A Review of Effect of Welding Parameters on the Structure and Properties of the Weld in Shielded Metal Arc Welding Process

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Abstract The shielded metal arc welding (SMAW) is one among the most common welding processes that is generally used in the fabrication process in industries to join components, as its operation is easy. Shielded metal arc welding is a prominent process of metal fabrication which finds its best usage in shipbuilding operations, construction, and metal structure industries. This paper investigates the descriptions and findings of different researchers. Several researchers performed experiments on SMAW and investigated the effect of rate of welding heat input on the structure and properties of the materials. The heat rate is the function of welding speed, welding current, and welding voltage. The properties of the materials are affected by welding current, welding voltage, and welding speed. This review research paper includes the selected important research papers which describe the effect of current, voltage, and speed of welding on the effect of mechanical and microstructural properties. The joints produced by shielded metal arc welding process have enough strength, and when these joints are compared with any other joints, the cost is relatively low.

Keywords Shielded metal arc welding · Polarity · Welding current · Weld · Strength · Process · Heat rate

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1 Introduction

Welding is a joining process in which two or more faying surfaces are joined together permanently to form one surface. Welding is a very reliable, "high-tech," and cost-effective process for materials to be joined. Manufacturers prefer welding process over any other technique to join the metals and their alloys efficiently. Welding is used in several constructional applications like buildings, bridges, computers, vehicles, etc., and some of these applications cannot be completed without applying the welding process. Many varieties of materials and products are used in welding process by using advanced developed technologies including laser and plasma arcs. Shielded metal arc welding process is one such process that finds its usage in small-scale industries; it is one of the most widely used welding processes in the world. It requires a human welder to weld and is often termed as manual metal arc welding process since it is not automated and is difficult to use in large-scale industries. It is also known as flux shielded arc welding process or stick welding process. In the process of shielded metal arc welding, a consumable electrode containing flux is used. The main advantage of the flux is to avoid the contact of atmospheric gases with the weld zone by providing a layer of slag. An electric arc is generated in between the work and the tip of the electrode using either the direct current or alternating current from a power source. There are several important terms in shielded metal arc welding process like arc voltage, welding current, welding speed, heat input, electrode, weld heat-affected zone, power supply, and polarity.

2 Literature Review

Molleda et al., performed the experiment on the mild steel welding with SMAW process and noticed spattering at the time of welding which was the result of the liquid metal droplets that are thrown out from the weld pool due to the action of tiny droplets from the electrode. They took the covered electrode and produced a resulting weld on the base metal. They found that the spatter particle welds to the base material and transfers heat very quickly to it and produces a very thin re-crystallized region in the heat-affected zone [1].

Ravindra Kumar et al., examined a low carbon steel ASTM SA210 GrA1 weld using shielded metal arc welding process. On HAZ, base metal, and the weld metal, the oxidation studies were made after the plates were exposed to air under cyclic conditions at 900 °C. Kinetics of oxidation was developed using the technique called the thermo-gravimetric technique. The analysis on the oxidation products was performed using scanning electron microscopy/energy dispersive and X-ray diffraction (XRD). The result made from XRD analysis was that the high intensity of Fe_2O_3 was formed as the base metal oxidizes in air and when compared at 900 °C, thicker oxide scale is formed on the base metal rather than the weld metal [2].

Goyal et al., noticed that the initial heating by arc which is having double ellipsoidal nature is the primary heat that is being transferred to the weld pool. They developed an analytical model. They used the different analytical techniques and considered two sources of heat which are not similar in nature and estimated the distribution of temperature in the region of HAZ and the weld pool. They told that the base metal which melts under the sway of two dissimilar heat sources can lead to the estimation of the profile of weld pool by evaluating the weld isotherms [3].

Tabatabaeipour et al., compared two different arc welding processes, the first one shielded metal arc welding process, and the second as gas tungsten arc welding processes. They performed the ultrasonic testing of these two welding processes and used the technique of time-of-flight diffraction (ToFD). B-scan images that were collected by using ToFD technique revealed that the specimen that was made from SMAW is much easier as compared to that of the specimen prepared by GTAW process, because waves are scattered to a greater extent in the latter case [4].

Gurpreet Singh Sidhuet al., studied the effect of consumable electrodes on the properties of a weld due to the intermixing of the weld metal from consumable electrode used in shielded metal arc welding process. They found that to attain the high productivity, high weld quality, economy, and strong weld, the flux is intermixed, and the chemical compositions of the electrode is changed to obtain the required cost-effective process and robust product structures [5].

Izzatul Aini Ibrahim et al., measured the hardness and microstructural changes as a consequence of using different process parameters of welding for mild steel with a thickness of 6 mm. They used welding speed, welding current, and voltage as the variables, performed hardness test, and studied the microstructure. They used current from 90 to 210 A and concluded that on increasing the current the depth of penetration increases. They also told that the depth of penetration is a function of arc voltage [6].

Pravinkumar et al., examined a material to find out the tensile strength using the vibration concept. They used stirring of the molten metal before its solidification. The conclusion that was derived reveals that as the molten metal is stirred, it increases the material strength [7].

Maridurai et al., investigated the tensile properties of carbon steel P91. They welded the root pass by three different processes namely tungsten inert gas welding process, submerged arc welding process, and shielded metal arc welding process. They studied the characteristics of fracture, impact strength, and tensile strength of the weld and the base metal in the three processes. They used crack tip opening displacement for their study [8].

Olawale et al., established correlation between heat treatment and some mechanical properties in shielded metal arc welding process. They selected carbon steel as the material and the AWS E6013 as electrode for their investigations. They kept the voltage as constant and the current as varying and subjected the heat treatment to work piece at different temperatures. They concluded that the hardness and ultimate tensile strength both increase with the increase of current before heat treatment, but after heat treatment these values decrease if current is increased [9].

Praveen Kumar et al., selected welding voltage, welding current, welding speed, and electrode angle as welding parameters for shielded metal arc welding process. They used ANOVA and conducted the experiments to analyze with orthogonal array [10].

Rohitjha et al., investigated two different weld designs. V grooved and flat surface welding joints were obtained with the help of SMAW process. They evaluated the mechanical properties like tensile strength, yield strength, and percentage elongation of weld metal for different welding current and welding speeds. They found that V joint has maximum ultimate tensile and yield strengths [11].

Rajeev Ranjan et al., tested the optimization of different welding process parameters which include the welding current, voltage, welding speed by evolving a mathematical model for a mild steel specimen for a sound weld deposit. They used various process parameters and the factorial design to disclose that there is a direct variation in the weld deposited area with the welding current and the welding voltage. Their study also revealed that the welding speed and the weld deposited area have an inverse relationship [12].

Rohitjha et al., investigated the effect of welding parameter, welding current, voltage, and heat input on mechanical properties like UTS of mild steel in SMAW process and evaluated the optimum welding current. The UTS of weld metal is to be investigated by using tensile testing machine, and the welding current is varying. They found that at 120 A, the tensile strength of weld metal is high, and after optimum value, if the current is increased, the value of UTS decreases [13].

Kchaou et al., used shielded metal arc welding process for two stainless steel plates and investigated the microstructure and mechanical properties of the weld. They found that the ductility decreases in weld metal in comparison with the base metal. They told that due to the rapid cooling of weld metal the microhardness of weld metal increases [14].

Olga Liskevych et al., measured the thermal efficiency and the heat input and developed a method which can be used for the determination of the metallurgical aspects using shielded metal arc welding process. They found that the results depend on the welding parameters, environmental conditions, the dimensions of the sample work, and the base metal. They used these parameters for the estimation of amount of heat loss from the surface of the welded plates [15].

Brajesh Kumar Singh et al., studied how the weldment properties are affected with the variations in the design of joints. They used samples for the study on IS 2062:E250 plates of mild steel with the help of shielded metal arc welding process. They used the variation in the geometry of the joint and studied and compared the effects of these variables on the properties of the plates of mild steel for different geometries. They concluded that double 'V' joint is more effective and superior to other joints in terms of the mechanical properties [16].

Abhishek et al., used FEM and ANSYS software to investigate the effect of temperature distribution in weld joint on residual stresses and distortion. They found that the distortion and residual stresses can be minimized by optimizing current, voltage, and speed of welding in shielded metal arc welding process [17].

Dutta et al., used optical and scanning electron micrograph to investigate the different regions of the weld and found that the peak temperature in the case of shielded metal arc welding process is lower than that in gas tungsten arc welding process by about 75 °C, and the duration of peak temperature is also less in the case of SMAW process [18].

Bbodule et al., compared shielded metal arc welding process with oxy-acetylene welding process using low carbon steel as the base material. They found that if heat input is increased, the yield strength, ultimate tensile strength, and hardness values decrease, and the 'V' grooved weld has better mechanical properties in comparison with that of the straight edged surface welds. They told that if toughness is increased, the hardness and tensile strength values decrease [19].

Deogade et al., performed thermal analysis of the heat-affected and weld zones of ferrite stainless plates welded by shielded metal arc welding process. The simulation was done by using ANSYS and three-dimensional finite element analyses. They analyzed the residual stress distribution with the temperature and warned that the higher heat input rates become dangerous for residual stresses in thin plates [20].

Raffi Mohammad et al., tried to matchup the mechanical and the microstructural changes of high stainless steel, which is free of nickel, by using different welding processes such as shielded metal arc welding, gas tungsten arc welding, and electron beam welding. They found that the weld obtained by shielded metal arc welding process is the cheapest of all but beneficial for general joining work [21].

Pengfei Baia et al., developed a sensing method, completely based on the arc voltage to sense the depth of penetration. In their method to imitate the beginning of the process, the work piece was made to act upon by a stationary arc for about 2 s. They used peak current and fluctuating voltage to describe the penetration status [22].

Vijayesh Rathi et al., used shielded metal arc welding process to establish relationship between microhardness and input welding parameters like heat input, voltage, current, and welding speed for weld and heat-affected zones. They found that at low heat input, the microhardness of weld metal decreases, but it increases for the heat-affected zone. They also concluded that in shielded metal arc welding process at lower heat input, better impact strength and hardness values are obtained. They told that at higher heat input, the cooling rate becomes higher; and hence, the cracks are developed in heat-affected zone and weld metal [23].

Shukla et al., analyzed the effect of different input welding parameters on depth of penetration for shielded metal arc welding process. They used AISI 1020 plates for welding and applied surface response method and concluded that welding current is the main input parameter which has very large effect on depth of penetration [24].

Chen et al., used S 690 Q grade steel to form butt weld and studied the effect of this steel on tensile strength of the weld. They found that S 690 Q grade increases tensile strength of the welded joint, but the relation in between these two cannot be established easily written with any equation but can be approximated by using some other tools [25].

Zhang et al., studied the weld of 12 Cr_2Mo_1R heat-resistant steel. They formed butt joint using arc welding process. They added different amount of phosphorous in different welds and analyzed the variation of microstructure and impact strength of the weld with phosphorous and found that phosphorous makes the size of microstructure small which increases the impact strength of the weld. They found phosphorus to be highly depleted in the δ phase, which inhibits δ-phase precipitation by reducing δ-phase nucleation and growth in the weld [26].

Kumar et al., had experiments for performance of electrodes with arc welding process. They utilized probability density distribution and signal-processing technique in their work. They concluded that probability density distribution is a very good method to obtain almost actual value of the output for the given input values. They also found that different electrodes provide the property of their constituents, and also if current is constant, then smaller diameter electrode has greater energy density and larger depth of penetration [27].

Sumardiyanto and Sushilowati experimented low carbon steel, API5L using shielded metal arc welding process. They analyzed the effect of input welding parameters on mechanical properties of the weld. They used three different electrodes E 6010, E 7016, and E 7018 and two values of current as 90 and 100 A and concluded that depth of penetration increases with current and electrodes also have effect on mechanical properties of weld [28].

3 Conclusion

Ongoing through the investigations done by the selected researchers, some conclusions can be derived for input–output process parameters for the structure and properties of the weld obtained through shielded metal arc welding process. These can be summarized as below:

1. The mechanical properties of the weld have strong relation with the macro and microstructure of the weld obtained by shielded metal arc welding process.
2. If number of passes of weld is more, then complete transformation of delta ferrite to austenite is not possible due to the existence of differential heating and cooling rates in passes. This develops superior quality of weld having more tensile strength and hardness.
3. If arc voltage or welding current is increased, the hardness increases, but tensile and impact strength values decrease.
4. If voltage is increased, the weld width increases.
5. The microstructures of weld zone and heat-affected zone are entirely different.
6. Manganese, silicon, sulfur, etc., are alloyed to increase some specific properties of the weld.

4 Scope for Further Work

1. Little work is reported on metal transfer influencing chemical composition, bead geometry, strength, and metallurgy of weld in submerged arc welding process.
2. Transient study of current voltage in shielded metal arc welding requires more work, as it is the least searched area.
3. The optimum values of input output welding variables are not searched yet; it should be tried by utilizing MATLAB and ANN, etc., to simulate properly.
4. Application of magnetic field can be utilized properly to distribute the input heat of welding on the weld surface, so serious work over this area is needed.
5. The process is slow as after electrode consumption, new electrode rod requires some time in adjusting it with the electrode holder. Methods should be searched to have continuous feeding of electrode rod to work.
6. The process can be made semi-automatic by using some other arrangements like lathe machine in which lead of screw of lathe machine can be utilized to provide speed of welding as automatic.

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