Review of Optimization Process Parameters in Welding System

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Abstract

This study was based on design of experiment (DOE) using Taguchi method with four welding parameters namely welding current, welding speed, root gap and electrode angle considered for experimentation. An orthogonal array of L9 experimental design was adopted and ultimate tensile strength was investigated for each experimental run. The tensile test was carried out on extracted welded and unwelded specimens using universal testing machine (UTM). Microstructures of the welded specimens were carried out and analyzed. Statistical analysis (ANOVA) and signal to noise ratio were used to study the significant effect of input parameters on ultimate tensile strength and optimized conditions for the process performance respectively. The results showed that experiment number 7 has the highest ultimate tensile strength (UTS) of 487MPa and S/N ratio of 53.74 dB. The S/N ratio of higher value indicates better characteristic of optimum MMAW process performance. The study shows that the optimum condition is A3B1C3D2 at welding current 100A, electrode angle of 700, root gap of 3.3 mm and a welding speed of 3.6 mm/s.

Keywords: optimized conditions, welding parameters, welding processes, work piece

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INTRODUCTION

Welding process is very critical to the development of a nation because it is the hub on which modern industries revolve. Gasser *et al*. [1] stated that no secondary process has been and continues to be more important to the survival, comfort and advancement of mankind than welding. According to him, welding has made it possible to build our world. It is in view of this that many researchers have employed various optimization techniques to improve different welding process parameters on both semi and full automated welding processes. Although, the semi and full automatic welding processes are more productive, experience has shown that due to complexity and economic cost of the equipment and their operations, the choice of manual metal arc welding (MMAW) process is very popular in developing countries. This is so because of its several advantages such as low cost and simple operation. The MMAW process is portable and it can easily be used in places where other welding methods are not possible. Manual metal arc welding is also known as shielded metal arc welding (SMAW), or stick welding process. It is one of the oldest and most widely used arc welding processes. The process involves the use of arc current to strike an arc between the base material and a consumable electrode rod. The electrode rod is made of a metal that is compatible with the base material being welded and it is covered with a flux. The heat generated melts a portion of the tip of the electrode, its coating and the base metal just below the arc. As the coating on the electrode melts, the flux gives off vapors that serve as a shielding gas and provide layer of slag, both of which protect the weld from atmospheric contamination. The slag formed during welding is chipped off from the weld after cooling. MMAW process can operate with either direct current (DC) or alternating current (AC) power supply depending upon the coating design. The process is portable, versatile, inexpensive equipment and requires little operator training. Also, the electrode produces and regulates its flux, it has lower sensitivity to wind and draft than gas shielded welding process and the process is applicable in all positions. On the hand, the process is slow and time wasting due to frequent changing of electrode and chipping of slag. Also, it is characterized with excessive spatter, arc stability and rough surface of weld bead and provides limitation deposition rates compared to other arc welding processes. With the incorporation of automation into the arc welding process, many production companies adopted complete experimental designs and mathematical models to investigate the relevant process parameters to obtain quality weld stated that high quality can be achieved by optimizing various quality attributes or by selecting an optimal process environment that is efficient enough to fetch the desire requirements for quality.

Taguchi method has been found to be a powerful tool to improve overall process quality by optimizing the welding process parameters in a way that variation is reduced to the barest minimum. Design of experiment (DOE) techniques had been used to carry out such optimization in the last two decades with a view to improving on the mechanical properties of weld materials.[2–4] optimized the parameters of welding 7075-T6 aluminum alloy using Taguchi method. Among other investigators who have also worked on the optimization of welding variables using Taguchi method are Kim and Lee.[5] They used the method to suggest optimal combinations for process factors of hybrid welding methods to optimize the welding parameters of resistance spot welding process. In this study, the application of Taguchi L9 orthogonal array for the selection of manual metal arc welding process parameters of welded mild steel plates was investigated. The ultimate tensile strength and the microstructures analysis were carried out on each samples and analyzed.

Signal-to-noise (S/N) ratio to determine the optimal parameters that affect the response and ANOVA analysis to determine the significant effect of the input variables on the ultimate tensile strength were both investigate0.35% Mn, 0.28% Si, 0.02% S, 0.04% P and 99.08% Fe. Mild steel was considered for this study because of its availability in the market and low cost. Mild steel electrodes of 350 mm long and 3.25 mm diameter (E6010 and E6013 steel grade 2, Oelikon) were used for the root running and weld deposits respectively.

WELDING PROCESS

Selective laser melting (SLM) and laser cladding are laser additive manufacturing methods that have been developed for application to the near-net-shape process and 3D printing. The temperature distributions and track profiles of SLM and clad layers require additional in-depth investigation to optimize manufacturing processes. This research involved developing a tailored laser heat source model that contains a comprehensive selection of laser beam characteristics and can be used in finite element analysis of the laser melting process. This paper presents a systematic experimental validation of the applicability of the proposed laser heat source model to single-track Nd:YAG and CO2 laser melting simulations. The evolution of the melt pool isotherms and the variation in track profiles caused by adjusting the laser power and scanning speed were numerically predicted and experimentally verified. Appropriate process parameters and the threshold power for continuous track layer formation were determined. The balling phenomenon on preplaced powder was observed at power levels below the threshold values. Nd:YAG laser melting resulted in a wide and shallow track profile, which was adequately predicted using the numerical simulation. CO_2 laser melting resulted in a triangular track profile, which deviated slightly from the finite element prediction.

The results indicated a high level of consistency between the experimental and the numerical results regarding track-depth evolution, whereas the numerically predicted track width evolution deviated slightly from the experimentally determined track width evolution. This parametric laser melting study validated the applicability of the proposed laser heat source model in numerical analysis of laser melting processes such as SLM and laser cladding. A mild steel plate was cut into 100 × 75 × 5 mm^3 (length and breadth and thickness) using cut-off machine. This was followed by edge preparation and a single groove butt joint was selected for the joining process in flat position. The surfaces and the prepared edges of the samples were thoroughly cleaned with wire brush to remove any dirt or unwanted inclusion that could affect the weld. In this study, the welding process was a bit different from the normal convectional manual welding process as the electrode (electric arc) was constrained in stationary position while the work piece moved relative to it. This help to maintain relative stable welding speed and improve the quality of the weld. A 400A capacity manual metal arc welding machine with direct current (DC) straight polarity was used for the welding operations. This is because with DC, it is easier to maintain short arc in the starting stage of welding operation. The E6010 electrodes were first applied for the root running. Thereafter, the grooves were cleaned before the E6013 electrodes were used for the weld deposits in 2 – pass. Fifty four work pieces were used for this experiment that was carried out in the Department of Mechanical Engineering workshop, Federal University of Technology Minna, Nigeria (Figure 1).

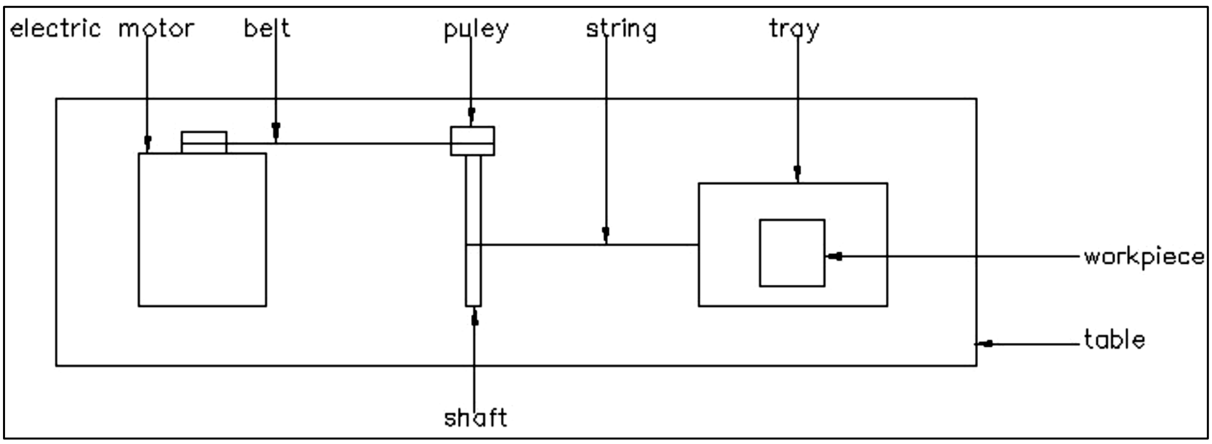

Fig. 1. *Welding Rig.*

The welding rig consists of a speed reduction electric motor (1hp), three different sizes of belts and corresponding pulleys, a shaft, tray, string, six ball bearings and the stand. The main feature of the rig is the variable speed of workpiece relative to a stationary electrode or electric arc. The rotation of the electric motor was converted to linear motion through the belt drive system and guided string as shown in Figure 1. Input welding parameters selected from the structural codes of American Welding Society,[6] and manuals of metal arc welding system for this study are: welding current, welding speed, root gap and electrode angle. Even though, arc length is one of the critical welding parameters, it cannot be used as welding parameter in manual metal arc welding process. An orthogonal array of L9 was selected for experimentation. Based on the Taguchi orthogonal array designed, nine experimental runs were conducted and each welding process was repeated three times under the same conditions. These welding input parameters and their levels that is, Laser Beam Welding, Electron Beam Welding, and Plasma Arc Welding are used to improve surface properties and perform surface hardening. Although welding is recognized as a process for connecting parts, but it is regarded as one of the most important and widely used coating processes through mass-coating on the surface of industrial parts. They found that with a 50A continuous current, the hardness variations are reduced from the sample surface towards center with a mild gradient; but considerable increase in surface hardness has not been obtained compared to base metal. This trend has a steep gradient with a 60A current and the sample has a mean hardness. With a 75A continuous current, the trend of hardness variation has a steep gradient and the maximum surface hardness has been obtained in this state. With a 75A pulsed current (Figure 2, Table 1).

Table 1. *From Hardness Measuring for Tested Samples.*

Distance from the surface (mm)	Current(A)			
	50	60	75	75 pulse
0	380	503	600	520
1	355	401	505	450
2	337	339	406	376
3	336	335	339.4	335.9
4	335	334	334.1	334.5

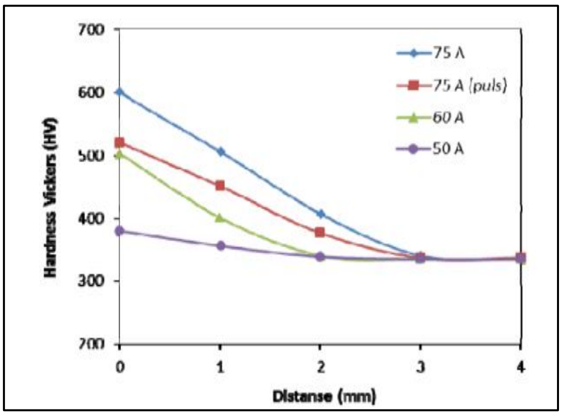

Fig. 2. *Graph for Variations of Hardness Versus Distance for Welded.*

Thermal analysis of laser processes can be used to predict thermal stresses and microstructures during processing and in a completed part. Thermal analysis is also the basis for feedback control of laser processing parameters in manufacturing. A comprehensive literature review of thermal analysis methods utilized in laser sintering (LS) has been undertaken. In many studies, experimental methods were commonly used to detect and validate thermal behavior during processing. Coupling of thermal experiments and FEM analyses were utilized in many of the latter studies. Analytical solutions were often derived from the Rosenthal solution and other established theories LS was initially developed at the University of Texas at Austin. [1] LS is a process in which a high energy laser beam scans the surface of a powder bed (the powder can be metal, polymer or ceramics) and the melted powder solidifies to form the bulk part. Selective laser melting (SLM) is the most commonly used terminology to describe laser sintering of metals, however, the terms Laser Cusing and Direct Metal Laser Sintering (DMLS) are also used by certain manufacturers.[2] SLM makes it possible to create fully functional parts directly from metals without using any intermediate binders or any additional processing steps after the laser melting operation.[3] Laser sintering is very complicated because of its fast laser scan rates and material transformations in a very short timeframe. The temperature field was found to be inhomogeneous by many previous researchers. [4–8] Meanwhile, the temperature evolution history in laser sintering has significant effects on the quality of the final parts, such as density, dimensions, mechanical properties, microstructure, etc. For metals, large thermal gradients increase residual stresses and deformation, and may even lead to crack formation in the fabricated part. Thermal distortion of the fabricated part is one serious problem in SLM. [9] Therefore, understanding the process mechanisms and effects of process parameters are significant for the future development of SLM beneficial for demonstrating the influence of various parameters. Those models are the essential tools for identifying proper parameters without extensive testing [5] is a schematic representation of heat transfer in SLM. [10–14] The laser scans on the top of the powder bed following a prescribed scan pattern. The heat transfer process consists of powder bed radiation, convection between the powder bed and environment, and heat conduction inside the powder bed and between the powder bed and substrate. The latent heat of fusion is large in SLM. The complexity brought about by the powder phase change and the corresponding variation of the thermal properties during SLM also complicates the heat transfer problem (Figure 3).

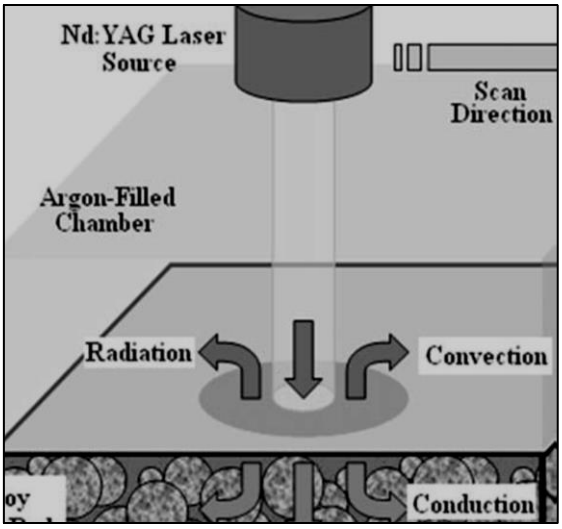

Fig. 3. *Schematic Representation of Heat Transfer.*

Table 2. *Summary of Simulation Model from Literature Review.*

Reference	Material	Basement	Model size: mm	Element size: mm	Laser popup: w	Scan speed: mm/s	Hatch space: mm	Laser beam: mm	Laser type
50	Nickel alloy	N	1.6x(5,10,20)x3.75	0.25	1000	4	0.75	0.75	N/A
51	titanium	N	0.1x0.1	12.5e-3	2	1	N/A	50e-3	Gaussian
7	titanium	N	Coarse: 5x5x2	Coarse:0.1	2	1	0.1	25	N/A
			Fine: 2x2x0.5	Fine:0.01					
40	Cu	N	Height:10	N/A	50-2500	N/A	N/A	0.8	Uniform
52	iron	N	0.03x0.9x0.9	7.5e-3	2,3,4	180,200,225	0.0225	0.03-0.06	Gaussian
8	W-Ni-Fe	Metal: 2x3x1.5	1x2x0.05	0.05	100	20-140	0.05-0.15	0.05	N/A
16	titanium	Mild steel: 3x3x3	1x1x0.15	0.025x0.025x 0.03	120	220	N/A	0.1	Gaussian
41	copper	4.8x2x0.5	3.4x1.6x.3	0.1	400	60,120,180	0.3	0.4	Gaussian
53	H13 hot work tool steel	mild steel	20x20x9	N/A	80	500	N/A	0.1	N/A
42	titanium	stainless steel 25x10x5mm	2x1x0.05	5e-3	110	200	N/A	0.034	Gaussian

NUMERICAL SOLUTIONS

Numerical methods are generally used for solving complex problems when closed-form solutions are not available for a physical situation. A number of research groups have reported their simulation strategies and results in the literature and are enumerated in Table 2. Strategies can be classified by model dimensions, linear/nonlinear approaches, substrate characteristics and laser beam characteristics. The computation time for a real comprehensive model which considers all the factors above is very large and it takes hundreds of hours to compute a 3D model with several layers of real-time SLM processing.

CONCLUSION

This study employed Taguchi method to optimize process parameters of manual metal arc welding (MMAW) process for mild steel products. From the tensile test carried out on welded samples it was observed that this study entailed a comprehensive experimental validation of a tailored laser heat source model used for simulating laser melting and laser cladding on a preplaced cobalt-based powder layer on a steel substrate. The effects of the beam power and scanning speed on the track profile were investigated experimentally and predicted numerically for a Nd:YAG laser and a CO_2 laser emitting TEM mixed mode beams. The threshold power for continuous track formation and the appropriate process parameters for laser melting were determined. The Nd:YAG laser formed a wide and shallow solidified track, whereas scanning using the CO_2 laser resulted in a triangular track profile. The experimental results were generally consistent with the numerical predictions in a wide range of process parameters. The simulation tool predicted the wide and shallow track profile achieved using the Nd:YAG laser more accurately than it predicted the deep triangular track profile created by the CO_2 laser. Greater consistency between the experimental and simulation results was observed in the trend in track depth variation than in the trend in track width variation as process.

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