学術論文

MONITORING AND ANALYSIS OF THE BEHAVIOR OF WELDERS DURING MANUAL WELDING

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Welding is an essential industrial process in the fabrication of a variety of products and also in maintenance activities. Although most welding processes have already been automated, the high reliability of the manual welding fabrication is still in demand. In this paper the necessity of the in-process monitoring of the performance of manual welders is addressed in order to assess the skill of a manual welder in the workshop environment. The behavior of welders with different skill levels was monitored during manual welding fabrication operations. The analysis confirmed that the parameters such as movement of the welding torch and the viewing point of the welders appropriately reflected the welder's skill level.

KeyWords : Maintenance, Training, Skill Transfer, Behavior, Monitoring

1. INTRODUCTION

Welding is an essential process in the fabrication of a variety of products in industry and also in maintenance activities. Most of the welding work in industry, such as in automobile production, has been already fully or semi-automated. Nevertheless, in the case of heavy industry, the proportion of automation is lower than in other industries, as the variety of products and joint positions are not necessarily accessible by automated welding machines. Thus it is sometimes difficult to improve efficiency through automation. Therefore the high reliability of manual welding fabrication is still in demand.

As a key observation, in manual welding the quality of welding is critically dependent on the skill and experience of the operative. The number of skilled welders is decreasing (especially in Japan)[1], because it is costly and time consuming to train operators to a level required for certification by national authorities. Today, the transfer of welding skills from experts has become a serious problem[2]. In addition, the workplace of a welder is perceived to be dangerous and welding itself

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is regarded as physically demanding work.

Although it is important in future to develop automated welding systems for the optimization of personnel involvement, the essential necessity for the development of a welder support system requires investigation. Kutsuna[3]has reviewed state of the art of computer aided welding systems. The functions of these systems are summarized as follows: storage of information, interpretation of standards, calculations, nesting systems, advisory systems, off-line programming [4][5]. These are merely education and training programs not for the acquisition of practical welding skills, but for the appreciation of good welding practices from a theoretical point of view, based on the guidelines of qualification programs identified by international welding engineers [6]. Mastering the practical skills and skills transfer of manual welding techniques are still highly dependent on job training through actual work experience. As a result, the human welder's work efficiency and training or skill development needs to be improved. In order to fulfill such a requirement, it is necessary to monitor and analyze in greater detail the behavior of the welder during the task.

In this paper, the basic concept of a monitoring and training support system for manual welding is described. In order to clarify welding skills, the behavior of welders at different skill levels has been monitored and analyzed during a practical welding fabrication experiment. Various parameters such as the viewpoint of welders and the characteristic movement of welding torch have been extracted, based on the images around molten weld pools acquired by a compact infrared CCD camera (IR-CCD camera) attached to the welding torch. The behavior of welders during welding has thus been investigated in some detail.

2. THE CONCEPT OF A MANUAL WELDING SUPPORT / TRAINING SYSTEM

It must be recognized that the operation of an automatic welding machine and a manual welding task are quite different from the point of view of the welder[3]. While automatic welding is remarkable for its high efficiency and reproducible quality, manual welding is highly adaptable to a variety of welding conditions.

Through the detailed analysis of such a manual welder's behavior, the final purpose of this research is focused on utilizing the acquired information for the quality assurance of the welded products. In the case of automatic welding, the reproducibility of weld quality is dependent on the welding being performed under certain fixed conditions. The machine "operator" has only to operate the welding machine properly in order to perform satisfactory welding. On the contrary, for specific types of welding, only welders whose skill has been certified by an authorizing organization are allowed to weld manually. However, the welder's behavior such as the weaving of the welding torch, the feed position of the welding rod and physical positioning are not unique, relying on the individual's personality or habit. Consequently, direct interpretation of the results is fairly difficult and normalization of the measured process is necessary even when sensors are properly employed.

Another perspective of the research is to address the improvement of the provision of information to assist welders. In ordinary manual welding, the monitoring of the welding conditions and control of torch and wire are performed by a human welder simultaneously. In automatic welding, as the machine is equipped with various sensors and the welding condition is monitored continuously, it is easy to confirm the quality both during and after manufacture. Similar information acquisition is particularly helpful for the quality assurance of manual welding. Such acquired data can also be utilized for the training and education of welders.

Additionally, tools and protective masks equipped with monitoring devices have to be designed in an appropriate fashion. For the monitoring of the behavior of a welder in a manual welding process, it should be clearly recognized that the measuring devices can obstruct the work. In other words, it should be taken into consideration that, during observation of the characteristics of manual welding the work itself must be fully accomplished by a skilled "human" without undue intervention. Of course it is possible to utilize the sensing system and sensors which were originally developed for automatic welding. While it is relatively easy to equip a welding robot or welding machine with various sensors, the addition of instruments might change the human working environment drastically and may affect the quality of the product because such alteration of the workplace may cause an unpredictable workload on a welder. To minimize these influences in a practical workshop the sensors have to be small and sufficiently light in weight to be installed or attached to the welding torch and protection devices.

The manual welding support/training system based on such concepts can be summarized as shown in Figure 1. In the present study, the validity of the "Welder's Condition Monitoring" and the "Welder's Action Monitoring" in Figure 1 have been evaluated experimentally. In the following sections the monitoring experiment, based on such strategy, is described.

3. EXPERIMENTS

3-1) Experimental Setups and Devices

In order to investigate the availability of sensing devices for the analysis of welder's behavior, an experiment was performed, the welding on the flat, joining two flat steel plates with single V groove on a stage. TIG welding (tungsten inert gas arc welding) was selected because in this process it is necessary for welder to control the welding rod and the welding torch simultaneously and therefore quite high level of welding skill is required.

Various sensors can be attached to the torch and protection devices. For example, welding torch was equipped with an infrared CCD camera (IR-CCD camera)[7], fixed to monitor the molten pool image without obstructing welder's view. The appearance of the welding torch with IR-CCD camera is shown in Figure 2. An example of the acquired image around the molten pool is shown Figure 3.

Viewpoint of the worker during the task is one of the most important parameters in completing such skilled work[8]. For the analysis of the viewpoint of welders during the work, measurements were performed

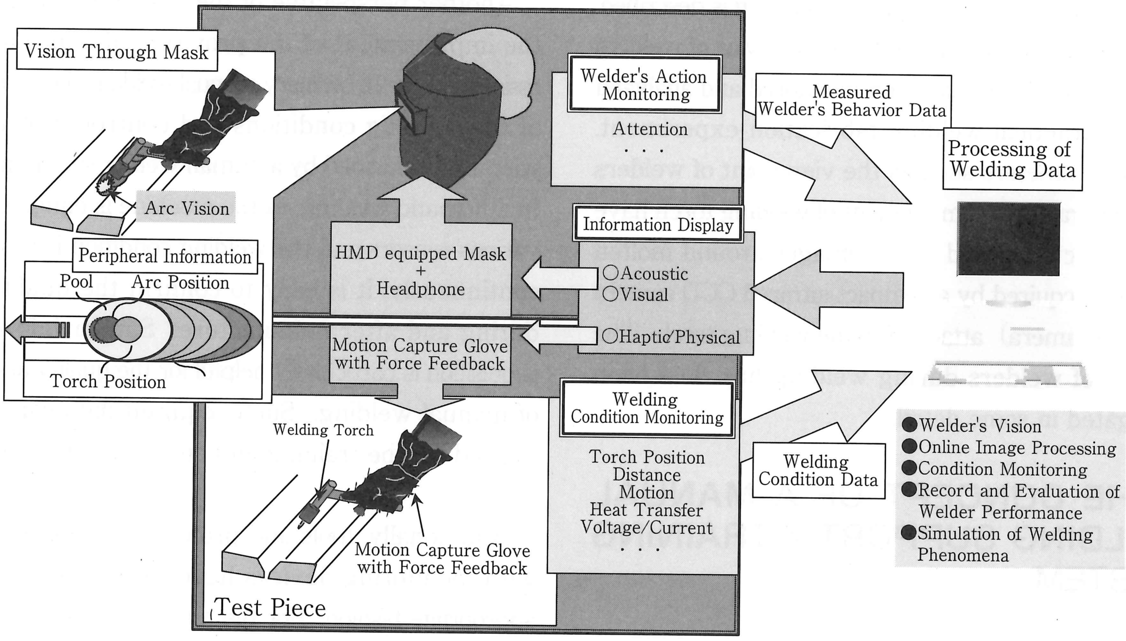

Fig. 1 Concept of manual welding support/training System

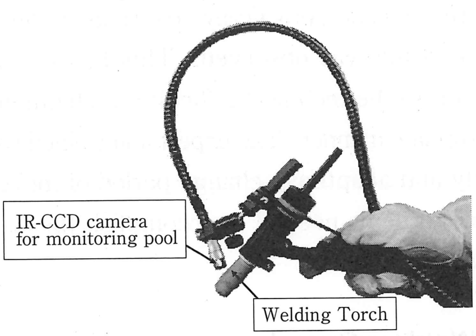

Fig. 2 Appearance of the welding torch with IR-CCD camera

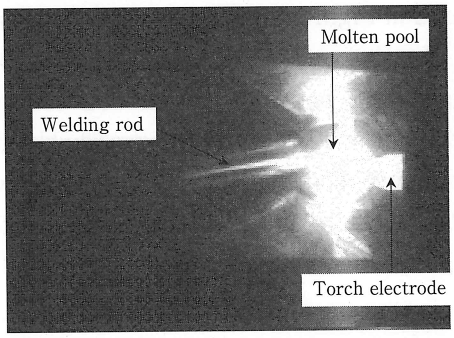

Fig. 3 Molten pool image acquired with the IR-CCD camera

offline because of the difficulty in equipping the face shield with the viewpoint-tracking device. After the welding experiment, the picture around the molten pool taken with the IR-CCD camera is displayed on a CRT and the viewpoint of welder on the display is measured with portable eye-mark recorder.

Three welders with different skill levels participated in the experiment (expert, trained and beginner). The monitored task was the welding of a first layer on a single V groove in a flat position. This welding position is the most basic one and it is difficult sometimes to distinguish the difference in skill level, especially between expert and trained welders. Only the welding of the first and second layers were monitored, although the actual welding fabrication is made using multi-layers, because the first layer weld is the most difficult part of the operation to successfully join material. The gap width between two plates was selected as the key parameter to control the difficulty of the welding work and other parameters were fixed. Three welders performed the welding task one time for each condition and the time duration required to complete the welding task for three welders is summarized in the Table 1. The stable parts (ten seconds) out of whole duration have been chosen for analysis.

Table 1 The time duration required to complete the welding task

	First Layer		Second Layer
Gap width	Standard (3.5mm)	Wide (4.5mm)	Standard (3.5mm)
Expert	120	165	50
Trained	160	180	105
Beginner	140	210	75

(sec)

Three parameters were estimated from the video images recorded during the welding work: i.e., torch angle, weaving movement (=displacement to the center of the V-cut centerline) and welding speed. It is possible to change a variety of parameters relating to the welding in order to control the difficulty of the work.

3-2) Weaving Movement

In order to change the difficulty of welding, base materials were prepared with standard conditions (the gap width of 3.5mm) and wider conditions (the gap width of 4.5mm).

The weaving movement of the torch, (the movement at right angles to the welding direction) was extracted from the pictures taken with the CCD camera attached to the torch. The result for the standard condition is shown in Figure 4 and Figure 5 is for the wider (more difficult) condition. For expert and trained welders, the amplitude of the weaving is different, but the movements are periodic and quite stable. In fact it is difficult to analyze the difference between the expert welder and the trained welder from just this result, as the welding of single V groove in the flat position is relatively easy and the difference in skill will not be apparent. In the case of the beginner, the amplitude of the weaving was unstable, and the welding condition would be correspondingly unstable.

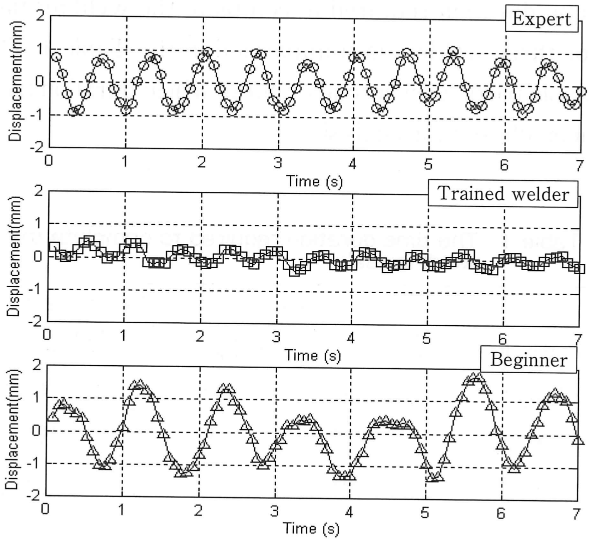

Fig. 4 Comparison of weaving behavior among three welders-standard condition

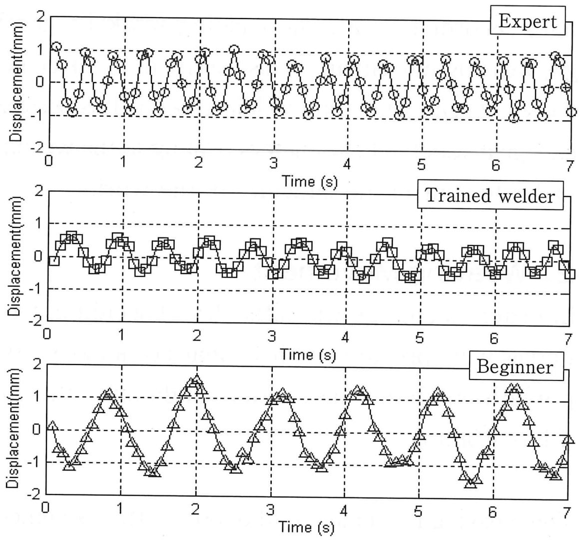

Fig. 5 Comparison of weaving behavior among three welders-wider gap

In case of the wider gap condition, in contrast with the behavior in standard condition, the expert and trained welder display different responses. The expert welder shortened the period of the weaving movement, while the trained welder changed the amplitude of weaving, keeping the period constant. In contrast with these two welders' behavior, the beginner did not display any difference and he might be ignorant of any need to change the conditions.

All welders move their torches periodically. In the case of the beginner, practically no change in the period and amplitude was observed. This feature can be attributed to the technical difficulty in changing it in an appropriate manner. The expert and trained welders properly and adaptively change period of movement and amplitude as needed to accomplish the welding successfully.

3-3) Welding Speed

The welding speeds were also extracted and are compared in Figure 6. The vertical bar indicates the extent of variation of the welding speed. The average welding speed is not very different between the three welders, but the fluctuations are remarkably different. The beginner's speed is unstable compared with the other two welders and it can be confirmed that the welding condition was unstable.

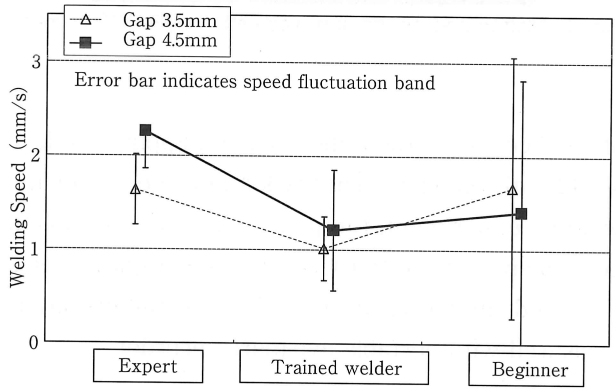

Fig. 6 Comparison of welding speed fluctuation among three welders

3-4) Viewpoint of Welders

Prior to the analysis, the molten pool image area was divided into 9 segments. The segments are numbered as shown in Figure 7. In the analysis of the viewpoints of the welders, the number of frames in which each welder focused their viewpoint on each segment is counted.

The result for the first layer welding is summarized in Figure 8. The beginner stares mainly at the center of the molten pool (segment(5)) and seems to be ignorant of welding rod insertion point or edge of the pool. Trained welder focuses his viewpoint around the Far side edge of the pool (segment(1) to (3)), the center of pool and rod-inserted segments. In case of expert welder, his attention is mainly focused on the rod-inserted segment (segment(6)) of the pool. It is possible to recognize that the expert and trained welder pay attention to the preservation of the molten pool but the observed viewpoint is slightly different. i.e., the expert mainly cares about the melting of the welding rod and the formation of the pool, the trained welder focuses on the wetting of base material around the molten pool in the welding of first layer.

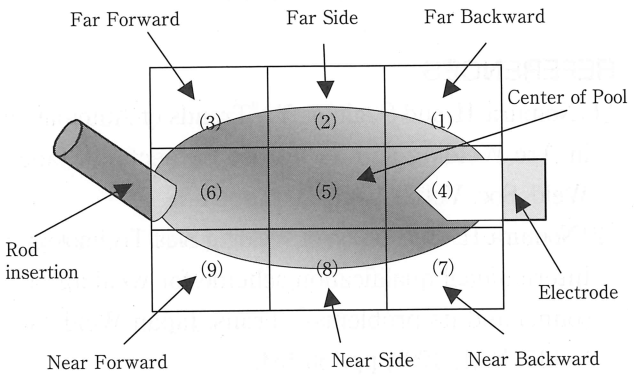

Fig. 7 Segmentation of the molten pool image for welders' viewpoint analysis

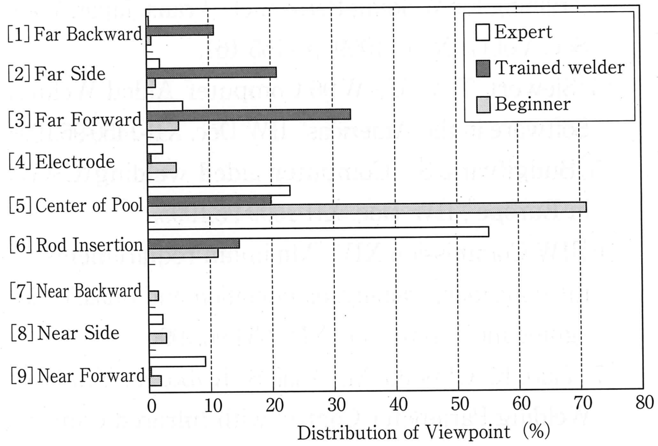

Fig. 8 Viewpoint distribution of three welders for first layer welding

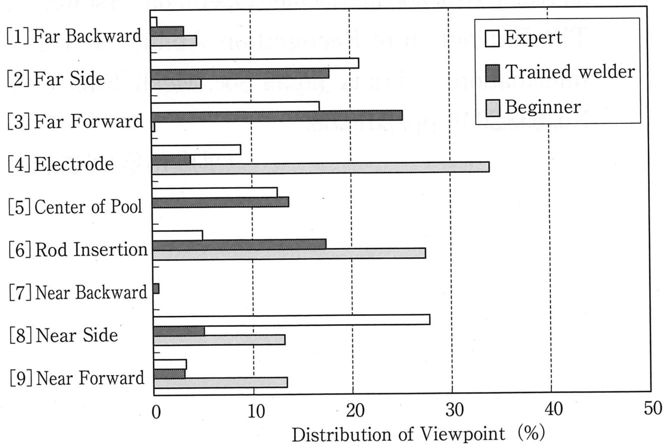

Fig. 9 Viewpoint distribution of three welders for second layer welding

Next similar analyses were applied to the viewpoint measurement for the welding of the second layer. The result is shown in Figure 9. In this case the base materials are already joined by the first layer welding and there is no need to be concerned with the penetration. In case of the Expert welder, the distribution of the viewpoint is quite different from that for the first layer. The expert mainly focuses on both side edges of the molten pool (segment(2) and (8)). This illustrates that the expert recognizes the difference in the layer and the shift of the viewpoint is quite rational. By contrast, the viewpoint distribution for trained welder does not indicate any obvious difference. The welder observes all around the pool equally. In case of beginner, the viewpoint concentrates on the electrode and the rod (segment(4) and (6)) where the other two welders mainly focus attention in the first layer welding.

3-5) Variation of Arc Voltage

The variation of the Arc Voltage, monitored at the Power supply, is shown in Figure 10. The variation of arc voltage corresponds to the stability of the gap width between the torch and the pool. The beginner's voltage instability also indicates that his welding condition is not stable.

In summary, the Expert welder properly adjusted welding speed and weaving period appropriate to the gap width. The Trained welder did not change the torch angle to the joint periodically but adjusted torch weaving amplitude and welding speed. The Beginner failed to adjust his welding behavior because he was unable to distinguish the difference in the difficulty of the welding. The weaving period was unstable and the weaving amplitude was relatively high.

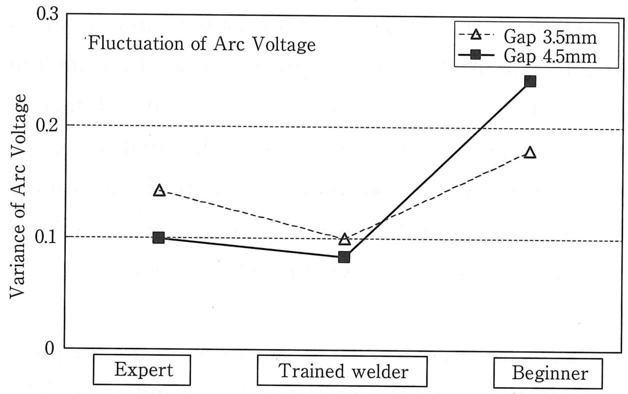

Fig. 10 Comparison of welding voltage fluctuation among three welders

4. CONCLUSION

In this paper the basic concept of a support /training system for manual welding is described, aiming at attaining higher reproducability of quality in manual welding performed by a skilled welder. Based on the concept, manual welding processes performed by several welders at different skill levels were examined. It was confirmed that the parameters such as appropriate movement of the welding torch reflected the difference in welders' skill level in the welder behavior monitoring experiment, using instruments devised for the purpose.

As shown in this paper, it was also illustrated that the methodology of monitoring welder's behavior and welding conditions, based on the images acquired with an infrared CCD camera attached to the welding torch, is applicable even under practical welding conditions in the workshop. As the number of subject is limited in the present study, the results should be interpreted that the proposed monitoring framework can provide indicators which distinguish the large differences in the skill level. In order to enhance the applicability of the proposed framework, further experiments with larger number of welders' participation are definitely necessary. As the continuing work, the welding behavior analysis for more difficult situations and the application to the welding training system are underway.

Although the further elaboration in the monitoring strategy is required, the authors believe that this monitoring methodology can form the basis for a system of welding performance monitoring and skills transfer, which is quite important to realize the higher reliability in maintenance activities.

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