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Effects of Process Parameters on SMAW Weld Quality using SK-260-M E6013 Electrodes

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***Abstract*— Shielded metal arc welding (SMAW) experiments on mild steel (MS) have been conducted by using two NICHIA SK-260-M E6013 electrodes (diameters: 3.2 mm and 2.6 mm). The present research is unique since it not only shows the effects of welding process parameters on the heat input and weld quality, but also determines the optimum current, voltage, and welding speed for a specified diameter of the electrode to obtain a satisfactory weld quality. The authors have shown the results of using different current values and welding speeds and their effects on the heat input and weld quality with the aid of photographs and graphical plots. Surprising results (contrary to literature) have been obtained; which have been scientifically explained and justified. The research findings would enable welding engineers to use correct amperage, voltage, and the welding speed when using SK-260-M E6013 electrodes in SMAW of mild steel.**

***Keywords*— Shielded metal arc welding (SMAW); SK-260-M E6013 electrode; welding speed, heat input**

I. INTRODUCTION

Shielded metal arc welding (SMAW) is the most common and economical fusion welding process. Owing to its flexibility and portability, SMAW is widely used in construction industry, pipelines repairing, ship-building, steel structures, and the like (Hariprasath, et. al., 2022). For a good quality fusion weld, it is desirable to melt the metal with minimum energy and high power density; which is defined as the power transferred to the work per unit surface area. Mathematically, power density is expressed by (Groover, 2010):

$$PD = P/A = (V\ I)/A \qquad (1)$$

where PD is the power density, W/mm^2; P is the power entering the surface, W; A is the surface area over which the energy is entering, mm^2; V is the arc voltage, volts; and I is the current, A.

The quality of a weld is determined by its weld-bead geometry, which strongly depends on the heat input during the welding process. If the arc is properly controlled in SMAW, the metal from the electrode will pass through the arc and deposit on the base metal. When the filler wire moves at a correct speed, the metal can be deposited in a uniform layer on the base metal called bead (Kamble and Rao, 2013; Ganjigatti, et. al., 2006). The amount of heat input in the SMAW process depends on a number of variables, including the electrode diameter, voltage, current, and the welding speed. The heat input can be calculated by using the following formula (Huda, 2018):

$$H_i = (0.06\ I\ V)/v_w \qquad (2)$$

where H_i is the heat input, kJ/mm; I is the current, A; V is the arc voltage, volts; and v_w is the welding speed, mm/min.

Busari and co-researchers have conducted SMAW experiments on mild steel specimens; they have concluded that the depth of penetration varies directly as the welding current (Busari, et. al., 2017). They have reported that the use of too high weld current may result in welding defects, such as excessive spatter, electrode overheating and cracking while too high weld voltage could cause the beads to be wider and flatter. The low arc voltage produces a stiffer arc that improves penetration; an optimum current of 135A was recommended to avoid weld defects.

SMAW process generally uses mild steel electrodes coated with a flux. During the burning of coating, the flux coating will mainly create gases (hydrogen & carbon dioxide) as a protective shield. The correct welding current setting mainly depends on the electrode diameter used; this dependence for a mild steel electrode can be expressed by the following relationship:

$$I = 40\ d \qquad (3)$$

where I is the current, A; and d is the electrode diameter, mm. For example, a 3/32 in. (2.4 mm) diameter E6010 electrode welds well by using current in the range of 40 –70 A; a 1/8 in. (3.2 mm) diameter E6010 electrode runs well from 70 to 130 A; a 3/16 in. (4.8 mm) diameter E6010 electrode welds at currents up to 225 A. These electrodes have been designed for use with direct current electrode positive (DCEP) (Materials Welding, 2022).

The present paper reports the effects of electrode diameter, welding speed, and current on the heat input and weld quality of SMAW mild steel. The authors aim to show the results of different current values obtained by using two SK-260-M E6013 electrodes (with diameters 3.2 mm and 2.6 mm) and their effects on the heat output and weld quality with the aid of photographs and graphical plots. The research findings would enable welding engineers to select correct electrode diameter for a specified current, voltage, and welding speed in SMAW of mild steel.

II. EXPERIMENTAL WORK

A modern welding transformer (EXPERT 300 – HELVI s.p.a, Italy) was used for SMAW. NICHIA SK-260-M welding electrodes (diameters: 3.2 mm and 2.6 mm) were used for performing welding operations on mild steel (MS) (ACE Weld Sdn Bhd, 2022). MS work-pieces were clamped to apply single surface welding. SMAW experiments were conducted at various process parameters with safety precautions; the direct current electrode positive (DCEP) rule was applied in electrical connections (see Figure 1). The experimental work was conducted in two phases. The first phase involved the use of two different-diameters electrodes; here first the voltage and welding speed were kept constant for the 3.2-mm dia. electrode while the current was varied; then the 2.6-mm-diameter electrode was used at constant voltage and welding speed at various current values. The second phase of experimentation was conducted on a specified electrode diameter and constant voltage and current while the welding speed was varied. A digital camera was used to take photographs of weld beads for visually examining the weld qualities.

(a) (b)

Figure 1. Welding experimental set up; (a) DCEP electrical connection, (b) arc welding in action

III. Results and Discussion

Since the experimental work was conducted in two phases, the analyzed results are presented in the following two sub-sections: (a) the effects of electrode diameter and current on the heat input and weld quality, and (b) the effects of welding speed on the heat input and weld quality.

3.1. *Effects of Electrode Diameter and Current on the Heat Input and Weld Quality*

In order to study the effects of current on the heat input and weld quality, the voltage and welding speed were kept constant (25 V and 300 mm/min, respectively) for the 3.2-mm-diameter electrode, while the current was varied in the range of 125 – 200 A. Equation (2) was used to calculate the heat input for various process parameters; the resulting data is presented in Table 1. The resulting weld appearances obtained by welding at various process parameters (1 – 8) (see Table 1) are shown in the photograph (Figure 2).

Table 1. Electrode diameter, process parameters, and heat input data in SMAW of MS

Experiment	Electrode Diameter (mm)	Voltage (V)	Welding speed (mm/min)	Welding current (A)	Heat input (kJ/mm)
1	3.2	25	300	125	0.625
2				150	0.75
3				175	0.875
4				200	1.0
5	2.6	35	300	125	0.875
6				150	1.05
7				175	1.225
8				200	1.4

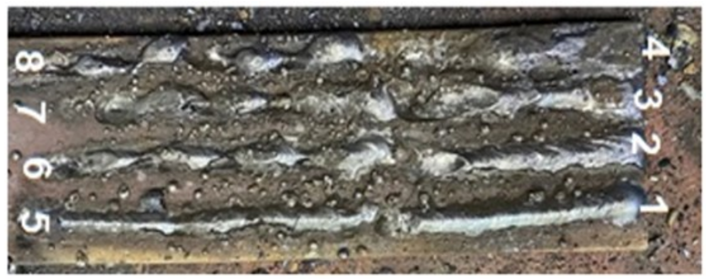

Figure 2. Weld beads appearances resulting from the experimental data in Table 1

It can be observed by visual examination of Figure 2 that all weld beads, except the weld bead # 1, are unsatisfactory in quality. A close observation of the weld beads indicates that the weld bead # 8 is the poorest in quality; this weld bead corresponds to the highest heat input of 1.4 kJ/mm (see Table 1). The weld bead # 8 indicates under-cut welding defect caused by excessive current and heat input; this observation is in agreement with the literature (Davim, 2021). On the other hand, the weld bead # 1 is observed to be of a satisfactory quality; this weld corresponds to the lowest current of 125 A and heat input of 0.625 kJ/mm. It may, therefore, be concluded that welding at a voltage of 25 volts at a welding speed of 300 mm/min using a current of 125 A by using the 3.2-mm-diameter electrode produces a satisfactory-quality weld. This observation and conclusion also validates Equation (3); according to which a welding current of 128 A should be used when using the 3.2-mm-diameter electrode. It is also logically thought that welding at a current lower than 125 A would result in a weld bead with a low depth of penetration. This logical conclusion is based on research findings in literature (Busari, et. al., 2017; Shukla, et. al., 2018).

The effects of electrode diameter and welding process parameter on the heat input are graphically illustrated in Figure 3. The graphical plot indicates that the heat input values (0.9 – 1.4 kJ/mm) for the 2.6-mm-diameter electrode are higher than those for the 3.2-mm-diamater electrode (0.6 – 1.0 kJ/mm). This result can be scientifically explained by references to Equation (2) and the Ohm's law. According to Equation (2), the heat input varies directly to the voltage V. According to the Ohm's law (V = IR), the voltage is proportional to the resistance. Now, the resistance (R) of a cylinder (here electrode) is related to its length (L) and the cross-sectional area (A) by:

$$R = \rho L/A \qquad (4)$$

where ρ is the resistivity of the material of the electrode (a constant value). Hence, a smaller diameter electrode (with a smaller cross-sectional area) has a greater resistance, as compared to a larger-diameter electrode. According to the Ohm's law, the greater resistance R would result in developing a greater arc voltage V. This is why, in the present investigation, the use of 2.6-mm-diameter electrode results in higher heat input values as compared to the heat input for 3.2-mm-diameter electrode. However, the present research finding is contrary to the data reported in literature (Evans, 1982). Evans has reported that the heat input increased from 0.7 to 1.8 kJ/mm as the electrode diameter increased from 3.2 to 6.0 mm by using iron powder type commercial electrodes (ISO 2560). The lower heat input values for the smaller-diameter electrode, as reported by Evans (1982) can be justified by considering the special electrode material (iron powder type basic electrodes) used in the arc welding.

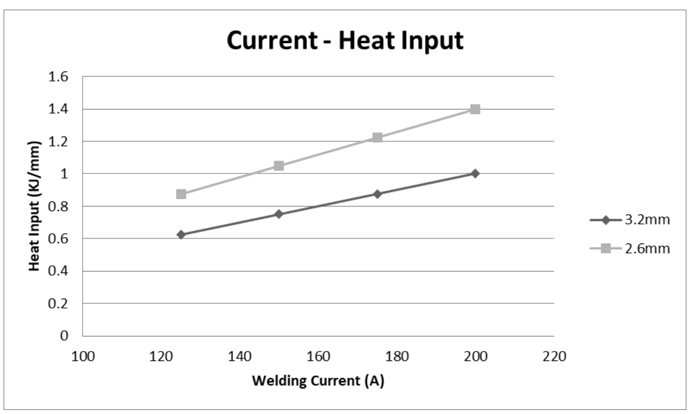

Figure 3. Plot showing the dependence of heat input on current and electrode diameter

It is evident in Figure 3 that the welding current, for a specified electrode, varies directly as the heat input. This result is in agreement with literature (Chandra, et. al., 2014). The use of excessive welding resulting in high heat input and poor quality of weld beads are clearly observable in Figures 2 (see weld beads # 2 – 8). A welding current of 200 A by using the 2.6-mm-diameter electrode results in the highest input and the poorest quality of weld bead (see Figures 2 – 3). Figure 3 also indicates that the rise in heat input due to a rise in welding current is more pronounced in a smaller diameter (2.6-mm diameter) electrode. This is why a low welding current (125 A) and the use of 3.2-mm-diamter electrode (corresponding to the lowest heat input) is recommended in the present investigation. However, a current lower than 125 A for the 3.2-mm-diameter would cause welding defect [see Equation (3)].

3.2. Effects of Welding Speed on the Heat Input and Weld Quality

In order to study the effects of welding speed on the heat input and weld quality, welding operations were performed at varying welding time durations (of 5 s and 10 s) while keeping the weld length constant as 50 mm; the electrode diameter, current, and voltage were also kept constant (see Table 2). Equation (2) was used to calculate the heat input for the various welding parameters.

Table 2. Welding speeds and heat input at specified voltage, current, and electrode diameters

Experiment #	Electrode Diameter (mm)	Voltage (V)	Welding current (A)	Welding speed (mm/min)	Heat input (kJ/mm)
1	3.2	25	125	600	0.3125
2				300	0.625

The effects of welding speed on the heat input is graphically illustrated in Figure 4. It is evident in the column chart (Figure 4) that the heat input decreases from 0.625 to 0.312 kJ/mm as the welding speed increases from 300 to 600 mm/min. It means that the heat input varies inversely as the welding speed in shielded metal arc welding (SMAW) of mild steel. This welding behavior is in agreement with the research findings of Hosseini and co-researchers, who have reported a lower heat input of 0.15 kJ/mm as the welding speed was increased from 20 to 30 mm/s in the electron beam welding (EBW) of aluminum alloy AA2024-T351 (Hosseini, et. al., 2019).

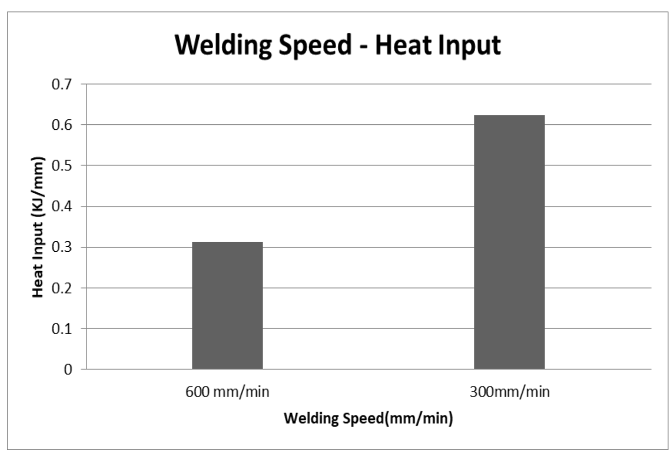

Figure 4. Column chart showing the effect of welding speed on the heat input

Figure 5 shows the weld bead appearances for various heat input values. It can be clearly observed that the weld bead # 2 (corresponding to Hi = 0.625 kJ/mm) is adversely defective as compared to the weld bead # 1 (corresponding to Hi = 0.312 kJ/mm); the latter weld bead may be treated as a satisfactory-quality one. This result is also in agreement with those reported by Hosseini and co-researchers, who have reported hot cracking welding defect in EBW of aluminum alloy AA2024-T351 resulting from a high input (a low welding speed of 15 mm/s) (Hosseini, et. al., 2019). Hence, it is concluded that a low heat input of 0.312 kJ/mm results in a satisfactory weld quality.

Figure 5. Weld beads resulting from two different welding speeds

(weld bead # 1 ↔ v_w = 600 mm/min, RHS = just after welding, LHS = after removal of slag)

(weld bead # 2 ↔ v_w = 300 mm/min, LHS = just after welding, RHS = after removal of slag)

IV. Conclusion

Engineering analysis of welding data showed that the heat input values (0.9 – 1.4 kJ/mm) for the 2.6-mm-diameter electrode are higher than those for the 3.2-mm-diamater electrode (0.6 – 1.0 kJ/mm). This surprising results (contrary to literature) have been scientifically explained and justified. Graphical analysis of welding data showed that the heat input varies directly as the current and varies inversely as the welding speed. It has been concluded and recommended that a satisfactory weld-bead quality results by using the lowest current of 125 A and the lowest heat input of 0.312 kJ/mm for the 3.2-mm-diameter electrode; the other optimum process parameters include an arc voltage of 25 V and a welding speed of 600 mm/min. The research findings would enable welding engineers to select correct electrode diameter for a specified current, voltage, and welding speed in SMAW of mild steel by using NICHIA SK-260-M E6013 electrodes.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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