A Study on the Measuring Method of Work Parameters to Evaluate the Skill of FCAW Welding Trainee

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Abstract

On industrial sites, FCAW is mostly performed by welders. In general, welder functional level evaluation is performed based on the appearance and mechanical testing of beads after welding. However, the actual welding quality obtained in the field is determined by the fluctuating characteristics of the working variables, depending on the welder's skill. Therefore, with trainees, a rating system is needed to evaluate proficiency by measuring work parameters. In this study, two welding cameras were used to measure the work parameters of a welder who performed FCAW semi-automatic welding using CO_2 gas. A method of grading the welder's proficiency by analyzing the average and standard deviation of work parameters, taking into account the important factors that affect weld quality, is presented. For Trainee to develop a desire to grow on their own, a method of grading proficiency was proposed using the changing characteristics of the work variables rather than the welding results.

1. Introduction

FCAW is mostly conducted by semi-automatic welding. In Korea, FCAW welders are most active in workshops such as shipyards. The welder's skill is typically evaluated by recording the results of defects, appearance of beads, etc. after welding, it can also be evaluated through mechanical tests. However, the welding quality obtained in the field is determined by the variation characteristics of the work parameters according to the welder's skill. Therefore, a simple and economic evaluation system is necessary to evaluate the skill of welding trainees by measuring the work parameters[1-3]. Moreover, when grading the skill of trainees, it must be evaluated by more rationally measuring the operations of actual welders. By scoring the work parameters' variation characteristics and providing feedback to the trainees, they can develop greater interest and focus on honing their skills. Accordingly, this study seeks to establish a method for measuring the work parameters of FCAW welders, quantify the variation characteristics of the work parameters, and propose a method for grading their welding skill.

2. Experimental method

2.1 Measured Four Work Parameters

The four main work parameters measured in this study are torch height, welding speed, work angle, and travel angle[4-6]. Torch height refers to the contact tip-to-work-piece distance (CTWD). Variations in these work parameters depend on the welder's skill and act as a factor that directly impacts welding quality. These variations in work parameters, the welder's empirical skill, were quantified and applied to the welder's skill evaluation and quality control.

2.2 Specimen and experimental method

The base metal used in this study was a 150 X 100 X 6 mm SM400. Four welders performed BOP welding in the flat position on the FCAW used in welder training. Welders A and B conducted straight welding, while

Table 1 Welding condition of flat position FCAW

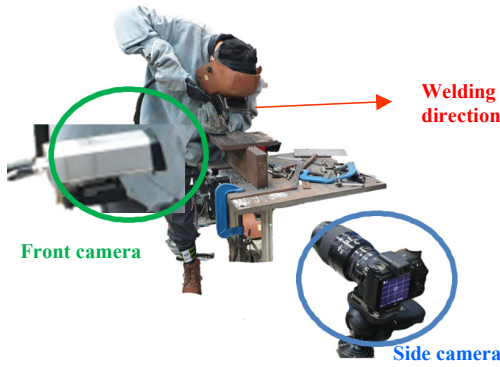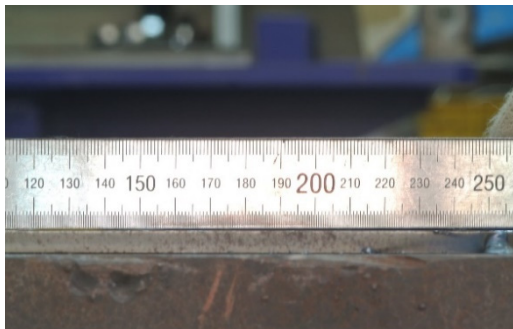| Filler metal	AWS A5.20 E71T-1C 1.2mm
Base metal	SM400 150 X 100 X 6 mm
Current	170~230 A
Voltage	21.6~25.4 V

Fig. 1 Arrangement of welding cameras

Fig. 2 Scale bar on welding plate

welders C and D conducted weaving welding. Table 1 shows the welding conditions used in the experiment.

2.3 Work parameter photography and measurement

Fig. 1 shows the arrangement of the welding cameras used in this experiment. A camera was arranged to photograph the side of the welding process and captured the welding speed, torch height, and travel angle (θ_T). Another camera was arranged to photograph the front of the welding process and captured the work angle (θ_W) and torch height.

Accounting for the distance between the camera and measurement target, just before welding, the side camera photographed a scale bar on a welding plate. Fig. 2 shows the photographed scale bar. To measure the torch height, travel angle (θ_T), and welding speed, still images were acquired at 1-second intervals from the arc starting point of images captured by the side camera.
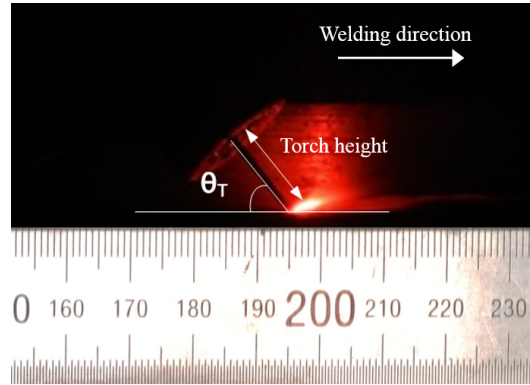

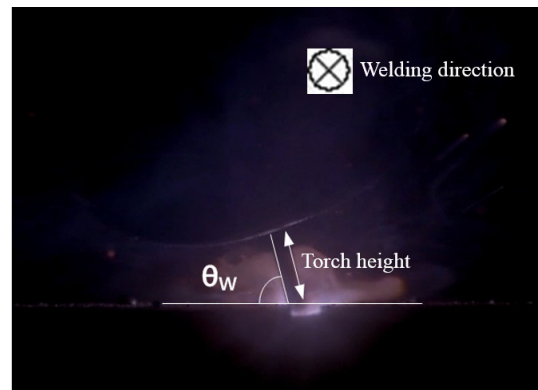**Fig. 3** Measurement by side camera video

Fig. 4 Measurement by front camera video

Accordingly, the still images and scale bar were used to measure the torch height, travel angle (θ_T), and welding speed at 1-second intervals. Fig. 3 shows the measurement of travel angle (θ_T), welding speed, and torch height by the side camera. Fig. 4 shows the measurement of work angle (θ_W) by the front camera. To correct the torch height error, it was calculated considering the work angle (θ_W).

3. Experimental results and discussion

3.1 Measurements of work parameters

Fig. 5 shows the torch height variations when welders A and B performed straight welding. Fig. 6 shows the torch height variations when welders C and D performed weaving welding.

Fig. 7 shows the welding speed variations when welders A and B performed straight welding. Fig. 8 shows the welding speed variations when welders C and D performed weaving welding.

Fig. 9 shows the work angle variations when welders A and B performed straight welding. Fig. 10 shows the work angle variations when welders C and D performed weaving welding.
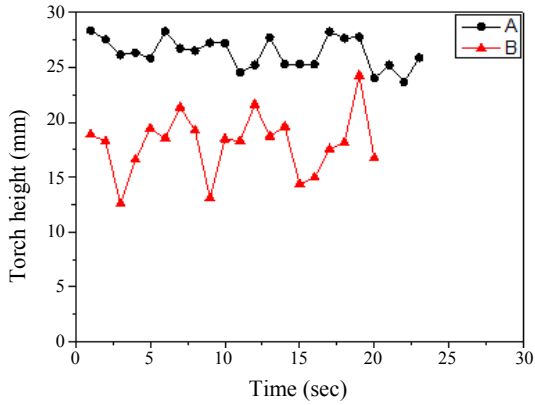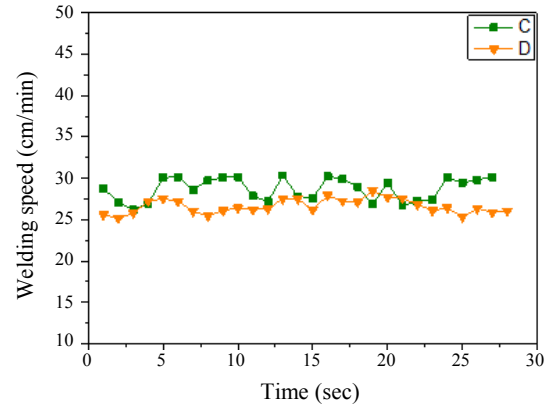
Fig. 5 Torch height variation graph of welder A and B

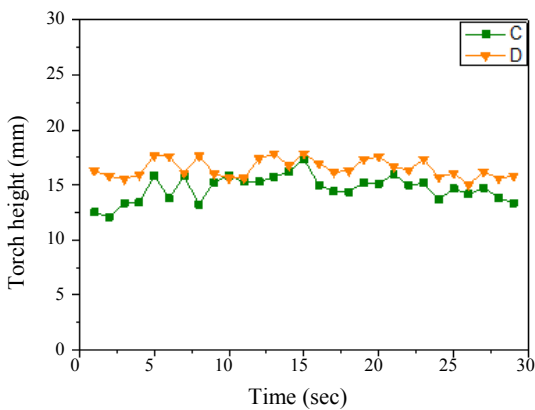**Fig. 8** Welding speed variation graph of welder C and D

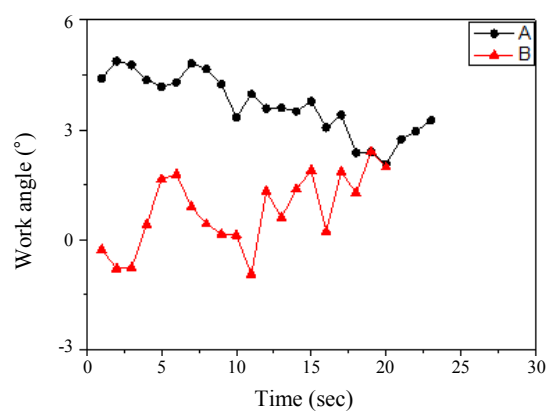**Fig. 6** Torch height variation graph of welder C and D

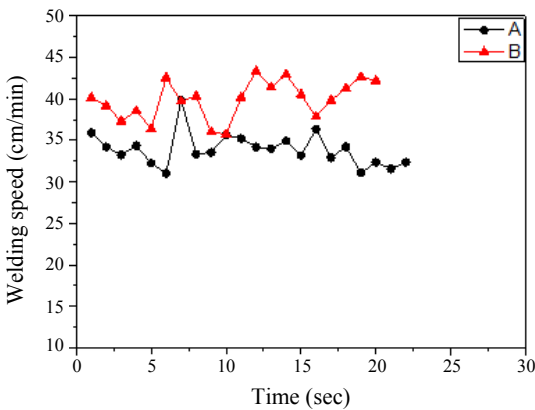**Fig. 9** Work angle variation graph of welder A and B

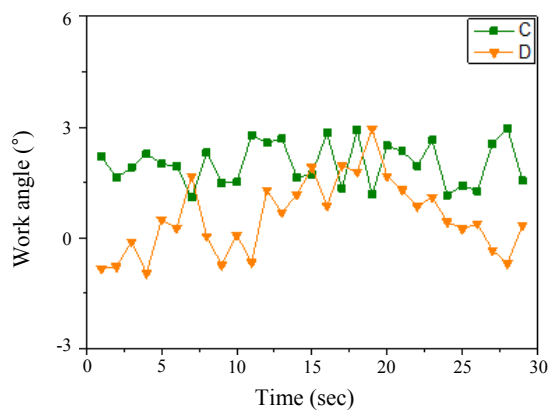**Fig. 7** Welding speed variation graph of welder A and B

Fig. 10 Work angle variation graph of welder C and D

Fig. 11 shows the travel angle variations when welders A and B performed straight welding. Fig. 12 shows the travel angle variations when welders C and D performed weaving welding.

Table 2 presents the mean and standard deviation of the work parameters of welders A to D. To assess whether they were within the normal range of work parameters, the mean values of the work parameters were calculated. Moreover, since variations in the welder's

work parameters impact the welding quality, the standard deviation was calculated to evaluate the variation in work parameters[4].

3.2 Evaluation method of work parameters

To evaluate the skill of welders A-D, scores were assigned considering the mean and standard deviation of the work parameters. Weights were assigned as follows
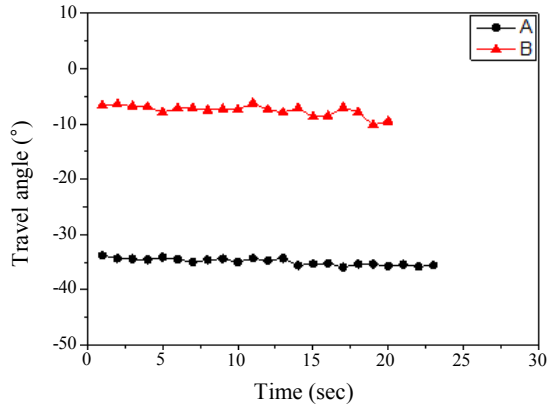
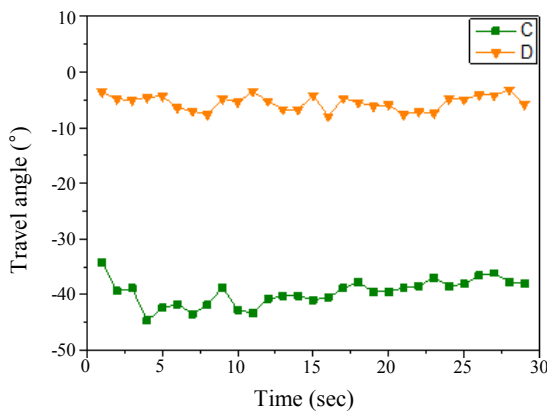**Fig. 11** Travel angle variation graph of welder A and B

Fig. 12 Travel angle variation graph of welder C and D

Table 2 Average and standard of working parameter of welder A~D

Welder	Statistical method	Torch height	Welding speed	Work angle	Travel angle
A	Average	26.35	33.9	3.68	34.92
	Standard Dev.	1.36	1.95	0.81	0.59
B	Average	18.03	39.9	0.78	7.59
	Standard Dev.	2.75	2.28	0.99	0.98
C	Average	26.35	33.9	3.68	34.92
	Standard Dev.	1.36	1.95	0.81	0.59
D	Average	18.03	39.9	0.78	7.59
	Standard Dev.	2.75	2.28	0.99	0.98

considering the importance of the work parameters impacting welding quality. The weight of torch height was assigned 3, welding speed 2, work angle 1, and travel speed 1. For torch height, the score was deducted when the mean deviated from the standard of 15 mm. For welding speed, the score was deducted as the mean decreased, and for weaving welding, a lower level range

Table 3 Score table based on average and standard deviation of working parameters

	Torch height	Welding speed		Work angle	Travel angle	Score
		Straight	Weaving			
Average	Within 15±2	Over 50	Over 30	0±2°	0±6°	5
	Within 15±4	Over 40	Over 25	0±4°	0±12°	4
	Within 15±6	Over 30	Over 20	0±6°	0±18°	3
	Within 15±8	Over 20	Over 15	0±8°	0±24°	2
	Within 15±10	Over 10	Over 10	0±10°	0±30°	1
Standard Dev.	0~1	0~1		0~1	0~1	5
	1~2	1~2		1~2	1~2	4
	2~3	2~3		2~3	2~3	3
	3~4	3~4		3~4	3~4	2
	4~5	4~5		4~5	4~5	1
Weight	3	2		1	1	

Table 4 Classification table by total score

	Total score					
	0~10	11~20	21~30	31~40	41~50	51~60	61~70
Grade	1	2	3	4	5	6	7

than straight welding was applied. For work angle and travel angle, the score was deducted when the mean deviated from the standard of 0°. The greater the standard deviation of the work parameter, the more the score was deducted. The mean and standard deviation were reflected in the evaluation scores with equal weight. Table 3 shows the score distribution for the mean and standard deviation. Table 4 is a classification table according to the total evaluation scores.

3.3 Work parameter evaluation results of welders A-D

Table 5 shows the evaluation scores for the work parameters of welders A-D. Welder 7 showed the highest score at 67, and was thus assigned Grade 7. Welders B and C scored 52 and 55 points, respectively and both were assigned Grade 6. Welder A was assigned Grade 4 with 40 points. The welders who participated in this evaluation were highly skilled in the field and thus obtained high grades. However, when beginner trainees receive a low grade, their individual welding operations

Table 5 Score and grade of welder A ~ D

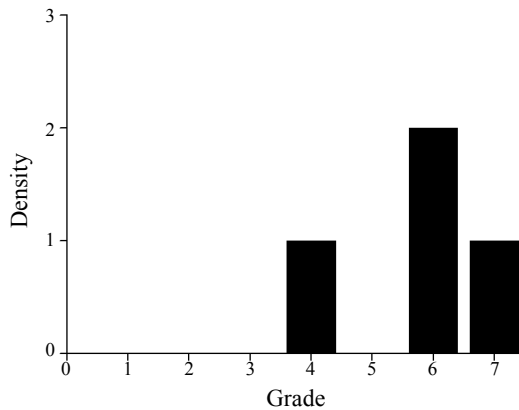| Welder	Average score	Standard Dev. Score	Total score	Grade
A	10	30	40	4
B	27	25	52	6
C	27	28	55	6
D	33	34	67	7

Fig. 13 Distribution of welder's grade in the form of probability density function

are quantitatively analyzed and the welder's skill is evaluated, thereby serving as individual feedback. Therefore, this system enables high-efficiency training and the trainee's psychology growth, inducing them to easily concentrate.

Fig. 13 is a graph of the four welders' grades expressed in the form of probability density functions. As the welders were all highly skilled, they are distributed among the higher grades. Meanwhile, beginners will be distributed among the lower grades, and the distribution characteristics will differ widely according to the learning group. Since these distribution characteristics can be used to easily evaluate the level of a group or corporate organization, they can also be easily applied to welding contracts.

4. Conclusions

To evaluate the functional levels of FCAW welders using work processes rather than welding results, the variation characteristics of four main work parameters (welding speed, torch height, work angle, and travel angle) were recorded in videos, measured, and analyzed, and the following conclusions were drawn.

1) This study proposed a method of measuring four main work parameters at 1-second intervals by taking videos of welders directly using an arc front camera, side camera, and scale.

2) When the welders' skill were evaluated considering the welding parameter's importance in quality: the weight of torch height was assigned 3, welding speed 2, work angle 1, and travel angle 1.

3) A system was presented in which the mean and standard deviation of the four work parameters are evaluated, scored with equal weight, and then provided to the trainees as feedback, though which they can hone their own skills.

4) A method was proposed for statistically evaluating the skill of a group or corporate organization by grading the welders' skill from 1 to 7, based on evaluation of the variation characteristics of the work parameters.

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