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Review article

Effect of SMAW process parameters on similar and dissimilar metal welds: An overview

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ABSTRACT

Shielded metal arc welding (SMAW) is the most economical and portable and robust welding processes which utilizes the power source, electrode holder and electrode to weld metals. It is utilized successfully in welding ferrous metals. Nowadays due to increased application of non ferrous metals, the joining of the same with this welding has been on rise. The further advancement in the field of material science, the welding of ferrous and non ferrous metals has found many takers. So SMAW has been tried in welding of ferrous and non ferrous metals i.e of oxygen rich copper with chromium and nickel rich stainless steel 304. The stainless steel due to its properties like corrosion resistance, high resilience, higher toughness has been utilized in automobile, household aerospace applications. Copper has wide spread application in engineering structure, electrical components, power plant industry due to its unique mechanical, physical and chemical properties. The purpose of review is to find work done by different researchers in the area of arc welding of similar and dissimilar metals, study the findings related to research, check the feasibility to weld oxygen rich copper to chromium and nickel rich Stainless steel 304 using SMAW process and to study the, economics, sustainability of SMAW in terms of green technology and eco-social aspects and to find the suitable electrode to weld.

1. Introduction

Welding is the one of the manufacturing processes used for joining various ferrous and non ferrous metals. The importance of welding has come out from the fact that complex geometry configured material can be made by making separate parts and assembling the separate parts together by joining. In this way the complex configured parts is being made with welding technology. On of the most common process is shielded metal arc welding. It is often called road side or on site welding because of its robustness, efficiency and less equipment. It has found application in not only in aerospace but also in automobile and home appliances. It utilizes the coating electrode which forms the slag and prevents the molten weld pool from oxidation and eliminating the impurities (Groover, 2007).The coating of flux plays an important role as it eliminates the atmospheric contamination and stabilizes the arc. The shielded metal arc welding contains the equipment such as power source, electrode, electrode holder has been depicted in Figure 1. The process variables formed in SMAW welding are electrode position, arc length, arc travel speed, temperature, power input (Agarwal, 1992). These process variables effects the out response in terms of material properties. The opting of right electrode material depicts the properties of material. The electrode coating plays an important role in addition of alloying metal in weld zone and plays a important role in fusion welding of not only similar metals but it is most important in dissimilar metals. In present report, the review was conducted for SMAW of similar metals, dissimilar metals, SMAW of oxygen rich copper and chromium and nickel rich stainless steel 304 and also various welding processes applied on copper and stainless steel 304. The main motive behind this review article is to select appropriate parameters, chemically correct electrode for best quality of similar and dissimilar welds. The joining of chemically distinguished metals of oxygen rich copper and chromium and nickel rich stainless steel has been widely used in chemical process industries, home appliances and nuclear industry as joining these two metals provides combination of corrosion resistance with good physical properties of copper.

2. Process parameter

(i) Current: During the welding, that is, while arc occurs in welding period, current used to generate arc for heating and melting is called as welding current. Current plays an important role in

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controlling heat input. Higher the current higher the heat input. Optimum level of current creates optimum heat input which results in more homogenized structure. With increase of current, the arc produced can be used to melt different metals, but certain metals needs to be clean first to remove the oxide layer, then only the metal is melted. For aluminium and magnesium AC current is used. For conducting experiment we have selected current range as 150, 160, 170 amp.

(ii) Voltage: Arc voltage affects the arc length. Arc length increases, heating and melting decreases as lesser temperature is reached since arc is in longer contact with the atmosphere which decreases the temperature and thus rate of heating and melting. Arc voltage increases the arc length increases but the welding current remains the same there the weld penetration remains unaffected.

(iii) Electrode Diameter: Diameter of the electrode should be according to the gap between two base material.

(iv) Polarity: Direct current electrode positive (DCEP) and direct current electrode negative (DCEN) are the two terminals used. DCEN is the preferred mode of supply as 70% heat is generated towards the work and 30% towards the electrode.

(v) Welding speed: Welding speed is important parameter which plays a crucial role in controlling the quality of bead geometry. Optimum welding speed has to be selected. Higher the welding speed lesser is the heat input which could lead to lack of penetration. Lesser is the welding speed, higher will be the heat input more time for grains to absorb heat hence nonuniform columnar structure is formed. So optimum welding speed is required in order to have more refined, uniform, axial and homogeneous structure.

(vi) Groove Angle: Higher the groove angle more will be the amount of molten weld pool formed as a result higher will be the homogenization, optimum will be the cooling rate and thus increases the joint strength.

(vii) Electrode Angle: Electrode angle plays an important role. Higher will be the electrode angle more accumulation of heat is done which results in homogeneous mixing as more heat is available to melt the material thus forming uniform mixture of base material. Figure 2 depicts the angle of electrode used during welding

3. Advantages of SMAW welding compared to other conventional welding techniques

(i) Low maintenance and equipment cost as compared to GTAW, FCAW and GMAW process as only electrode and electrode holder with power supply is used.
(ii) Quick changeability of electrodes from one material to another
(iii) The process itself leads to welding in confined places with variable positions with few problems.
(iv) No shielding gas is required
(v) Faster deposition rates as compared to GTAW process.
(vi) Has good portability as compared to other welding setups

4. Challenges faced by SMAW

(i) Lack of fusion is often created by non-uniform and negative position of electrode which is often the problem with manual process. The non penetration and insufficient fusion has been found to be demonstrated joint penetration (CJP) weldment (Agarwal, 1992)

(ii) Slag inclusion: The slag inclusion is common problem occurred in SMAW process. If it does not get cleaned out it causes defect in weld which can be inspected by Radiography test, Ultimate tensile test or bend test. The slag inclusion can be avoided by providing positive electrode work position just like in lack of fusion.

(iii) Overlap: If the work angle is exceeding beyond the adjusting point, the possibility of overlap on the weld interface. Overlap is an automatic defect which is not acceptable and the welds are rejected. This is because it makes the circumferential area which is subjected to stress which converts to accumulation of stress at a preferential sites and leads to development of crack initiation sites when the load is applied on it.

5. Challenges faced while welding dissimilar metals

1. The non matching time in heating of the metal. Larger the difference in melting point more difficult to weld.
2. The difference in coefficient of linear expansion. Larger the difference more difficult to weld
3. Larger difference in thermal conductivity, coefficient of thermal expansion and specific heat capacity of different metals
4. Difference in electromagnetic properties of base metals. Larger the difference more unstable the electric and magnetic fields, non uniform ignition of arc, difficult to weld

6. Literature review

6.1. *Shielded metal arc welding of different metal*

Different metals has been tried welded by shielded metal arc welding. Various parameters combination have been tried of different metals. The parameters including current voltage, current, types of welding electrode, electrode angle plays an important role in changing the output properties. In this section, account of research work on SMAW of metals like steel, magnesium, stainless steel, duplex steels, ferritic steel, austenitic steels, low carbon steels, medium carbon steels and high carbon steels has been tried. The effect of various parameters on mechanical and microstructure have been studied. Apart from this various optimization techniques used have also been investigated. The work related to corrosion properties along with innovative methods to increase properties has been undertaken by various researchers has been included in subsequent section.

6.1.1. *Effect of parameters on bead geometry, microstructure and mechanical properties*

(Abdulla *et al.*, 2018) performed the research study on tensile strength, yield strength, percent elongation, microhardness and impact toughness on mild steel AISI 1020 using combination of fillers. The two values of welding current was used with combination of different electrode. The experiment found that with increase of heat input mechanical properties increase. The results depicted the increased trends of tensile strength and hardness obtained by using electrode E7018 and E7016 (Shukla et al., 2018). performed the detailed analysis of SMAW parameters on bead geometry stainless steel 1020 plates with size (100 $\times$ 60 $\times$ 150) mm. The results obtained shows that mechanical properties depends on shape and size of weld bead. The shape factor depends on current. Higher the current wider is the width of HAZ and lower mechanical properties. The results reveals with DCEN polarity, 90° as the electrode angle and current at 120 A are the favourable parametric values at which highest penetration is obtained.as shown in Figure 3.

(Sumardiyanto and susilowati, 2019) analysed the influence input variables of mild steel API 5L. Two parameters namely welding current and composition of electrode found to have maximum influence on mechanical objectives. The investigation reveals, that amount of heat used in welding influences the weld properties. The mechanical properties show down ward trend (Chowda et al., 2018). investigated the effect of shielded metal arc welding on surface properties of low carbon steel. The experiments conducted shows that better hardness is obtained at optimized values of voltage and current (Patel et al., 2017). took to experimentation and analysis of crucial parameters on SMAW joints. The parameter taken into consideration are current, position of electrode, root gap and travel speed. Various optimization methods were tried by researcher but Taguchi based optimization technique was found to be

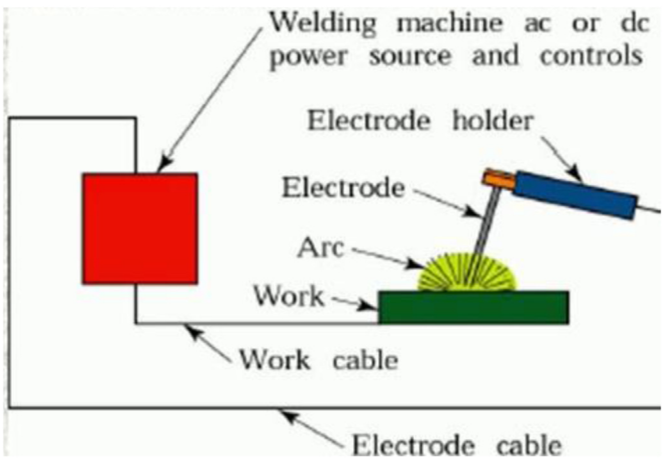

Figure 1. SMAW schematic view (Groover, 2007).

convenient and suitable according to number of parameters and levels. The analysis of the results revealed that the optimized results were obtained with output response in the form of penetration size factor, weld bead reinforcement, reinforcement form factor which directly affect the mechanical properties (Jadoun et al., 2016). studied about the process optimization of welding variable for mild steel (Grade-40) specimen. The observations revealed that plate thickness and electrode diameter are effecting the mechanical properties. The results indicates that at higher plate thickness and electrode diameter, the properties obtained are optimum. The investigation also reveals about the material thickness has larger influence on mechanical properties (Tanimu et al., 2013). take into consideration, the duplex stainless steel as workpiece material analysed. From the analysis it was found out that properties like ductility, resilience and toughness is largely influenced by electrode diameter, current and voltage (Thakur and Chapgaon, 2017) conducted the study to analyse the influence of combination of two arc welding processes namely GTAW-SMAW which are directly influence the microhardness of weld material low carbon steel. The results depicts that interpass temperature dominantly affects the resistance to indentation or scratch in weld fusion zone and heat affected zone (HAZ). The results also shows that change in gas flow rate had very less effect on hardness of weld and HAZ (Mohammed et al., 2013). studied the effect of welding variables on mechanical properties, microstructural and shape geometry of carbon steel having intermediate percent of carbon then low carbon steel material and high carbon steel material. The two zones were formed, at the centre the properties are found to be more than the heat affected zone where the hardness and tensile strength is found to be optimum but impact toughness has been low which results in brittle structure region as compared to fusion zone and parent material (Munawar, 2018) investigated the influence of arc welding on microstructural and mechanical characterization with and without heat treatment of S45c steel. From results of investigation and analysis the increased tensile and hardness properties reveal optimum heat input used to weld the metal. The optimum heat input on other hand decreases the toughness. This shows that optimum heat input is required increases some not always increases the mechanical properties (Yadav et al., 2020). performed the analysis by selecting the input variables namely welding current, voltage, welding speed on mechanical and microstructural properties of structural steels using manual metal arc welding. The warpage and distortion decreases as heat input decreases. This is due to the fact that higher welding current produces higher heat input. It has also has an effect of geometry. The decrease in distortion reduces the width of HAZ, ultimately increases the mechanical properties (Khamari et al., 2019). studied the influence of current, voltage, travel speed and electrode diameter on mechanical and structural properties of SMAW welded low carbon steel joints. The results shows the increase in hardness. The microhardness and impact toughness largely influenced by welding current. The distortion is minimized and narrow heat affected zone is obtained. The microstructural analysis reveals the refined grain structure with hard and soft phases and formation of ferrites and pearlite which increases the hardness and thus the mechanical properties (Chiong et al., 2019). performed the parametric study on weld structure which leads to improvement of tensile and hardness properties of mild steel. studies effect of welding current, welding voltage, welding speed on heat input, phases, weld bead geometry which leads to mechanical properties of low carbon steel. The investigation reveals the noticeable dilution in the fusion zone. The decrease in amperage and travel speed decreases the HAZ width, produces fine grains in fusion zone and thus increases the structural characteristics and joint features.

(Sukhbir, 2019) performed the review on effect of arc welding process parameters on mechanical properties and microstructure of stainless steel. The review of results indicated that the increment of heat characteristics is the major cause of distortion in microstructure which produces unfavourable phases. This effects the weld bead geometry, grain size in fusion zone. This leads to change in microstructure and ultimately mechanical properties. Higher the travel speed lower the heat characteristics this finer grains which leads to improve mechanical properties (Dadi et al., 2018). reviews the effect of SMAW parameters on MS plate using Taguchi approach. The results showed that increase in amperage and root width and plate thickness effects the mechanical properties. The grains size is affected and finally mechanical properties are effected. Larger is the grain size more reduced are the mechanical properties. More refined the grain size, improved are the properties (Bodude and Momohjimoh, 2015). Studied the influence of variable SMAW parameters, from amperage to travel speed on microstructural and mechanical characteristic properties of mild steel. The study shows that heat input is the main parameter which is affecting the grain size, thus microstructure is affected and ultimately mechanical properties. Heat input also increases the HAZ width which affects microstructure and decreases the mechanical properties. The investigation reveals that with decrease in amperage the heat flow characteristics decrease with increase in microhardness and strength (Haider et al., 2019). investigated the performance of various credible parameters on mechanical properties of joints of low carbon steel and steel 304. The properties investigated includes fatigue and creep properties as application of material is cyclic loading and load bearing with time. The results in review shows that higher amperage causing higher heat flow characteristics is found influencing factor which decreases the mechanical properties. The increment in amperage results in increase in heat flow characteristics which reduces the cooling rate in turn cause coarse grain structure, thus decreasing the tensile strength and hardness.

(Sharma et al., 2012) performed the analysis of influence of magnetic field and electrostatic field on weld joint properties and penetration size factor, height of weld bead reinforcement and reinforcement form factor of AZ31B magnesium alloy. The bead geometry was studied and it was found that change in magnetic field and electric field in perpendicular to the travel speed increases the width of reinforcement and decreases the penetration size factor (Sidhu and Chatha, 2012). observed the role of SMAW consumables on pipe weld joint. The results obtained showed that E6013 electrodes i.e rutile electrode exhibits good surface finish properties, deposits smooth surface and is resistance to corrosion and other surface impurities (Naik and Reddy, 2016). analysed the effect of SMAW process variables on distortion and warpage on ferritic and duplex stainless steel. The material size of 150 $\times$ 100 $\times$ 6 mm was used. In the investigation it was found that influence of electrode material on the welding angular distortion is negligible. The analysis conducted on duplex stainless steel reveals the reduced angular distortion 56.25μm in horizontal welding where current is medium 85 Amps and welding time is less than 1.45 min. Results analysis revealed that at high current of 95 Amps maximum distortion resulted is -374 μm in vertical welding position (Boob and Gattani, 2013). investigated the influence of shielded metal arc welding on weld width and heat affected zone width for mild steel 1005 grade. The size of mild steel plate is 125 $\times$ 75 $\times$ 4 mm and the

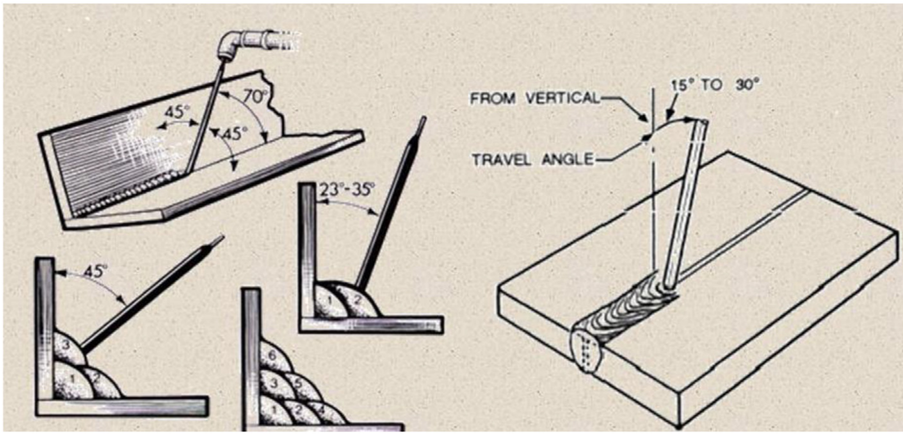

Figure 2. Electrode angle (Agarwal, 1992).

electrode used is E6013 of ms 5.1m. The different welding parameters were tried like from amperage to travel speed. The voltage and welding speed used was 30 V and 150,200 A. The results revealed amperage is most influencial parameter which is affecting the weld bead geometry. The higher amperage heat flow characteristics increases causing larger width zone. Proper control on travel speed becomes the important parameter for controlling the HAZ. Higher the heat input, wider is the width of distance of base metal butt jointed. The weld geometry is influenced by travel speed. Higher the travel speed lesser is the width of HAZ as time of torch remaining at per unit length is less, so less heat is available for the grains to grow and loss of alloying elements is less.

Figure 4a represents the bar chart depicting that at 977.37 J/mm, the distance of base metal region of two butt joint region is less than 2 mm whereas at maximum heat input of 2294.45 J/mm the distance of base metal region of two butt joint region also maximum i.e above 4 mm Figure 4b represents the bar chart depicting that at minimum speed of 156.9 mm/s, the distance of base metal region of two butt joint region is maximum i.e above 4 mm whereas at maximum speed of 276.24 mm/s, the distance of base metal region of two butt joint region minimum i.e below 2 mm.

(Gupta et al., 2018) investigated the penetration size factor, weld bead geometry of arc welding under electrostatic and magnetic field using non conventional optimization techniques. Mild steel of size 150 × 50 × 5 mm, butt welds with rutile electrode AWS E6013 and diameter of 3.15 mm was used. The parameters selected was welding currents, Arc voltages, welding speed and magnetic field strength. Width, reinforcement, depth of penetration were studied as responses. The results obtained indicates that if amperage is increased weld geometry characteristics also changes. The transverse size of weld, penetration size factor both rises. The effect of voltage is directly proportion to weld size and inversely proportional to penetration size factor and also if travel speed is increased, it has direct proportional weld size and penetration size factor, both generally decrease.

(Nagesh and Datta, 2002) performed the investigation on penetration size factor, height of weld bead reinforcement, reinforcement form factor using evolutionary technique like artificial neural network. The experimental analysis were done with parent material as cast iron and electrode material used low carbon steel. The initial parameter opted were of arc characteristics and electrode consumption rate. The weld geometry features as response were evaluated. The fractional factorial as optimization using DOE technique was implemented. The results obtained revealed arc length and travel speed has the most influencing effect. The results shows that arc length and arc travel rate are the influencing parameters. It was depicted that arc length is directly proportional to bead size and inversely proportional to height of weld bead reinforcement. It was also indicated that artificial neural network was power tool for modelling and optimization (Kamra et al., 2015). investigated and studied the effect of structural and metallurgical analysis of SMAW with different electrode combination. The material used in investigation was mild steel carbon pipe (IS 3589 GR 330 Class A91A) of size 120 × 80 × 6 mm was used. The electrode material E6010, E7016 was used as parameter. The microstructure, Vickers hardness test were measured. The results shows that similar combination steel material 6010-6010 exhibits fine grain microstructure as compared to the steel material combination of 6010–7016 which depicts good microstructure and morphological and metallurgical characteristics. Combination of steel 6010-6010 as it is similar structure so similar composition, melting point and coefficient of thermal expansion which produces fine pearlite grain structure

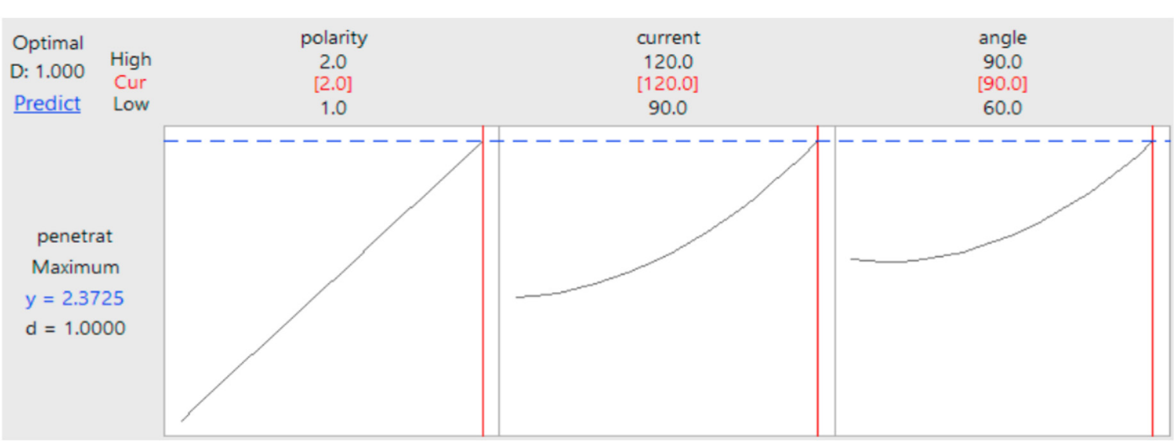

Figure 3. RSM D-optimal Test with parameters current polarity and angle on AISI 1020 plates (Shukla et al., 2018).

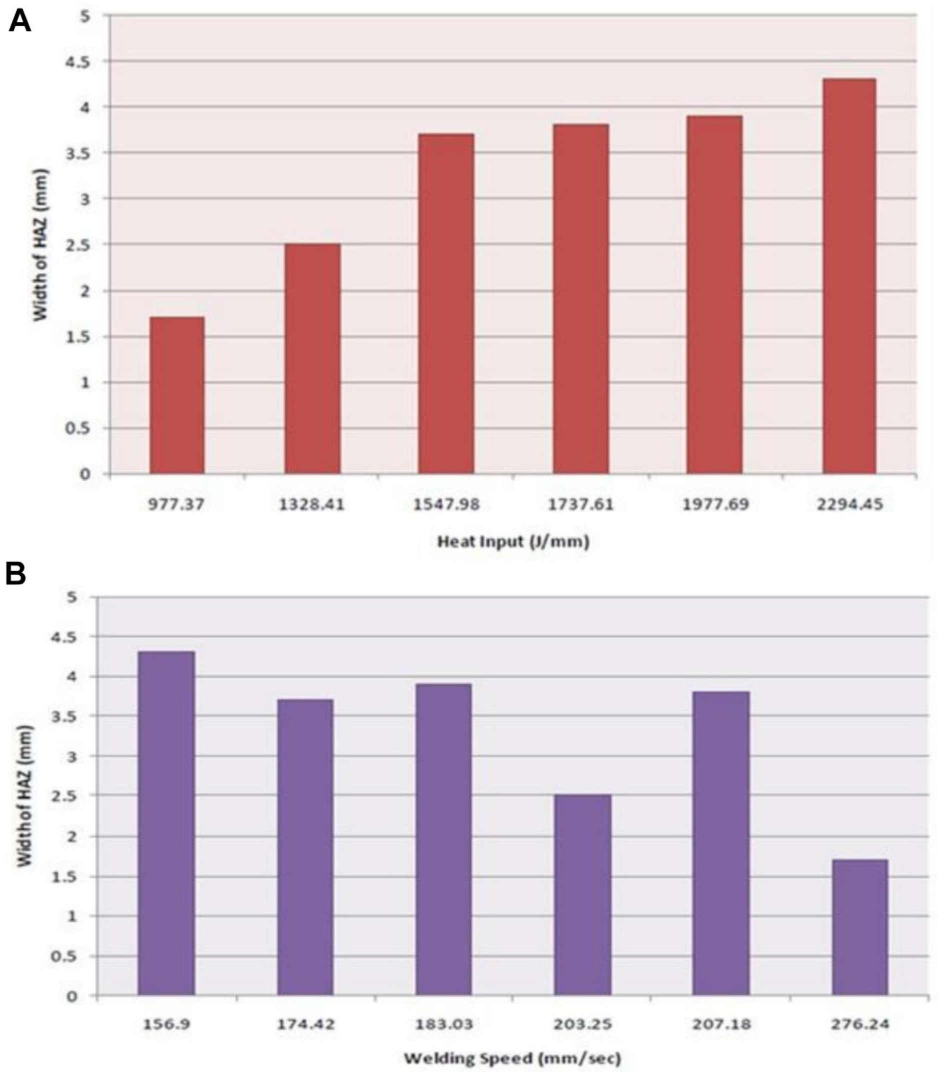

Figure 4. (a) Effect of heat generated flow characteristics on width of HAZ on MS plate (Boob and Gattani, 2013). (b) Effect of travel speed on HAZ width on MS plate (Boob and Gattani, 2013).

indicating much improved properties as compared to 6010–7016 where coarse pearlite structure is formed (Zoafakar and Hasan, 2017) conducted detailed analysis by optimizing the arc welding process variables on microstructure and morphological and metallurgical properties of medium carbon steel using design of experiment. Steel plates of 160 × 90 × 5mm was used. The parameters selected were groove angle, carbon equivalent % with current, heat input and preheating. Taguchi L16 orthogonal array was used as optimization technique. From the analysis, it was concluded that for improving tensile strength and ductility the percentage of carbon in the composition and chamfering angle plays a vital role.

(Ravikumar and Vijian, 2014) investigated and utilized Taguchi based grey relational analysis to optimize the weld characteristics in SMAW process. Low carbon steel plate of size 100 × 50 × 6 mm was used. The parameters selected were welding current, welding speed and wind velocity. The optimum setting of parameters were obtained based on optimization technique of Taguchi L9 orthogonal array. Welding current and welding speed were found to be most influencial parameter with maximum contribution followed by welding speed and wind velocity (Mohammed et al., 2015). investigated the effect of welded parameters on not only on microstructure but also on metallurgical behaviour of nitrogen enrich stainless steel. The electrode used was (17Cr–17Mn-0.36N). The parameters used which influences the quality of output apart from amperage and travel speed is place of electrode and electrode size. The objectives studied were Vickers hardness and microstructure. The investigation reveals the refined grain microstructure of nitrogen enrich steel because of the fact nitrogen act as catalyst and stabilizer creating more formation of austenitic structure. This increases the hardness. The formation of coarse austenite grains and reduction in preferential sites obtained with the formation of ferrite interface and reduction in chemical galvanization interaction between stainless steel structures resulted in improvement in pitting corrosion as depicted in Figure 5.

(Ali et al., 2014) performed the investigation on effect of process variables, temperature and cryo-treatment on mechanical and microstructural characteristics of low carbon steel plates using electrode of same chemical composition. The artificial neural network as optimization tool was used for modelling. The parameters used were Current and voltage. Table feed, Electrode feed rate, Electrode diameter are non-variable parameters. The weld characteristics analysis was performed. The response studied were penetration size factor, height of weld bead reinforcement, reinforcement form factor and size of HAZ. The result indicated that as the amperage increases the first the penetration increases. With further increase in current the penetration is in downward trend. From the experiments it was concluded that the HAZ size shows the increasing trend as the amperage increases up to the point where the arc become stable (Ghamashchi et al., 2015). performed the detailed analysis on X70 HSLA steel with cellulosic electrodes and evolution of microstructure using shielded metal arc welding. The electrode used was E6010. The process variables effecting the response are amperage, heat characteristics, linear speed etc. The parameters were used which are current, voltage, travel speed, heat input and preheat. The response studied were ferrite, bainite, pearlite, martensite in microstructure. The results shows the presence of favourable structure of fine pearlite and alternate layers on ferrite in lamellar pearlite (Gupta *et al.*, 2018). studied the effect of process variables on metallurgical, microstructure and morphological structure. The heat flow characteristics of arc welded duplex stainless steel were analysed. The material size of 210 × 97 × 5.5 mm with electrode E2595. The various parameters were tried but the main parameters which influencing the objective are amperage, voltage linear speed, heat flow characteristics, electrode chemical composition and direct current electrode positive polarity. The responses observed were microstructure, metallurgical, morphological and mechanical characteristics. The results revealed that at low and high heat flow characteristics, the size of HAZ is less. The result of large heat flow characteristics produces long columnar grain structure within the structure and segregation at the grain boundaries. The austenite and ferrite structure in weld metal of duplex stainless steel in Figure 6 depicts optimum heat input.

With addition of heat flow characteristics, the enriched ferrite content microstructure is obtained in base metal.

(Karthik et al., 2013) investigated the effect of input process variables on mechanical, microstructural and morphological characteristics of most common grade i.e stainless steel 304 using gas tungsten arc welding and shielded metal arc welding. The size of material plate was 200 × 150 × 6 mm and electrode used is (SS E308L). Numerous parameters were tried such as from amperage to travel speed. The responses observed were tensile test, yield strength, elongation, % area of reduction and youngs modulus. The result validation shows that mechanical properties obtained by TIG welding process is better than SMAW, but with suitable electrode and heat input the SMAW can weld numerous metals (Ranjan, 2014). performed the analysis and use factorial design approach of DOE for optimization of SMAW process. Various parameters were tried but three influencial parameters were taken into concentration, that were amperage, linear speed and voltage. The DOE approach was used with 8 runs and weld deposition area was studied. The result defined the approach of optimization as efficient as it points out the objective reinforcement form factor influenced by significant extent. The investigation gives the clue, that with increase in current result in increase in weld size and with higher linear speed, the weld size decreases. This is due to the fact that higher amperage increases the molten weld pool and simultaneously decreases the cooling rate whereas higher linear speed decreases the molten weld pool thus decreasing the weld size (Shivakumara et al., 2013). used Taguchi optimization tool for optimization of SMAW welded pipes. The material used is steel tube diameter 48 mm and 3mm wall thickness and electrode used (AWS code E6013). The numerous variable tried but main variables were amperage, place of electrode, gap between two plates. The results obtained showed that leak proof joint welding is obtained (Sheikh and Kamble, 2018) used the optimization tool for optimizing welding output and eliminating the defects in material ASTM A36 mild steel sheet. The material size is 150 × 75 × 2mm. The variable parameters which has highly influencial in effecting the output response used were amperage, linear speed, place of electrode. Taguchi L9 orthogonal Array is used. The result obtained showed that some principle defects associated with melting of molten weld pool has been eliminated successfully.

(Singh, 2014) investigated the use of various coatings on electrode for welding stainless steel material. The hard facing coating found to influence and alter the mechanical properties. The parameters used were types of electrodes, current, voltage. The results showed with reduction in heat input, cooling rate increases thus forming fine grain structure which produces refined and homogeneous structure which increases the mechanical properties (Shukla et al., 2015). performed the analysis to improve the joining properties to improve quality of SMAW welded low carbon steel pipe through Artificial Neural Network (ANN). The material used are ERW mild steel. The electrode used was A5.1 E-6013. The influencial parameters were amperage, linear speed and voltage. The objective response observed was tensile properties. The conclusive decision reveals the model to predict the joint properties of material through ANN (Khamari et al., 2019) investigated the influence of welding conditions on mechanical, metallurgical and morphological characteristics of Ni steel welded joints. The results reveals the cooling rater as influencing factor in deciding the microstructure of fusion zone and heat affected zone. More the heat flow characteristics, more time it will take to cool down which results in excessive grain growth. The grains becomes inhomogeneous and epitaxial structure is obtained. The next welding condition is interpass temperature. As the higher interpass temperature is reached, the larger influence is there on morphological structure which decreases the dendritic structure and increase amount of austenities was seen especially in central beads of welded joint. The trend is reversed when the interpass temperature reaches above 260 °C (Subramani et al., 2022). studied the influence of joining consumables on high armour steel joints. The different electrodes were used in welding. The properties used applied in various application were tested and it the result was that joint with LHF electrode exhibit high tensile strength and microhardness. Joint with ASS electrode exhibit highest impact toughness. The electrodes also affects the microstructure. From the observation SUUF possess superior strength properties, this was attributed to non-direction position of flakes of ferrite contained in weld joint structure. SUUA exhibited excellent ductility and high impact toughness (Jorge et al., 2018). investigated the influence of variables on microstructure, metallurgical and morphological characteristics on HSLA-80. The results reveal that there is increase in microhardness with when during joining only heat is supplied to weld metal. The impact strength is higher in region adjacent to fusion zone. This is because lower heat flow characteristics which reduces the HAZ size and increases toughness which change the structure and also changes the structure in flake like structure with alternate layers in ferrite as shown in Figure 7 (a and b).

(Pravin, 2019) performed investigation on mild steel and showed that properties can be enhanced by mechanical vibration. The parameters used in welding was current, welding speed and frequency. Taguchi L_9 orthogonal array was used. The vibratory motion was given to the weld pool which agitates the molten metal. The agitation of molten metal increases the dilution which makes the weld pool more homogeneous thus increasing the properties of the metallic joint. Figure 8 (a and b) depicts the vibratory setup used to agitate the weld pool. With the help of this setup the thermal gradient of weld is controlled.

The following affects are obtained due to vibratory setup. The vibratory setup alter the weld pool formation and agitates it thus increasing the dilution and homogenization of weld solution which increases the morphological and microstructure characteristics thus and increases the joint properties by breaking the growing dendrites and reducing the columnar structure, nucleation at the preferential sites, faster cooling thus prevents the nucleating grains from further melting produces fine grains and increases the grain number.

(Raza *et al.*, 2016) investigated the effect of input variables on metallurgical and microstructural properties of high carbon steel casting process. The observations revealed that amount of pearlite formation takes place which is inversely proportional to heat input. Also the formation of new grains and improvement of grains from large columnar and dendritic structure to more refined and homogeneous structure as austenitic structure and formation of flake ferrite results in improvement of metallurgical and microstructural properties of welded joints. The hardness increases as the cooling rate increases this is attributed to reduce heat input. The increased austenite phase increases the impact strength. Reduced heat input also results in reduce width of heat affected zone at which the failure generally occurs. Width of weld metal is also reduced which is attributed to reduce heat input and faster cooling rate due to optimum welding speed (Talabi et al., 2014). studied the welding variables and conditions on low carbon steel weld joint properties. The material size was 60 mm × 40 mm x 10 mm. The hardness values increases due to carburization. The increased hardness would lead to brittleness, hence post-welding heat treatment is applied to relieve the stresses and optimize the property. The mechanical properties decrease as the result of more time taken to cooling which is the result of higher heat flow characteristics. The results also showed that decrease as result of high heat input (Asibeluo and Emifoniye, 2015). investigated the influence of SMAW welding current on A 36 carbon steel weld joint properties. The specimens of size with thickness of 5.5 cm was welded with different current. The effect on weld joint properties and microstructure was studied. The investigation reveals that with increase in amperage, the temperature of the weld increases which caused decrease of toughness and hardness as a result of decreasing cooling time which give rise to rapid grain growth as enough heat is available for the grains to grow (Rohit and Jha, 2014) Performed the analysis of amperage and joint conditions on mild steel joints. A plate of size 150 mm × 50 mm x 12mm was used for the study. The welding currents as parameter was used. The current at which the best tensile strength is observed is 120 A. This is due to the fact that optimum value of current was applied due to which the heat input is optimum where the grains do not get enough heat to grow, so homogeneous, axial and refined grains are formed with structure converted from ferrite to austenite with alternate layers of acicular ferrite and pearlite (Kook et al., 2015). performed the analysis of heat flow characteristics on heat double pass and heat supplied before welding on metallurgical and mechanical properties numerous passes low carbon steel weld joint. The study revealed that higher the heat input higher the impact toughness but lower tensile strength as lower acicular ferrite formation was there. Higher heat input results in slower cooling rate which has sufficient available energy to grow larger in size i.e coarse grain structure is obtained which decreases the tensile strength. Lower recovery of alloying elemets like Mn and Si is observed. The effect of heating during welding is taken into consideration, no before and after heating has been taken into account on impact strength.

6.2. Shielded metal arc welding of dissimilar metals

SMAW of dissimilar metals is a difficult task to exhibit as different microstructure phases are formed. Intermetallic phase is formed which is the brittle phase formed when the composition of two metals to be joined is different. Various researchers has attempted to weld dissimilar metals. But the reports are related to validation of structural and joint properties.

6.2.1. Effect of parameters on microstructure and mechanical properties

(Lokesh et al., 2015) studied the structural and metallurgical and microstructural properties of austenitic stainless steel (304)- Ferritic Stainless Steel (430) non-similar joints developed by gas tungsten arc welding and shielded metal arc welding process. The dimensions of the plate were 150 × 75 × 4 mm. The results indicated that SMAW is comparable to GTAW but GTAW is slightly better in improving the corrosion properties (Mohan et al., 2013). investigated the influence of natural coating and chemical coating on electrodes used in SMAW welding of non-similar joints. The joint of low carbon steel 1144 with stainless steel 304 was formed. The dimensions of plates were 100 × 75 × 8 mm. The initial parameters which has been employed for non-similar joint are amperage, linear speed and voltage. The electrode used was rutile (E6012) and cellulosic (E6010) with diameter of 3mm. The results revealed that cellulosic electrode is better because of higher tensile strength and hardness and good microstructure (Velu and Bhat, 2013a, b). investigated the effect of dissimilar joint of non ferrous with ferrous i.e copper with steel using properties of nickel. The material used was steel (EN31) + copper (UNSC11000) with dimension 150 × 40 × 10mm. The parameters used were welding voltage, welding current, welding speed. The filler used was Inconel 82 with 3.15 mm. The result brought out from investigation shows improvement in microstructural and mechanical properties. The results showed that nickel based superalloy filler is best suited for mechanically and metallurgically (Velu and Bhat, 2013a,b). investigated the structural and material properties of dissimilar joint of ferrous and non ferrous i.e copper to steel joint using properties of nickel.The material dimension 150 × 40 × 10mm and 300 × 40 × 6 mm was made. The parameters used were current, voltage, welding speed. The filler used were bronze filler and nickel filler. The results reveals once again the importance of amperage as most influencial variable effecting tensile properties, Impact toughness, yield strength, percent elongation. The reduced heat flow characteristics increases the tensile and toughness properties of the material. The refined grain structure obtained as a result of fast cooling improves the homogeneity and thus alters the microstructure and increases the microhardness (Afriansvah and Arifin, 2020). investigated the effect of input variables on output response of the process. The studies on mechanical strength was studied. The metallurgical and structural studies were conducted on dissimilar ferrous metals like various grades of steel and varying carbon percentage in steel. The results reveal that if heat input is controlled the mechanical and microstructural properties can be controlled. With reduced heat flow characteristics, the time required to cool is lesser which produces homogenization of grains producing refined grain structure which is depicted in the SEM (Mohanaruban et al., 2014). performed the investigation on the influence variable parameters on metallurgical, structural, and material properties on SMAW welded dissimilar weld of austenitic and ferritic stainless steel. The results shows that hardness increases because of recrystallization of grains in the weld region. Slight elongation grains are formed this is due to the fact of high temperature. The orientation and direction of flow of grains is from base material towards the weld pool (Omiogbemi et al., 2021). performed the survey microstructural, metallurgical and material properties of SMAW welded two grades of stainless steel 2205 and 2507. The absence of ferrite and presence of austenitic structure and acicular ferrite improved the tensile strength and toughness within the material. This is possible on when heat input is lesser which increases the cooling rate thus, producing refined and homogeneous structure (Bala Srinivasan et al., 2006). investigated the effect of influencial variables on metallurgical, microstructural and material property on dissimilar combination of duplex type steel with mild alloy steel using SMAW. The plates dimension is 200 × 80 × 5 mm. The analysis reveals excellent mechanical and excellent intergranular and pitting corrosion resistance.This is due to the fact that chloride preferential sites for granular growth is less with particle size in nano scale.

6.3. Copper to stainless steel with other welding

welding with ferrous to non ferrous material has been the burning point of investigation by various researchers around the world. They are difficult to weld as ther chemical composition, physical and chemical properties are different. But joining them is the need of the hour. In dissimilar family of metals, joining of copper to stainless steel welding has been tried by various researchers using different welding processes. Different arc welding has been tried by various researchers with processes like GTAW, SAW, GMAW etc.

6.3.1. Effect of parameters on microstructure, metallurgical and mechanical properties

Figure 9 depicts SEM images showing fractured interface of dissimilar joint side of copper which is kept on right side and stainless steel which is on left side. Figure 9 (a) (b)depicts the voids on cu side which shows small voids are created due to ductile nature of copper whereas Figure 9 (c) (d) depicts huge voids on SS side, this is due to the fact that strength of steel is more so more austenite matrix is depicted in the figure which shows more homogenised Structure. The fracture shows the strength of joint is high so large voids are created within the weld metal.

Copper to stainless steel with other welding has been done by various researchers. The dissimilar joining has been done with limited success as

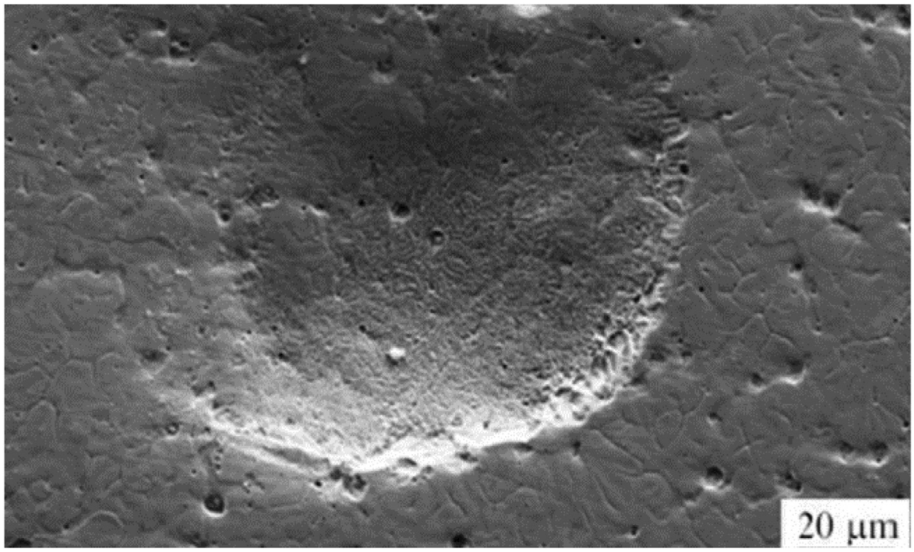

Figure 5. Crack initiation formation of nitrogen enrich stainless steel weld (Mohammed et al., 2015).

during cooling a columnar and dendritic structure i.e δ-ferrite is dispersed within the microstructure which is not turned in to more refined and homogeneous autenitic structure which remains inside the microstructure causing intermettalic zone which produces brittleness and decreases the creep and fatigue properties of steel (Vyas et al., 2021). investigated the joining of dissimilar ferrous and non ferrous metals with retrofitted friction stir welding machine. The size of plate was 3mm thick and 300mm long. Variable Welding speeds were used for doing the experiments. The investigation reveals that improved hardness was the result of reduced linear speed. The results also shows that linear speed has the maximum effect on ultimate tensile strength and elongation and is lower than the copper material properties (Turna et al., 2011). performed the analysis of dissimilar joint of ferrous and non ferrous metals using electron beam welding. The influencial parameters used were linear speed and amperage. The properties associated with structure, microstructural and material properties were found out. The results described that microhardness of steel decreases towards weld metal. It was also found that recrystallization has taken place (Chang et al., 2017). investigated the effect of process variables on structural, morphological, metallurgical properties of dissimilar ferrous and non ferrous metals. The thickness of the plates were 100 × 55 × 3mm. The parameters used were welding current, travel speed, flow rate. The result shows that dissimilar joining of ferrous and non-ferrous metals shows excellent material properties when done using GTAW, this is due to the fact that heat flow characteristics are less which increases the cooling rate thus refined and homogeneous structure is obtained with improved microstructural and morphological properties (Chinnakannan, 2016). performed the analysis on ferrous and non ferrous joint of friction welded steel and copper. The investigation was done on circular rod of length and diameter of 75 mm and 24 mm. The variable input parameters used which influences the output objective function. The results shows tensile strength closer to base metal is obtained. The impact energy absorbed by the material before fracture and resilience were about 70 J/cm^2. The surface roughness and texture and morphological characteristics were equal to the base material (Parasiya et al., 2015) investigated the effect of variable process factors on structural, morphological and material property of ferrous and non ferrous metal joint obtained by arc welding. The parameters chosen were root gap, Joint angle, welding current. Successful welds obtained such as UTS is 229.600 MPa and microhardness is 134.214 H V. More studies on microstructure and on intergranular corrosion has not been studied in detail (Joshi and Badheka, 2019a,b). investigated the joint framed of ferrous and non ferrous metals by clean welding process i.e electron emitted welding process. The structural, metallurgical and morphological properties examined and evaluated using various focused techniques with higher magnification devices. The result and conclusion drawn firmly acknowledges the joint diffusion of ferrous and non ferrous metals inside the molten metal. This shows the high stirring and homogeneous mixing ferrous and non ferrous of material joint interface. The properties are increased with acceptable values (Sahin, 2009) studies about the parameters which are affecting the tensile strength and microhardness of the joint. The parameters include spindle speed and axial pressure. The observations reveals the segregation and accumulation of alloying elements at joint interface which is due to increased heat flow characteristics which leads to presence of brittle phase. The observations reveals the percentage of alternate layers of ferrous metals in copper region which indicates homogeneous and uniform stirring within the material (Cheng et al., 2020). studied the ferrous and non-ferrous both sided joints of two primary arc welding using different chemical composition of filler. The nickel and Inconel filler were used for investigation. The investigation and the results shows that ferrous based filler increased the toughness of material whereas Cu based filler increases the tensile strength. The HAZ is softened on copper side with increased non homogeneity of structure and burger vector. The results indicate that Cu filler joint increases the homogeneity and produces uniform structure with coarser copper structure (Kar et al., 2016). investigated the influence of beam movement in radial and circular pattern on ferrous and non ferrous joints. It was found that the movement of beam in radial and circular direction influences the microstructure and thus improves the

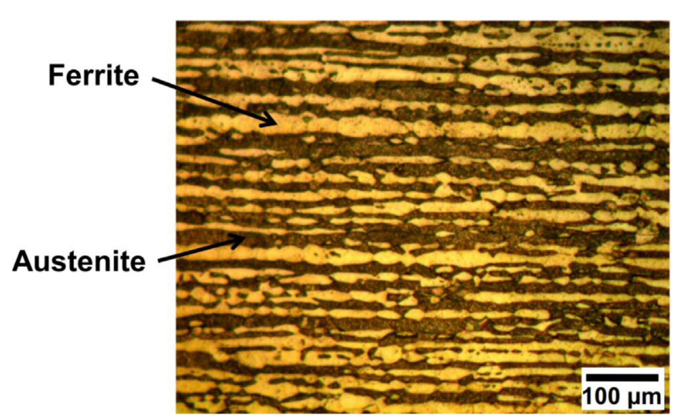

Figure 6. Depicting austenite and ferrite structure in duplex stainless steel (Gupta *et al.*, 2018).

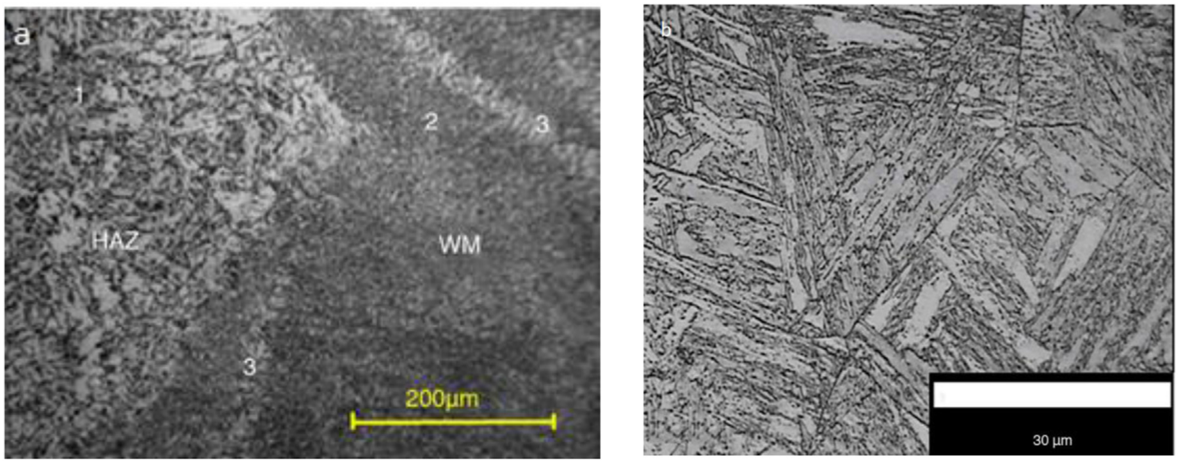

Figure 7. (a) Higher magnification of joint where heat supplied during welding. The microstructure are:1-fine bainite (FB); 2-flake ferrite (AF); and 3-grain boundary ferrite. (b) SEM micrograph of basemetal (Jorge et al., 2018).

material properties of joint. The results obtained that beam oscillation with fixed diameter increases the impact strength and percentage elongation, because the oscillation of the beam agitates the molten metal increases the mixing of Cu in SS. This produces uniform and refined grain structure within the fusion zone which improves microhardness and tensile properties. If the oscillating diameter is increased, the mechanical properties are said to be reduced.

(Cheng et al., 2018) investigated the effect of process variables on ferrous and non ferrous metals of butt joints made by primary arc welding processes. The investigation come to the consensus that improved structural, morphological and material property has been obtained, this is because to reduced heat flow characteristics due to lower amperage which increases the cooling rate, thus produces the fine grained, refined and homogeneous structure (Poo-arporn et al., 2019). performed the detailed analysis on influence of variable process parameters of GTA welding on structural, metallurgical and material properties of ferrous and non ferrous weld joint for aerospace and chemical process plant application. The butt joint of oxygen free copper with high carbon steel was made. The investigations revealed the occurrence of micropits and cracks with preferential sites for crack initiation in fusion zone. The solidification at the interface produces minute flakes on copper side and formation of columnar structure on stainless steel side (Sabetghadam et al., 2010). performed the air to air fusion bonding of ferrous and non ferrous metals using nickel metal. From the results it was obtained that proper dilution of SS in Nickel and of Cu in nickel taking place. This increases the metallurgical and microstructural properties which is depicted using EDS, SEM, optical microscopy. The structure obtained is refined and homogeneous which indicates uniform solid solution of nickel in Cu and SS. The mechanical properties are enhanced by this process (Mannucci et al., 2018). investigated the influence of process variables on the effect of magnetron emitted welding on tensile strength and corrosion behaviour was discussed. The results predicted the magnetron and klystron power of laser emission, travel speed and inclined beam angle has the major effect on weld composition. The complete dilution is obtained in the fusion zone which makes the pool more homogeneous and uniform. The metallurgical behaviour i.e immersion test reveals small pores are formed which does not effect the crack intimation, thus no crack propagation is there (Martins, 2013). investigated

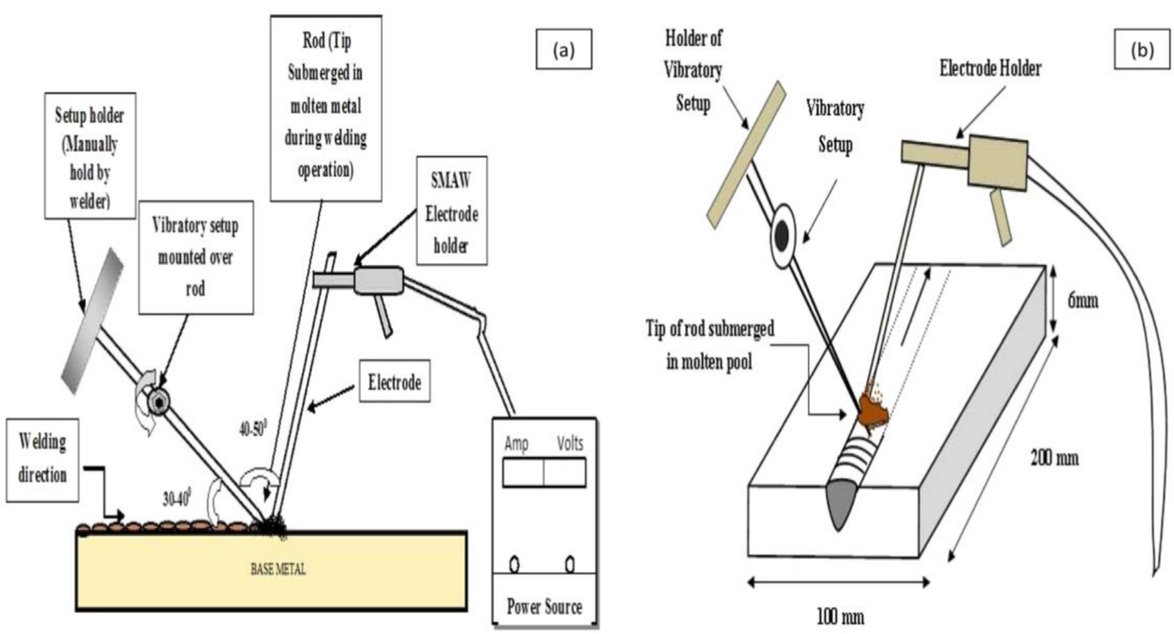

Figure 8. (a) Schematic block diagram of vibratory set up presenting the angles and positions of vibratory setup. (b) Top view diagram of vibratory setup (Pravin, 2019).

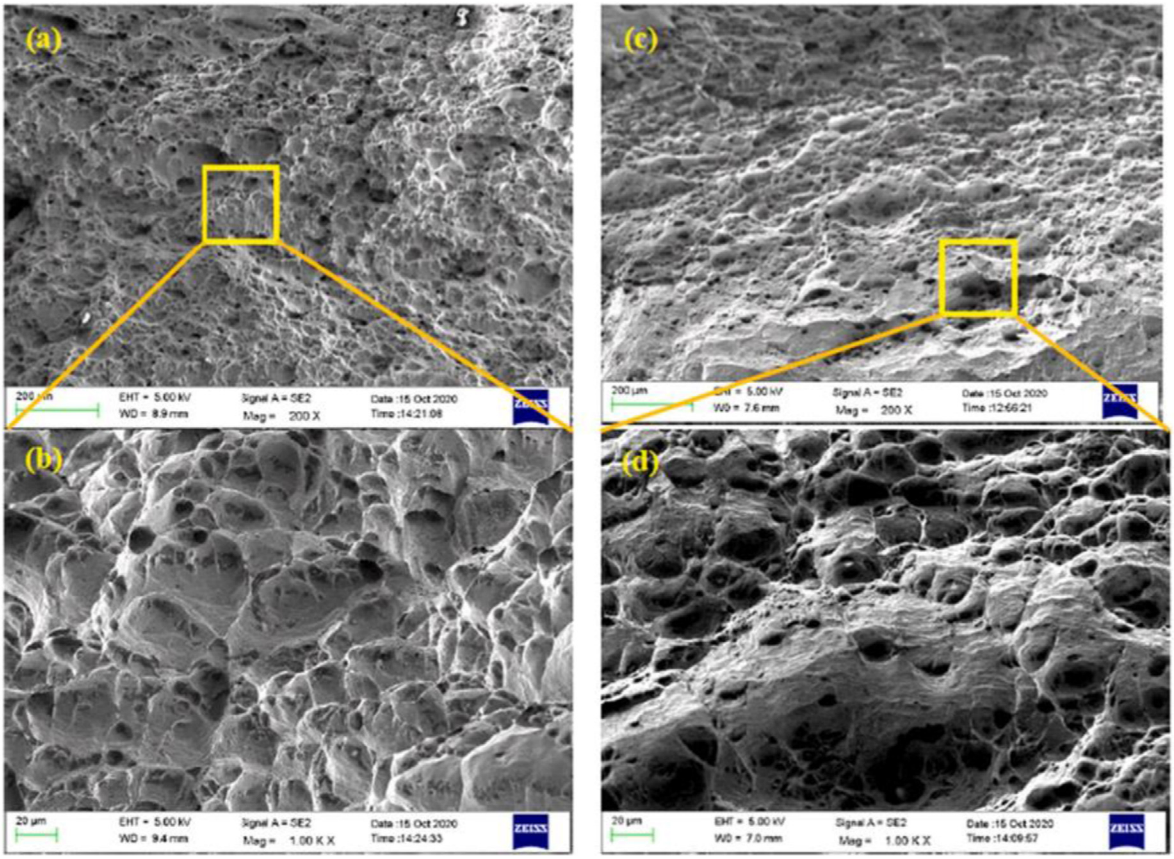

Figure 9. SEM images of the fractured surfaces in case of sample D, (a) and (b) fractured surface images at Cu side, and (c) and (d) fractured surface images at SS side [Niknamian (2019).

the influence of process variables on the microstructural, morphological and material properties of ferrous and non ferrous metals. The results revealed that with slow rise in rotational torque width increases which increases the joint width and decreases the mechanical properties while this decreases when travel speed is high. This is attributed to lower friction thus producing lower heat input producing finer and homogeneous grains thus increases the material properties of the joint (Gu et al., 2021). investigated the influence of Nickel and other fillers on copper to stainless steel joint. The results indicate that high dilution percentage of SS to Nickel and Cu to nickel is obtained. The homogeneous solution is obtained between the SS/Ni and Cu/Ni which produces refined grain structure in weld metal zone and reduced size of HAZ is obtained which alters the bead geometry and increases the material, microstructural and morphological properties of joint (Marton and Anna, 2021). investigated the effect of material thickness, distance between the ultrasonic head and concentrator with the workpiece, axial pressure, wide altitude of welding with ultrasonic head and concentrator on the weld chemical, physical

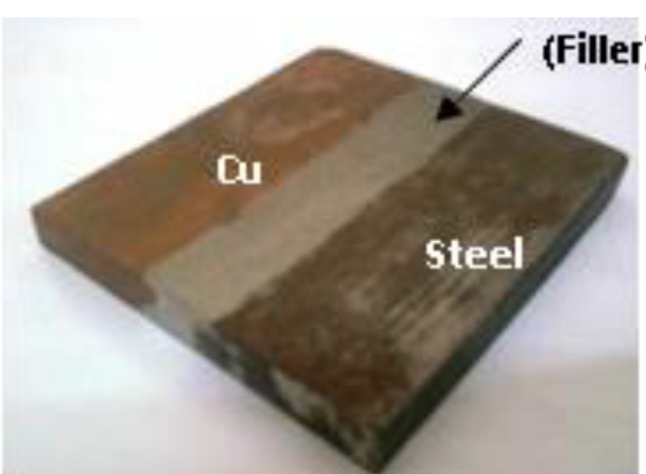

Figure 10. Depicting Cu to steel joint using Inconel (ENiCrMo3) (Velu and Bhat, 2012).

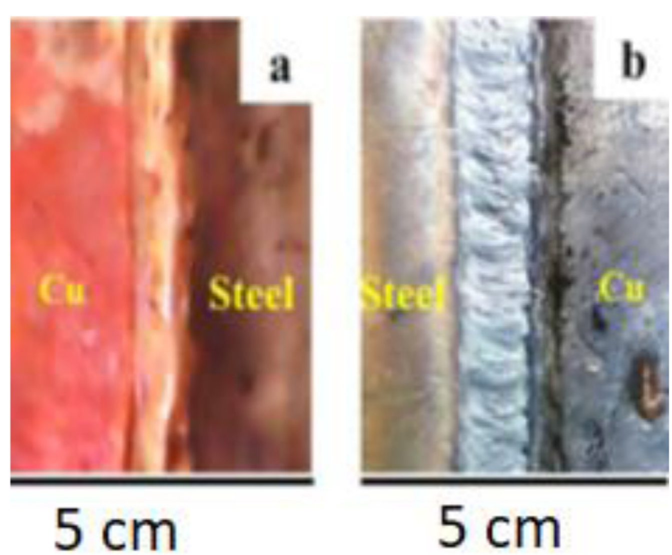

Figure 11. The dissimilar joints between cu and steel (a) III method -Preheated with 150 °C and welded at 120A (b) IV method-Preheated with 200 °C and welded at 190A (Niknamian, 2019).

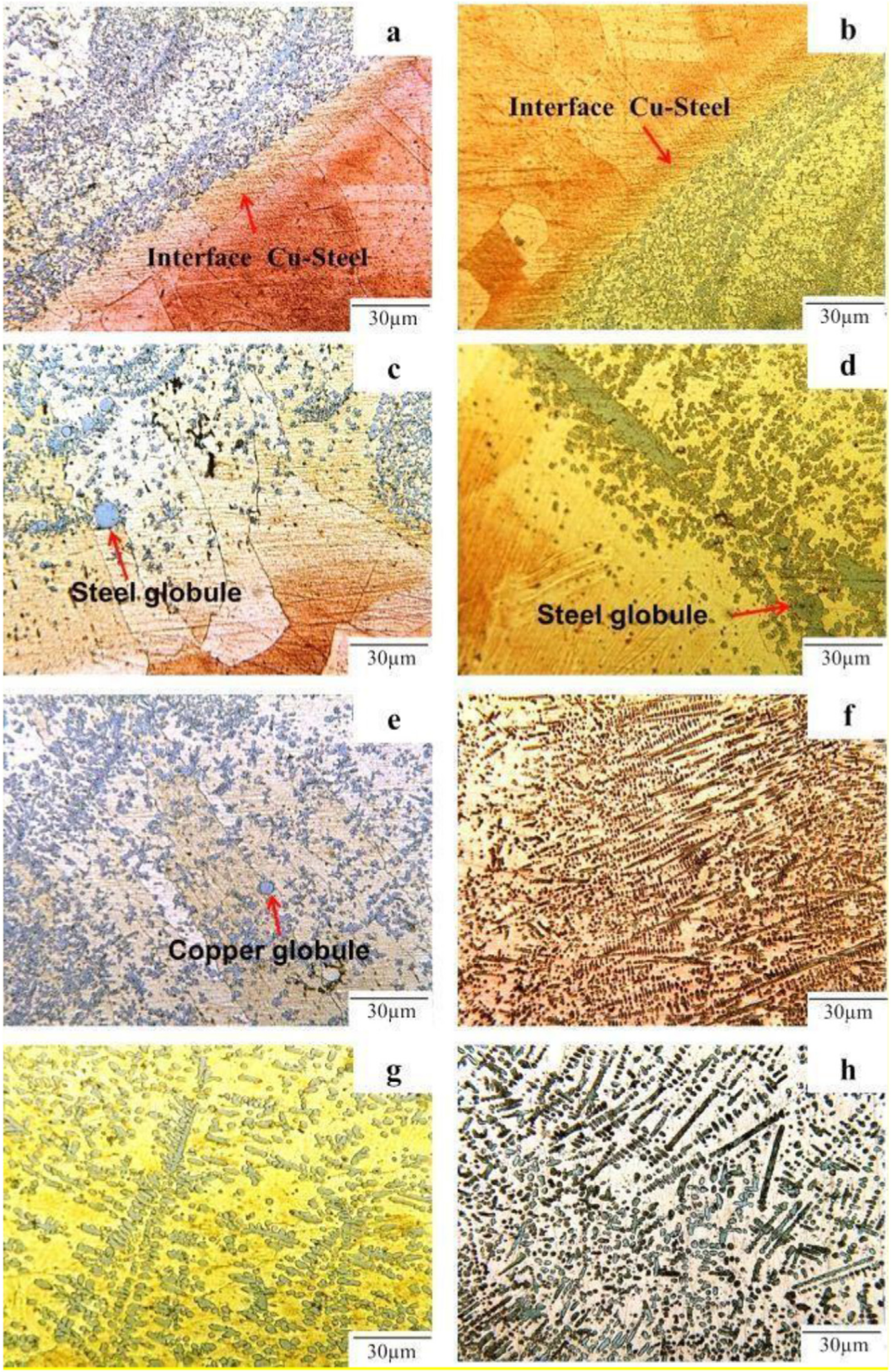

Figure 12. (a) The OHFC copper with chromium rich steel interface in the welding using El-Cu-Mn2 electrode. (b) OHFC copper with chromium rich steel interface in welding using EniCrMo-6 and ER70S-4 electrodes. (c) the presence of steel flakes in the copper matrix in the welding using El-Cu-Mn2 electrode. (d) the presence of steel circular flakes in the copper matrix using EniCrMo-6 and ER70S-4 electrodes. (e) the presence of copper flakes alternate in the steel matrix using El-Cu-Mn2 electrodes. (f) the presence of steel columnar structure in the copper matrix using EniCrMo-6 and ER70S-4. (g) the presence of columnar structure in the weld metal obtained from the welding using El-Cu-Mn2 electrode. (h) the presence of columnar structure in the weld metal obtained from the welding using EniCrMo-6 and ER70S-4 electrodes (Niknamian, 2019).

and material properties. The results indicate that good joint is obtained by this welding weith improved joint properties. The reduced shear force result in increased material properties (Shiri et al., 2012). produces the GTAW joint of ferrous and non ferrous joint using nickel and Inconel filler material having soluble in ferrous as well as non ferrous metals. The results indicate that enhanced mechanical properties are obtained when copper based filler material is used as it has grater solubility with stainless steel. The mechanical properties obtained are good but lower tensile strength is obtained. The defects produced are solidification crack and lack of fusion but no micro crack initiation and propagation takes place (Zhang et al., 2014) investigated the influence of magnetron and klystron emitted beam variables on material properties using non ferrous filler wire having same composition as that of copper base metal. The evaluation results reveals the uniform and refined structure with weld joint region with slight inhomogeneity on top of fusion zone. The microhardness decreases as content of composition of in solid solution is higher which increases the fatigue and cyclic loading properties (Jafari et al., 2017). investigated the influence of variable process parameters of solid state friction welding on joint properties of ferrous and non ferrous material. The results indicate that non-presence of melting and formation of weld metal in molten state, the defects produced are lesser and fine grains are obtained due to refined grain structure within the fusion zone. The dynamic recrystallization in fusion zone increases the hardness within the joint. The results further showed that strength and ductility decreases as number of passes increases (Joshi and Badheka, 2019a,b). tried the investigation on solid state friction welding on joint properties

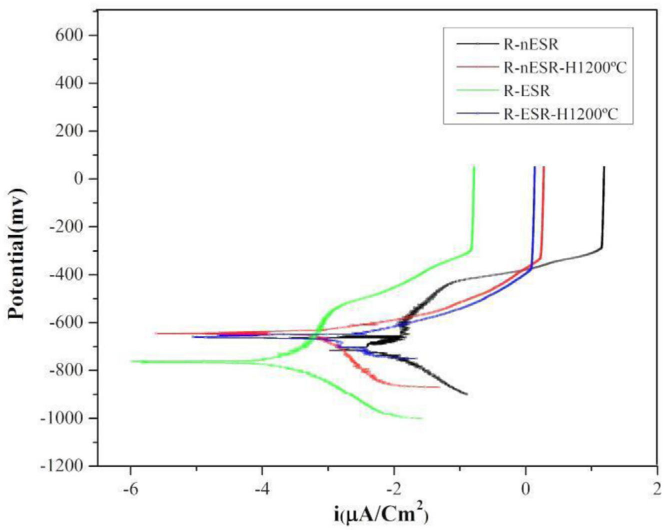

Figure 13. The residual values of the pitting and granular corrosion test to investigate the influence of the El-Cu-Mn_2 electrode on the chemical properties of metal joint (Niknamian, 2019).

of ferrous and non ferrous metals. The different tool geometry were tried but increased efficiency of joint and material properties is obtained with shoulder diameter of 20 mm. The tool pin and shoulder diameter controls the frictional heat which produces uniform and homogenized structure in the fusion zone.

(Navrotski and Brajuskovic, 2016) evaluated the microstructural, morphological and material properties of ferrous and non ferrous joint of oxygen free copper to austenitic stainless steel for the application of accelerator vacuum chamber construction. The results showed that TIG and friction welding produces higher chemical, physical and tensile properties. This is because of reduced region adjacent of fusion zone and higher solubility within the weld region. The addition of nickel or copper as filler material in TIG welding increases the joint properties due to higher dilution (Sahul et al., 2015). Investigation the effects of wave length, power of circular laser welding on microhardness of ferrous and non ferrous joint. The results showed that uniform ands axial structure is obtained at the fusion zone which increases the microhardness of the weld joint. The reduced width of HAZ due to pin point control of heat flow characteristics rises the joint efficiency of the copper to stainless steel (Imani et al., 2011). investigated the influence of offset of pin, linear speed, rotational speed of solid state friction joining process on micro-structural, metallographic and morphological properties of ferrous and non ferrous joint. Since it is plastic deformation joining process, the molten weld pool formation do not exist. The plastic deformation is taking place, so higher material and metallurgical properties are reached. The intermetallic phase which is the brittle phase is restricted at the crack initiation site which takes place on the account to lower heat flow characteristics.

6.4. Shielded metal arc welding of copper to stainless steel 304

Figure 10 depicts joining of ferrous and non ferrous with Inconel filler (ENiCrMo3).

The shielded metal arc welding of oxygen enrich copper with ferrous chromium and nickel reach stainless steel 304. Due to this lot of difficulties are associated with this type of welding. Some studies has been conducted to describe the behavior of combination of oxygen enrich cooper with ferrous and chromium and nickel rich stainless steel 304 joint properties (Roy et al., 2014). investigated the influence of process variables on joint metallurgical, morphological and material properties of OHFC copper with chromium rich stainless steel. The oxygen enrich copper and nickel and chromium rich stainless steel 304 of size 150 × 5 × 3mm were used. The parameters selected were current (111, 110A), Voltage (29, 30, 31V), Electrode diameter (3.2mm). The electrode used were chromium rich Inconel (ENiCrMo3), nickel and copper rich Monel (ENiCu7) and chromium rich stainless steel (E316L) with 3.2mm diameter. The responses selected were tensile strength, microhardness and microstructure characterization. The results obtained shows that Inconel (ENiCrMo3) is best electrode showing maximum strength, hardness and equiaxed structure (Niknamian, 2019). Used four methods to join stainless steel 304 with copper. In first method SMAW was used with electrode EI-CuMn_2. The SMAW welding current was 140–150 A. The metal was preheated at 250 °C. The investigation reveals the reduced properties and more serious defects are produced like reduced arc concentration, porosity and slag inclusion in the weld joint. The next method used GTAW process to form the weld joint. The EI-Cu-Mn_2 electrode is used. The preheating of copper was done at 150 °C. The welding current of 180–200 A was used to form the joint. The process has certain disadvantages, that increased heat input is decreasing the microstructure properties. The third method includes the combination of GTAW + SMAW process. The welding current were 220 A for GTAW operation and 120A for SMAW operation. The preheating of copper is done at 150 °C as it done as it has lower conductivity. The electrode used is EI-CuMn_2. The complete joint are obtained without distortion and lack of fusion and penetration. The next method which is the fourth method used the combination of same as that of combination of (GTAW + SMAW). The different method is tried. The electrodes used EniCrMo-6 which is the nickel base electrode is utilized for cladding and the higher chemical composition filler ER70S-4 is used for making complete joint. The welding current for GTAW is 170A and 190A for GTAW to make successful and free from defects joint. The successful joint was obtained using third and fourth method as depicted in Figure 11 a and b.

After obtained the joint which continuous bead appearance, the mechanical and microstructural characterization was done to reveal the existence of uniform mechanical properties through out the joint. The mechanical properties are dependent on the material properties of joint of metal. The X-ray investigation at nano level reveals the presence of steel flakes and circular like structure in copper matrix. Copper and steel interface contains the dendrites shown in figure 12 (a-h).

The polarization test was conducted to depict the pitting corrosion on the workpiece. The workpiece was kept in chemical atmosphere of HCLand NaoH, to check PH and concentration of chloride ions. The test reveals the granular like structure and very small pits which are in nanoscale and no preferential sites for crack initiation and propagation. The effect of consumable electrodes El-Cu-Mn_2 from which the joints were formed is checked on the corrosion resistance has been depicted in Figure 13.

7. Conclusion

1. The parameters which are affecting the mechanical properties and microstructure and corrosion properties like intragranular corrosion and pitting corrosion are amperage, flux, voltage, linear speed and electrode dimensions and composition.
2. Inconel ENiCrMo3 is found to be best electrode showing maximum strength, hardness and equiaxed structure in not only in similar welding but also in dissimilar welding specially copper and stainless steel.
3. Welding flux amperage and linear speed were found to be main parameters which influence the heat flow characteristics and rate of solidification thus alters the mechanical properties.
4. The preheating, post heating, polarity, interpass temperature are main condition affecting mechanical properties.
5. SMAW is found to be more sustainable, economical in terms of environmental impact.
6. SMAW is found to be effective joining technique for welding dissimilar ferrous and non-ferrous metals.

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Data availability statement

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Declaration of interest's statement

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Additional information

No additional information is available for this paper.

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