparison of microstructure and mechanical properties of ultra-narrow gap laser and gas-metal-arc welded S960 high strength steel. Optics and Lasers in Engineering. 2017; 91:1-15. https://doi.org/10.1016/j.optlaseng.2016.11.011

[5] A. Sık. Comparison between microstructure characteristics and joint performance of AZ31 magnesium alloy welded by TIG and friction stir welding (FSW) processes. Kovové materiály - Metallic Materials. 2013; 51(3):197-203. http://www.kovmat.sav.sk/full.php?rr=51&cc=3&ss=197

[6] Cai W, Daehn G, Vivek A, et al. A state-of-the-art review on solid-state metal joining. ASME. International Manufacturing Science and Engineering Conference, Volume 2: Materials; Joint MSEC-NAMRC-Manufacturing USA (): V002T04A044. doi:10.1115/MSEC2018-6683

[7] Sajjad Gholami SHIRI, Mohsen NAZARZADEH, Mahmood SHARIFITABAR, Mehdi Shafiee AFARANI. Gas tungsten arc welding of CP-copper to 304 stainless steel using different filler materials. Transactions of Nonferrous Metals Society of China. 2012; 22(12):2937-2942. https://doi.org/10.1016/S1003-6326(11)61553-7

[8] A. El-Batahgy and M. Kutsuna. Laser beam welding of AA5052, AA5083, and AA6061 aluminium alloys. Advances in Materials Science and Engineering, vol. 2009, Article ID 974182, 9 pages, 2009. https://doi.org/10.1155/2009/974182

[9] Davi Sampaio Correia, Cristiene Vasconcelos Gonçalves, Sebastião Simões da Cunha Jr, Valtair Antonio Ferraresi. Comparison between genetic algorithms and response surface methodology in GMAW welding optimization. Journal of Materials Processing Technology. 2005; 160(1):70–76. https://doi.org/10.1016/j.jmatprotec.2004.04.243

[10] Edward R. Bohnart (2014) Welding Principles and Practices, Fourth Edition. Published by McGraw-Hill Education (India) Pvt. Ltd. ISBN-10: 93-392-0401-8

[11] A. K. Lakshminarayanan, V. Balasubramanian, K. Elangovan. Effect of welding process on tensile properties of AA6061 aluminium alloy joints. International Journal of Advanced Manufacturing Technology. 2009; 40(3-4):286-296. https://doi.org/10.1007/s00170-007-1325-0

[12] K. Shanmugam, A. K. Lakshminarayanan, V. Balasubramanian. Effect of welding processes on tensile, impact, hardness and microstructure of joints made of AISI 409M FSS base metal and AISI 308L ASS filler metals. Ironmaking & Steelmaking. 2009; 36(1):75-80. https://doi.org/10.1179/174328108X378224

 DOI : 10.35291/2454-9150.2019.0066

[13] V. Balasubramanian, A. K. Lakshminarayanan, K. Shanmugam. Effect of welding processes on fatigue crack growth behaviour of AISI 409M ferritic stainless steel joints fabricated using duplex stainless steel fillers. Fatigue & Fracture of Engineering Materials & Structures. 2009; 32(8):656-664. https://doi.org/10.1111/j.1460-2695.2009.01371.x

[14] Dhananjay Kumar, Dharamvir Mangal. Study and analysis of the effect of welding process on distortion with 304l stainless steel weld joints. International Journal of Engineering Sciences & Research Technology, February. 2017; 6(2):212-216. http://doi.org/10.5281/zenodo.290145

[15] M. Ericsson, R. Sandstrom. Influence of welding speed on the fatigue of friction stir welds and comparison with MIG and TIG. International Journal of Fatigue. 2003; 25(12):1379-1387. https://doi.org/10.1016/S0142-1123(03)00059-8

[16] T. Mohandas, G. Madhusudhan Reddy, Mohammad Naveed. A comparative evaluation of gas tungsten and shielded metal arc welds of a ferritic stainless steel. Journal of Materials Processing Technology. 1999; 94 (2-3) -133-140. https://doi.org/10.1016/S0924-0136(99)00092-8

[17] S.M. Tabatabaeipour, F. Honarvar. A comparative evaluation of ultrasonic testing of AISI 316L welds made by shielded metal arc welding and gas tungsten arc welding processes. Journal of Materials Processing Technology. 2010; 210(8):1043-1050. https://doi.org/10.1016/j.jmatprotec.2010.02.013

[18] G. Karthik, P. Karuppuswamy, V. Amarnath. Comparative evaluation of mechanical properties and micro structural characteristics of 304 stainless steel weldments in TIG and SMAW welding processes. International Conference on Advances in Mechanical Sciences 2014, International Journal of Current Engineering and Technology. 2014; Special Issue-2: 200-206. http://dx.doi.org/10.14741/ijcet/spl.2.2014.36

[19] Radha Raman Mishra, Visnu Kumar Tiwari, Rajesha S. A study of tensile strength of MIG and TIG welded dissimilar joints of mild steel and stainless steel. International Journal of Advances in Materials Science and Engineering (IJAMSE). 2014; 3(2):23-32. DOI : 10.14810/ijamse.2014.3203

[20] G.R.C. Pradeep, Dr. A. Ramesh, Dr. B. Durga Prasad. Comparative study of hard facing of AISI 1020 steel by three different welding processes. Global Journal of Researches in Engineering Mechanical and Mechanics Engineering. 2013; 4(1): 11-16. https://engineeringresearch.org/index.php/GJRE/article/view/760/692

[21] Weiwei Yu, Minyu Fan, Jinhua Shi, Fei Xue, Xu Chen, Hui Liu. A comparison between fracture toughness at different locations of SMAW and GTAW welded joints of primary coolant piping. Engineering Fracture Mechanics. 2018; 202:135-146. https://doi.org/10.1016/j.engfracmech.2018.09.021

[22] A. Benoit, P. Paillard, T. Baudin, V. Klosek, J.-B. Mottin. Comparison of four arc welding processes used for aluminium alloy cladding. Science and Technology of Welding and Joining. 2015; 20(1):75-81. https://doi.org/10.1179/1362171814Y.0000000257

[23] Humberto N. Farneze, Jorge Carlos F. Jorge, Luís Felipe G. de Souza, Ivaní de S. Bott. Comparative study of high-strength steel weld metals obtained by the SMAW and FCAW processes for offshore applications and mooring chains. Welding International. 2010; 24(12):903-910. http://dx.doi.org/10.1080/09507110903568943

[24] V. Balasubramanian, B. Guha. Effect of welding process on fatigue crack growth behaviour of ASTM 517 'F' grade steel weld metals. Science and Technology of Welding and Joining. 1999; 4(4):233-239. http://dx.doi.org/10.1179/136217199101537833

[25] S. Raghu Nathan, V. Balasubramanian, S. Malarvizhi, A. G. Rao. Effect of welding processes on mechanical and microstructural characteristics of high strength low alloy naval grade steel joints. Defence Technology. 2015; 11(3):308-317. https://doi.org/10.1016/j.dt.2015.06.001

[26] Jorge Carlos Ferreira Jorge, Joel Lemos Dias Monteiro, Antonio José de Carvalho Gomesa, Ivani de Souza Bott, Luís Felipe Guimarães de Souzaa, Matheus Campolina Mendesa, Leonardo Sales Araújo. Influence of welding procedure and PWHT on HSLA steel weld metals. Journal of Materials Research and Technology. 2018. https://doi.org/10.1016/j.jmrt.2018.05.007

[27] R. Bendikiene, G. Janušas, D. Žižys. Comparative analysis of microstructure and quality of gas metal arc welded and shielded metal arc welded joints. Mechanika. 2015; 21(4): 323-328. http://dx.doi.org/10.5755/j01.mech.21.3.9861

[28] Ramkishor Anant, Jag Parvesh Dahiya, B P Agrawal, P K Ghosh, Ravindra Kumar, Sudhir Kumar, Kaushal Kumar. SMA, GTA and P-GMA dissimilar weld joints of 304LN stainless steel to HSLA steel; Part-1: thermal and microstructure characteristics. Materials Research Express. 2018; 5(9). https://doi.org/10.1088/2053-1591/aad403

[29] Andrés R. Galvis E, W. Hormaza. Characterization of failure modes for different welding processes of AISI/SAE 304 stainless steels. Engineering Failure Analysis. 2011; 18(7):1791-1799. https://doi.org/10.1016/j.engfailanal.2011.04.008

[30] Shrirang Kulkarni, Prakriti Kumar Ghosh and S. Ray. Improvement of weld characteristics by variation in welding processes and parameters in joining of thick wall 304LN stainless steel pipe. 2008; 48(11):1560-1569. https://doi.org/10.2355/isijinternational.48.1560

[31] A K Lakshminarayanan, K. Shanmugam, V. Balasubramanian. Effect of welding processes on tensile and impact properties, hardness and microstructure of AISI 409M ferritic stainless joints fabricated by duplex stainless steel filler metal. Journal of Iron and Steel Research International. 2009; 16(5): 66-72. https://doi.org/10.1016/S1006-706X(10)60013-1

[32] Amber Shrivastava, Manuela Krones, Frank E. Pfefferkorn. Comparison of energy consumption and environmental impact of friction stir welding and gas metal arc welding for aluminium. CIRP Journal of Manufacturing Science and Technology. 2015; 9:159-168. https://doi.org/10.1016/j.cirpj.2014.10.001

[33] C. Yeni, S. Sayer, M. Pakdil. Comparison of mechanical and microstructural behaviour of TIG, MIG and friction stir welded 7075 aluminium alloy. Kovové materiály - Metallic Materials. 2009; 47(5):341-347. http://www.kovmat.sav.sk/full.php?rr=47&cc=5&ss=341

[34] E. Taban, E. Kaluc. Comparison between microstructure characteristics and joint performance of 5086-H32 aluminium alloy welded by MIG, TIG and friction stir welding processes. Kovové materiály - Metallic Materials. 2007; 45(5):241-248. http://www.kovmat.sav.sk/full.php?rr=45&cc=5&ss=241

[35] Stefano Maggiolino, Chiara Schmid. Corrosion resistance in FSW and in MIG welding techniques of AA6XXX. Journal of Materials Processing Technology. 2008; 197(1-3):237-240. https://doi.org/10.1016/j.jmatprotec.2007.06.034

[36] Stéphane Godin, Denis Thibault, Jean-Benoît Lévesque. An experimental comparison of weld-induced residual stresses using different stainless steel filler metals commonly used for hydraulic turbines manufacturing and repair. Materials Science Forum. 2014; 768-769:628-635. https://doi.org/10.4028/www.scientific.net/MSF.768-769.628

[37] A. S. Elmesalamy, J. A. Francis, L. Li. A comparison of residual stresses in multi pass narrow gap laser welds and gas-tungsten arc welds in AISI 316L stainless steel. International Journal of Pressure Vessels and Piping. 2014; 113:49-59. https://doi.org/10.1016/j.ijpvp.2013.11.002

[38] HE Zhen-bo, PENG Yong-yi, YIN Zhi-min, LEI Xue-feng. Comparison of FSW and TIG welded joints in Al-Mg-Mn-Sc-Zr alloy plates. 2011; 21(8):1685-1691. https://doi.org/10.1016/S1003-6326(11)60915-1

[39] A. Cabello Munoz, G. Ruckert, B. Huneau, X. Sauvage, S. Marya. Comparison of TIG welded and friction stir welded Al–4.5Mg–0.26Sc alloy. Journal of Materials Processing Technology. 2008; 197(1-3): 337–343. https://doi.org/10.1016/j.jmatprotec.2007.06.035

[40] Jau-Wen Lin, Hsi-Cherng Chang, Ming-Hsiu Wu. Comparison of mechanical properties friction of pure copper welded using stir welding and tungsten inert gas welding. Journal of Manufacturing Processes. 2014; 16(2):296-304. https://doi.org/10.1016/j.jmapro.2013.09.006

[41] Liang Zhang, Xiaoyan Li, Zuoren Nie, Hui Huang, Lanqiang Niu. Comparison of microstructure and mechanical properties of TIG and laser welding joints of a new Al–Zn–Mg–Cu alloy. Materials and Design. 2016; 92:880-887. https://doi.org/10.1016/j.matdes.2015.12.117

 DOI : 10.35291/2454-9150.2019.0066

[42] T. Pasang, J. M. Sánchez Amaya, Y. Tao, M.R. Amaya-Vazquez, F. J. Botana, J. C Sabol, W. Z. Misiolek, O. Kamiya. Comparison of Ti-5Al-5V-5Mo-3Cr welds performed by laser beam, electron beam and gas tungsten arc welding. Procedia Engineering. 2013; 63:397-404. https://doi.org/10.1016/j.proeng.2013.08.202

[43] Zhao Jiang, Xueming Hua, Lijin Huang, Dongsheng Wu, Fang Li, Yuelong Zhang. Double-sided hybrid laser-MIG welding plus MIG welding of 30-mm-thick aluminium alloy. The International Journal of Advanced Manufacturing Technology. 2018; 97(1-4):903-913. https://doi.org/10.1007/s00170-018-1997-7

[44] Ruifeng Li, Zhuguo Li, Yanyan Zhu, Lei Rong. A comparative study of laser beam welding and laser–MIG hybrid welding of Ti–Al–Zr–Fe titanium alloy. Materials Science and Engineering A. 2011; 528(3): 1138-1142. https://doi.org/10.1016/j.msea.2010.09.084

[45] Xiaohong Zhan, Yubo Li, Wenmin Ou, Fengyi Yu, Jie Chen, Yanhong Wei. Comparison between hybrid laser-MIG welding and MIG welding for the invar36 alloy. Optics & Laser Technology. 2016; 85:75-84. https://doi.org/10.1016/j.optlastec.2016.06.001

[46] G. Li, M. Gao, C. Chen, C. Zhang and X. Y. Zeng. Characterisation comparison of laser and laser–arc hybrid welding of Invar 36 alloy. Science and Technology of Welding and Joining. 2013; 19(1):30-37. https://doi.org/10.1179/1362171813Y.0000000159

[47] Xiaohong Zhan, Yao Meng, DongdongGu, Huimin Wang. A comparative study between pulsed metal inert gas welding and continuous metal inert gas welding on thin Invar alloy. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture. 2017; 233(2):527–538. https://doi.org/10.1177%2F0954405417748186

[48] A. Mathivanan, K. Devakumaran, A. Senthil Kumar. Comparative study on mechanical and metallurgical properties of AA6061 aluminium alloy sheet weld by pulsed current and dual pulse gas metal arc welding processes. Materials and Manufacturing Processes. 2014; 29(8):941-947. http://dx.doi.org/10.1080/10426914.2014.912314

[49] Z. Bingul, G. E. Cook, A. M. Strauss. Comparison of constant current and pulsed gas metal arc welding processes on basis of electrode resistive dissipation. Science and Technology of Welding and Joining. 2003; 8(1):19-28. https://doi.org/10.1179/136217103225008865

[50] R. Garcia, V. H. Lopez, E. Bedolla. A comparative study of the MIG welding of AI/TiC composites using direct and indirect electric arc processes. Journal of Materials Science. 2003; 38(12):2771-2779. https://doi.org/10.1023/A:1024471610718

[51] Jaime Casanova Soeiro Junior, Mauro Apolinário da Luz, Sérgio Duarte Brandi. Comparison of deposition rate and deposition efficiency between ER70S-6 and E71T-1C consumables. Welding International. 2017; 31(2):79-89. http://dx.doi.org/10.1080/09507116.2016.1218602

[52] Jiang Qinglei, Li Yajiang, Wang Juan, Zhang Lei. Characterization on strength and toughness of welded joint for Q550 steel. Bulletin of Materials Science. 2011; 34(1):161-167. https://doi.org/10.1007/s12034-011-0039-y

[53] M. T. Liao, W. J. Chen. A comparison of gas metal arc welding with flux-cored wires and solid wires using shielding gas. The International Journal of Advanced Manufacturing Technology. 1999; 15:49–53. https://doi.org/10.1007/s001700050038

[54] H.T. Lee, T. Y. Kuo. Analysis of microstructure and mechanical properties in alloy 690 weldments using filler metals I-82 and I-52, Science and Technology of Welding and Joining. 1999; 4(2):94-103. http://dx.doi.org/10.1179/136217199101537626

[55] K. Devendranath Ramkumar, Siddharth D. Patel, S. Sri Praveen, Dip Joy Choudhury, P. Prabaharan, N. Arivazhagan, M. Anthony Xavior. Influence of filler metals and welding techniques on the structure–property relationships of Inconel 718 and AISI 316L dissimilar weldments. Materials and Design. 2014; 62:175-188. https://doi.org/10.1016/j.matdes.2014.05.019

[56] Abhijit Sarkar, Prasenjit Dey, R. N. Rai, Subhash Chandra Saha. A comparative study of multiple regression analysis and back propagation neural network approaches on plain carbon steel in submerged-arc welding. Sadhna. 2016; 41(5):549-559. DOI: 10.1007/s12046-016-0494-7

[57] I. S. Kim, S. H. Lee, P. K. D. V. Yarlagadda. Comparison of multiple regression and back propagation neural network approaches in modelling top bead height of multipass gas metal arc welds. Science and Technology of Welding and Joining. 2003; 8(5): 347-352. https://doi.org/10.1179/136217103225010998

[58] Nitin Kumar Sahoo, Atul Kumar Sahoo, Anoop Kumar Sahoo. Optimization of weld bead geometry of MS plate (Grade: IS 2062) in the context of welding: a comparative analysis of GRA and PCA–Taguchi approaches. Sadhna. 2017; 42(2):321-244. DOI: 10.1007/s12046-016-0589-1

[59] S. C. Juang, Y. S. Tarng, H.R. Lii. A comparison between the back-propagation and counter-propagation networks in the modelling of the TIG welding process. Journal of Materials Processing Technology. 1998; 75(1-3):54-62. https://doi.org/10.1016/S0924-0136(97)00292-6

 DOI : 10.35291/2454-9150.2019.0066