CONCEPTUAL DESIGN OF SHIELDED METAL ARC WELDING WORKSTATION: WORK POSTURE AND BEAD DIMENSION CONSIDERATION

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ABSTRACT: The aim of this study was to propose a conceptual design of SMAW workstation which considered work postures of welders and weld bead dimensions. This study applied full factorial design of experiment. The independent variables were table height, table surface inclination, and work position whereas the dependent variables were bead height, bead width, and RULA score. Results of analysis of variance showed that the table height, table surface inclination, and work position had an effect on bead width and bead height. This study concluded that the proposed SMAW workstation can offer acceptable bead dimensions when it is designed with adjustable table height, flat table surface (0°), and standing work position. However, the work posture still requires further investigation.

KEYWORDS: *Shielded Metal Arc Welding; Workstation Design; Table Height; Table Surface, Work Position; Bead Dimension*

1.0 INTRODUCTION

Shielded Metal Arc Welding (SMAW) is a manual arc welding process that utilizes a consumable electrode covered with a flux to form the weld. SMAW is the most commonly used welding method because of the versatility of the process and the simplicity of its equipment and operation [1]. In metal fabrication workshop, the SMAW process can be performed at SMAW workstation. A SMAW workstation consists of a welding table, arc welding power supply, power cables and clamp, torch and electrodes.

Welding table is often made of steel because welding on a wooden surface can trigger a fire hazard. Technically, using a steel table, the clamp can be attached to it, and the workpiece placed on the table will be electrically connected with the surface of the table. There are two types of welding table commonly used in fabrication workshops: adjustable and fixed. The adjustable type offers several advantages such as the table can be tilted/ inclined so that the welders can place the workpieces on the table in various orientations. To date, an adjustable welding table has been designed with multiple functions such as lifting (adaptable table height), tilting table, and rotating table to help welders to perform SMAW process in an efficient manner. These functions allow welders to set the height, orientation, and position of the workpiece according to their preference. On the other hand, an adjustable welding table could be associated with high cost as it uses a hydraulic cylinder, a foot pedal actuation, and requires maintenance.

As an alternative to adjustable welding table, a fixed welding table could be a worthwhile choice. The advantage is that it can offer basic function for welding process and lower cost than the adjustable one. Based on visits to a few metal fabrication workshops in Malaysian universities and online review, it is observed that the fixed welding table is popularly deployed. However, one of the ergonomics design issues related to the fixed welding table is its inappropriate height. A suitable table height has long been a discussion among global welders who have been using a fixed type welding table [2]. In the discussion, they are struggling to find out what the absolute table height is that can accommodate every welder. A fixed welding table height burdens the welders in terms of work postures. For instance, when a tall welder works at a low table surface, he has to bend his torso downwards to perform the SMAW process. On the other hand, a short welder needs to raise his shoulder when working at a high table surface. This constraint leads to awkward work posture.

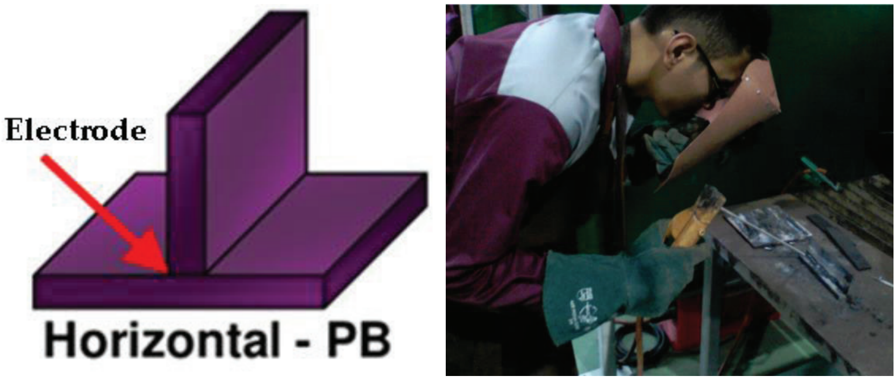
One of the consequences of performing welding process in awkward body postures is work-related musculoskeletal disorders (MSDs) such as back pain. Previous studies have identified back pain as one of the most common work-related musculoskeletal disorders experienced by the welders [3]-[4]. In the past three years, the Social Security Organization (SOCSO) of Malaysia reported 6163 cases of injuries related to the back. In addition to back pain, awkward body postures while performing welding process can cause fatigue, reduce concentration and lead to poor welds [5]. Besides, poor workstation design such as incompatible height between table surface and worker also leads to low efficiency of work [6].

A study is found related to welding workstation table height [7]. The study proposed a table to tabulate a recommended dimension of table height with respect to the welder's height. For example, in standing welding workstation, if the welder's height is 170 cm, the recommended table height is 70 cm. However the dimensions of the table height proposed by the study were developed based on their study population, hence it is not suitable for population from other countries (e.g. Malaysia) as the body size is different across continents [8].

When welders work at a fixed type welding table, they prefer to control the inclination of welding electrode rather than to control the inclination of table surface. However, working at a flat surface welding table is difficult to maintain the inclination of welding electrode when performing horizontal welding (PB) [9], as shown in Figure 1 (a). The welder has to bend the torso or wrist when performing the welding in standing position, as depicted in Figure 1 (b). The ISO 6947 has developed a standard measurement for the weld working position (angle of slope and rotation); however, the measurement is applied to welding electrode angle and not for the welding table surface inclination.

The bead dimensions such as bead height (representing the depth of penetration) and bead width are important to ensure that the weld joint is properly filled and has minimum defects, particularly in multi-pass weldments. On the other hand, inadequate weld bead dimensions will contribute to failure of welded structure. A reputable study shows that, in the past, research on weld bead quality was mainly concerned with welding current, voltage, and speed as parameters to determine the weld quality [10]. In addition to these parameters, a reputable study highlighted that work posture is one of the indirect contributors to the weld quality [11]. Recently, a study proved that the work posture is highly influenced by table surface inclination and table height [12].

Thus far, there has been few quantitative studies on the effect of table height and table surface inclination on weld bead dimension. In recognition of this gap, the aim of this study was to present a conceptual design of SMAW workstation which considered work postures and bead dimensions. The scope of this study was limited to the factors that influence the work posture and bead dimensions such as working positions (standing and sitting), table height, and table surface inclination. An experimental work was performed through a case study at a metal fabrication workshop in a Malaysian public university.



(a) (b)

Figure 1: Horizontal welding position, PB (a) and awkward posture (b)

2.0 METHODOLOGY

This study had three stages as shown in Figure 2. Each stage utilized different research methodologies. Stage 1 was a problem investigation stage, where existing issues were investigated at existing SMAW workstations. In Stage 2, an experimental study was conducted to explore potential solutions and their effect on welders' postures and weld performances. The output from Stage 2 served as the groundwork for Stage 3, which focused on the development of new SMAW workstation design.

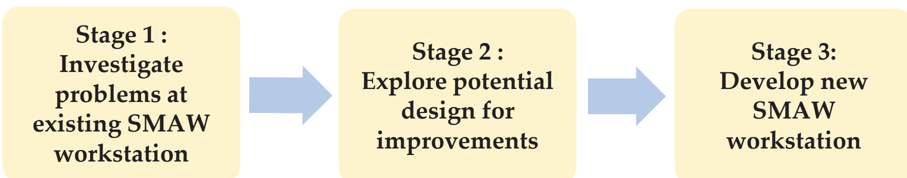


Figure 2: Three different stages applied in this study

2.1 Stage 1: Problem Investigation at existing SMAW workstation

2.1.1 Observation

An observation study was conducted among 40 part time welders to investigate issues at current SMAW workstations. Field notes, pictures and videos were utilized to document the welding process at current workstations. A discussion among team members was then conducted through review of pictures and videos to identify potential ergonomics issues.

2.1.2 Questionnaire Survey

A survey through questionnaires was administered to document issues at the existing SMAW workstations. This study recruited 40 part time welders for the survey sessions. The questionnaire was divided into three sections: A) demographic information, B) discomfort levels, and C) design proposal. The demographic information (section A) asks for responder's age, gender and working experience. The discomfort level section (section B) investigates the specific body parts and the magnitude of discomfort, due to working at current SMAW workstations. The design proposal (Section C) seeks respondents' agreement on certain design requirements of an ideal SMAW workstation such as the surface, height, availability of armrest, working position, tool and materials arrangement at the table, local exhaust fume and workstation clearance.

2.1.3 Work Posture Assessment

Work posture assessment using Rapid Upper Limb Assessment (RULA) was conducted on existing SMAW workstation. RULA, developed by McAtamney & Corlett is a screening assessment tool to investigate the loads on musculoskeletal system of operators due to ergonomics risk factors exposure such as poor postures, muscle work, and force exertion [13]. The assessment was conducted using Computer Aided Design (CAD) software (CATIA V5R20). Few researchers have used this specific method to capture RULA score at workplaces [14-15].

Anthropometry of 5 welders was measured using an anthropometer. The following body dimensions of welders were then captured: stature, axilla, chest height (standing), waist height (standing), crotch height (standing), acromion-radiale length, radiale-stylion length, chest breadth, waist breadth, hip breadth, and elbow height (standing). A manikin was created based on the averages of welders' anthropometric data. Consequently, dimensions of existing SMAW workstations were documented using measuring devices, and reconstructed in 3D CAD drawing. The manikin was positioned similar to actual working condition using posture editor module. The work postures were then assessed using RULA method integrated within CATIA software (Human activity analysis module).

2.2 Stage 2: Exploring the Potential Effect of SMAW Workstation Design

2.2.1 Selection of variables

Through observation, questionnaire survey, and Rapid Upper Limb Assessment activities, a few study variables were screened for further investigation. A pilot study involving two part-time welders was then conducted to select independent and dependent variables. Each subject performed butt joint welding task to see the effects of table height, table surface, lighting, arm rest and working position to welder's posture and weld bead dimension.

2.2.2 Experimental Work

A repeated measure Full Factorial Design of Experiment was selected to be the experimental work method. Five experienced part-time welders were recruited as experimental subjects. The participants were to follow welding safety requirements such as wearing personal protective equipment. Additionally, the participants needed to follow the Standard Operating Procedure (SOP) of the SMAW process to ensure the consistency of the welding process. The welding specimen was mild steel and welding electrodes E6013 with 3.2 mm diameter. Other tools included a Vernier caliper, chipping hammer, wire brush and AC/DC power supply. The welding position of flat fillet weld was chosen because the experiment participants can control the welding puddle easily.

Three independent variables (table height, table surface inclination, and working position) were tested in this experiment. Each independent variable was tested on two levels, table height: 84 cm and 90 cm, table surface inclination: 0° and 15°. The working positions were standing and sitting. Each participant performed 3 repetitions of welding test, and was randomly assigned from the experimental settings. Besides, the dimension of bead height, bead width, and RULA score were selected as dependent variables. The dimension of bead height and bead width is shown in Figure 3. It should be noted that RULA captures loaded on musculoskeletal system due to posture, force and muscle activity. However, force and muscle activity were assumed to be consistent (constant) throughout all experimental set-ups.

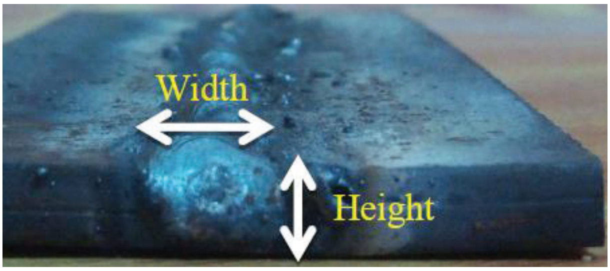


Figure 3: Bead width and bead height

2.3 Stage 3: Development of new SMAW Workstation

2.3.1 Focus Group

The focus group involved assistant engineers, students, and lecturers. Through the focus group, potential solutions to minimize poor work posture at the existing SMAW workstation and collective agreement on workstation redesign specifications can be obtained.

2.3.2 Idea Generation, Screening, and Conceptual Design

Initial new designs were generated based on criteria set during focus group sessions such as adjustable table height, flat table surface, and adjustable fume exhaust. Pugh method was used as a screening tool to compare the alternative designs to a set of determined criteria. A new design of SMAW workstation was proposed, consisting of an adjustable exhaust fume, adjustable table height, side tool and material arrangement, flat table surface and standing working position.

2.3.3 Work Posture Assessment

Work posture assessment was then conducted on the proposed conceptual workstation design, using RULA method integrated within CATIA software (Human activity analysis module). This simulation provided visualizations on how the redesigned SMAW workstation could improve the work posture.

3.0 RESULTS AND DISCUSSION

3.1 Ergonomics Issues at Existing SMAW Workstation

Based on observations at the SMAW workstation, the welders were found to be in awkward posture as they had to bend their body forward and maintained repetitive hand movement during the welding processes.

The questionnaire survey result showed that at least 70 percent of the respondents felt discomfort or extremely discomfort in the lower back, shoulder, as well as wrist and hand. This condition could be due to the fact that SMAW is a continuous process that needs the welders to maintain their raised hand positions while bending forward over an extended period of time.

3.2 Effect of Table Height and Table Surface Inclination

3.2.1 Analysis of Variance (ANOVA)

Table 1 shows the Prob > F values from the ANOVA to determine the strength of interaction of the dependent variables (bead width, bead height and RULA score) and the independent variables (table height, table surface inclination, work position, and combinations). Values of "Prob > F" less than 0.05 indicated that the effect of the independent variables on the dependent variables was significant. Based on Table 1, this study shows that table surface has a significant effect on bead width. The table height, table surface, working position as well as the interaction of table height and work position had significant effects on the bead height. There was no independent variable having significant effect on RULA score. Residual analysis for model adequacy showed no major concerns.

Based on the analysis, this study revealed that table height, table surface and working position are factors that can significantly contribute to bead height. Interestingly, the bead width is highly affected by table surface only. Surprisingly, the parameters studied in the experimental work do not significantly affect the RULA scores. Hence, the levels of the factors studied require further investigations to improve the work posture [13]. Based on the results of RULA scores, SWAW task pose limitation on the ergonomic postural improvement was required. Increased table height, for example, can reduce the bending of body during welding, hence, improving the RULA score. Unfortunately, excessive table height could cause the hand of the welder to be higher than the shoulder level which resulted in awkward hand posture (or worse RULA score).

Table 1: Results of Analysis of Variance (ANOVA)

Dependent variables	Bead width	Bead height	RULA score
Independent variables	Prob > F	Prob > F	Prob > F
Table height (A)	0.3176	0.0272	0.6885
Table surface (B)	0.0014	0.0102	0.6685
Work position (C)	0.2641	0.0002	0.2384
A*B	0.1462	0.4067	0.2384
A*C	0.5408	0.0155	0.6885
B*C	0.2760	0.0689	0.6885
A*B*C	0.1615	0.9653	0.0581

3.2.2 Optimization

The next statistical analysis was to find the optimum setting of SMAW workstation. This was carried out through optimization analysis using Design Expert software. The variables (table height, table surface, work position, bead width, bead height and RULA score) were set at certain goals. For example, minimum bead height and bead width dimensions and RULA score were the target for weld quality and better work posture. In each variable, the importance level was set to 3 (medium), representing an equal importance among them and no goals are favored over others.

Based on the optimization analysis, table height of 90 cm, flat table surface (0°) and standing work position can promote acceptable bead width and height dimensions. However further study is needed to improve the work posture.

3.3 Conceptual Design of SMAW Workstation

Based on the optimization analysis, this study analyzed three conceptual designs of SMAW workstation (concept A, B, C). All workstation concepts required the welder to perform welding process in standing work position. Standing workstation offers flexibility to welders, for instance, they can handle a variety of work materials such as small and big sizes. Besides, standing provides high degree of freedom, and enables welders to move their body easily. Another advantage of standing work position is it allows blood to flow smoothly, hence, making the welders more energetic in performing welding process.

Each workstation comprised a flat table surface and was equipped with an adjustable height feature, a horizontal platform at the right hand side and a flexible fume exhaust. The horizontal platform was used to locate welding tools such as chipping hammer and wire brush. Concept A had a round flexible fume exhaust which was attached to the workstation. Concept B applied a flexible, rectangular shaped fume exhaust. The size of the fume exhaust was similar to the table dimension and it was assembled on the workstation. Both Concept A and B used localized fume exhaust system. On the other hand, concept C had a cone shaped flexible fume exhaust which was hanged on the ceiling. The fume exhaust was connected to a centralized fume exhaust system.

Concept screening matrix was applied to select the best concept. As for benchmarking purposes, the existing SMAW workstation was selected as a reference. The selection criteria were flexible fume exhaust, adjustable table height, flat table surface and side arrangement of tools and materials. Through concept screening matrix, concept C was selected as it fulfiled all the selection criteria. Then, this concept was sketched using CATIA software for postural assessment.

The new concept of SMAW workstation design was featured with adjustable table height. The table height could be adjusted in the range of 84 to 90 cm from the floor, or 20 - 40 cm below the elbow height [16] to enable welders to perform welding process at an appropriate height. This height made the lower and upper arms in the range of neutral posture. Additionally the new workstation is designed with flat table surface (0° inclination). The advantage of having flat table surface is that the metal to weld will be in a firm position, hence, welding process can be performed in a consistent manner. As opposed to inclined surface, the metal tends to move downwards leading to ineffective welding process. Another advantage is that a proper height of flat table surface limits the head down. This can benefit the neck by avoiding sore and tight muscles when performing welding process for a long period of time.

As lillustrated in Figure 4, postural assessment using RULA was conducted to determine the impact of new SMAW workstation concept on the work posture. The RULA score was 3, indicating the new design of SMAW workstation still required further investigation to improve the work posture. This is because welders need to bend their body slightly forward to visualize the welding area and control the welding electrode movement in order to acquire acceptable bead dimensions.

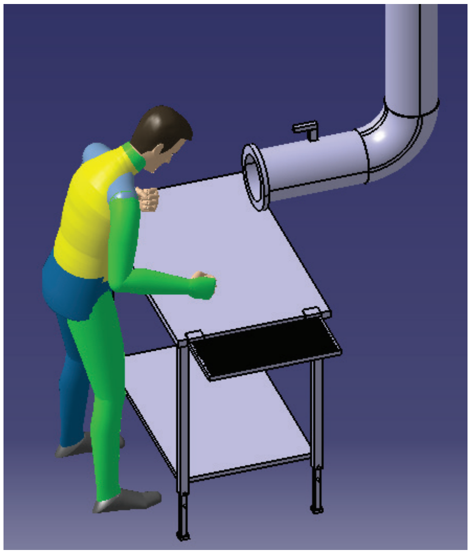


Figure 4: Postural assessment using RULA at new SMAW workstation concept

4.0 CONCLUSION

This study has performed a questionnaire survey among users of SMAW workstation at a metal fabrication workshop in a Malaysian public university. Majority of users felt discomfort or extremely discomfort in the lower back, shoulder, as well as wrist and hand. Through full factorial design of experiment, this study reveals that workstation design variables such as table height, table surface, and work position have a significant influence on bead height. This study generates a conceptual SMAW workstation by considering these variables. This study concludes that SMAW workstation designed with adjustable table height, table surface is flat (0°), and standing work position can offer acceptable bead dimensions. However, the proposed SMAW workstation still requires further study on the work posture. It is suggested that more sensitive measurement tools such as electromyography (EMG) be utilized to objectively quantify the effects of SMAW workstation design such as table height, table surface inclination, and work position on muscle activities.

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