Exploration on the Application of Numerical Simulation and Virtual Reality Technology in Welding Training Teaching

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Abstract—In view of some common problems existing in the current welding training teaching, in order to better improve the welding training effect, this paper explores how to apply the numerical simulation method and virtual reality technology into the welding teaching to achieve such objectives as saving the welding training cost, improving the scientificity of the selection of welding process parameters, deepening the students' understanding and cognition of the welding process, and improving the students' learning interest and training enthusiasm. Then a training process is put forward that combines a theoretical teaching method assisted by numerical simulation method, a virtual welding training method based on virtual reality technology and a more targeted welding practice training method. By this way, a better improvement students' learning interest and a better welding training effect can be obtain. Teaching according to this process can better improve students' learning interest and welding training effect.

Keywords- welding training; numerical simulation method; virtual reality technology; welding process parameters

1 INTRODUCTION

Mechanical manufacturing engineering training, which is also called metalworking practice or metalworking process practice, is an important experimental course and practical teaching for engineering majors in colleges and higher vocational colleges [1]. And the metalworking practice courses offered by most schools mainly include the training links of turning, fitter, welding, casting, etc [2]. Among them, the welding training course is one of the most important course, which is also a course with higher requirements for practical ability and greater difficulty in becoming qualified. On the one hand, welding processing is widely used in the processing of steel structures, covering many industries such as aerospace, ships, automobiles, bridges, and buildings, and its welding quality directly affects the safety of products and is closely related to the national economy and the people's livelihood. On the other hand, due to

many invisible and intangible metallurgical and chemical reactions occurring in the welding process, moreover, the selection and adjustment of some welding process parameters depend heavily on operating experience, which makes it more difficult for students to correctly master and skillfully use welding skills than other machining methods. This has also led to many students' lack of interest and willingness to work hard in the process of learning and training welding skills, which has led to a low rate of talent growth in welding courses or majors, and the lack of high-quality welding skilled personnel in society. In the process of welding teaching and training, there are also many problems, such as high training cost, insufficient input of training equipment and consumables, and lack of scientific, standardized and systematic teaching methods [3].

Focusing on the above issues, this paper starts with the scientific teaching methods and effective promotion of students' interest in learning, and explores how to add numerical simulation methods and virtual reality technology to welding teaching. And in order to make the exploration work more specific, in combination with the project teaching method commonly used in the engineering training course [4], this paper discusses the exploration and implementation process by taking the typical training project in the welding skills training - low carbon steel plate V-groove welding by SMAW as an example.

2 APPLICATION OF NUMERICAL SIMULATION TECHNOLOGY IN WELDING THEORITICAL TEACHING

There are two main purposes for adopting numerical simulation method. One is to reproduce the welding process through simulation, so that students can perceive the phenomenon that is difficult to observe in the actual welding process [5]. The other is to enable students to deepen their understanding of welding parameters, and at the same time help students to determine process parameters more accurately, so as to avoid such problems as the heavy workload, low scientific level and difficult to ensure welding quality caused by completely relying on experience to select process parameters in production [6].

2.1 Determination of simulation scheme

The two most intuitive indicators for evaluating welding effect are welding efficiency and welding quality, both of which are closely related to welding process parameters. Welding process parameters include welding current, welding voltage, electrode diameter, welding speed and welding layers, among which welding speed is the most difficult one to select. This is because that unlike other process parameters, which can be selected by querying specifications and manuals, welding speed can be determined only by experience in usual, which is very difficult for the students as beginners. Through analysis, the temperature of molten pool is an important bridge between welding process parameters and actual welding effect (i.e. productivity and quality). A too high or too low temperature of the molten pool is not allowed. The former is easy to cause burn through, severe splash, too large heat affected zone and other problems, which will affect the mechanical properties of the welded joint. And the latter indicates insufficient energy input and low productivity, which will also cause slag inclusion, lack of fusion and other defects [7]. The temperature of the molten pool is

determined by the process parameters. Qualitatively, the temperature of the molten pool is related to the linear energy, but the difficulty at present is that there is no definite relationship expression or relationship curve between them. In order to determine the quantitative relationship between the two, the orthogonal experimental design method is used for welding simulation in this paper, and the welding current range is selected as from 150A to 220A. Then as the values of voltage and efficiency are relatively fixed, the range of input power is determined. According to the data obtained from operating experience, the welding speed range is from 1mm/s to 8mm/s. Taking welding current and welding speed as two design variables, and taking uniform values within each range of values, a 2-factor, 8-level orthogonal test table can be constructed, and 64 groups of design variables can be combined. Taking each group of parameters as input variables, the welding simulation is carried out by using the finite element simulation software SYSWELD to obtain the temperature of the molten pool, so as to fit the relationship between the temperature of the molten pool and the welding current and the welding speed.

2.2 Establishment of finite element model

According to the size of the workpiece and groove shape in the actual course, which are 200mm x 100mm x 10mm and V-shape groove respectively, the three-dimensional model of plate butt welding is established in SYSWELD software, and the grid is divided. The finite element model is shown in Fig. 1. Set the current, voltage and efficiency of the input heat source, add it into the model, and set its moving speed. The moving direction of the heat source is shown in Fig. 2.
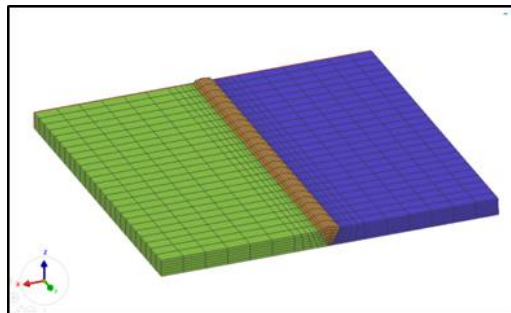

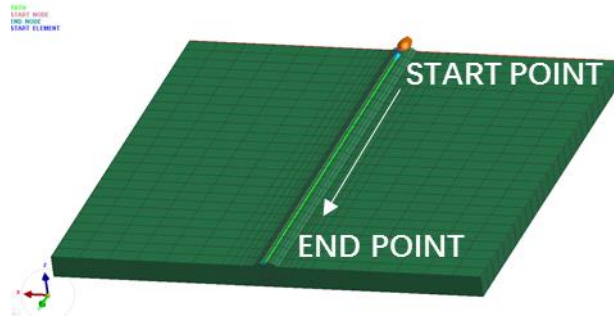**Figure 1.**   Finite element model of flat butt welding

Figure 2. Welding heat source and its moving direction

64 groups of temperature field simulation results can be obtained by simulating each model with welding process parameters. As shown in Fig. 3, it is the simulation result of the 1st group, whose welding current is 150A and welding speed is 1mm/s. According to the properties of welding materials, the temperature field is divided into fusion zone, overheating zone, normalizing zone, incomplete recrystallization zone and recrystallization zone from high to low in Fig. 3 [8].
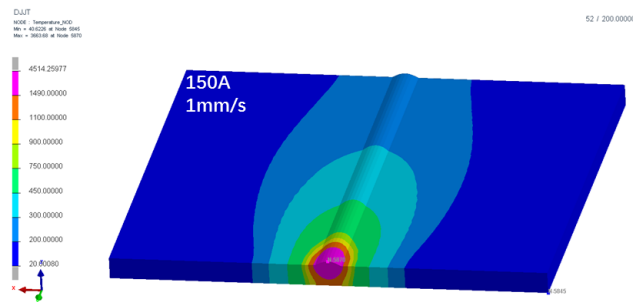

Figure 3. An example of the temperature field simulation results

2.3 Data processing and result analysis

The melting point of the base metal is 1490℃, so the area where the temperature is higher than the melting point in the temperature field diagram is the molten pool area, that is, the most central area of the molten pool in Figure 3, where the center point has the highest temperature and the temperature away from the center gradually decreases. Therefore, it is determined that a node in the molten pool area is the average temperature of the molten pool, and 64 groups of corresponding tables of molten pool temperature, welding speed and welding current are obtained, as shown in Table I.

The relationship function can be fitted as follows

$$T = f(I, v) \qquad (1)$$

In (1), T is the temperature of the molten pool, I is the welding current, and v is the welding speed, their units are °C, A and mm/s respectively. Using MATLAB software to fit the data in three dimensions, the relationship function can be obtained as shown in (2).

$$T=973.8+13.88I-254.8v-0.01492I^2-0.1128Iv+12.06v^2 \quad (2)$$

TABLE I. THE TEMPERATURE OF MOLTEN POOL OF EACH GROUP(UNIT: °C)

Speed (mm/s) / Current(A)	1	2	3	4	5	6	7	8
150	1986	1769	1619	1450	1331	1227	1137	1061
160	2061	1839	1692	1522	1387	1295	1205	1124
170	2131	1904	1761	1590	1473	1359	1268	1187
180	2195	1979	1827	1656	1541	1422	1329	1247
190	2256	2051	1890	1719	1607	1482	1388	1305
200	2313	2120	1950	1779	1669	1542	1445	1361
210	2366	2186	2007	1836	1730	1600	1501	1414
220	2417	2248	2061	1893	1789	1656	1556	1467

The error analysis shows that the error between the temperature value of the molten pool calculated by equation (2) and by numerical simulation is -0.90%~0.95%, indicating that the fitting relationship function can accurately reflect the simulation results.

2.4 The application in welding teaching

The numerical simulation method is mainly applied to the theoretical teaching of welding in the following three aspects:

1) A clearer understanding of the welding process

The essence of fusion welding is to move the heat source to melt the base metal and filler material along the weld, so as to form the weld to achieve the purpose of welding. By watching the animation of the simulation process, the welding process can be understood more clearly by students. The students can also have a deeper understanding of the shape of the heat source, the molten pool and the heat affected zone, as shown in Fig. 4, which shows the shape of the molten pool and the effect range of its heat during the movement of the heat source, and Fig. 5 shows the location and temperature distribution of the heat-affected zone seen from the profile of the workpiece.
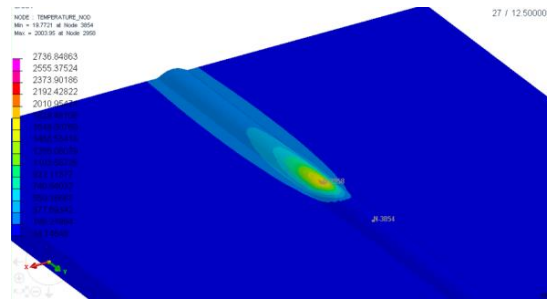
Figure 4.   The shape and effect range of the molten pool
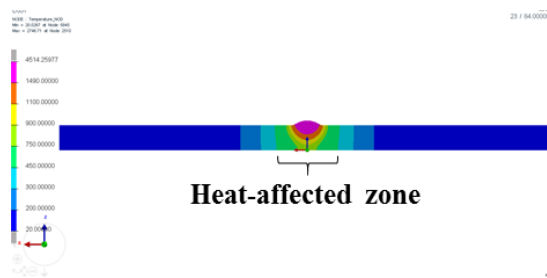

Figure 5.   The temperature distribution of the heat-affected zone

2) A deeper understanding of welding process parameters

Select several typical groups from 64 groups of calculation results and compare them with each other, it can be seen that the state of the molten pool and the width of the heat-affected zone will change with the change of welding speed and welding current. The shapes of the weld pool and heat-affected zone under different welding currents and speeds are shown in Fig. 6. Through comparative observation, the influence of welding process parameters on the welding effect can be seen, so that students can learn to qualitatively analyze the influence of welding speed and welding current on the weld pool volume, temperature and heat-affected zone width, so as to deepen their perceptual knowledge and understanding of functional process parameters.
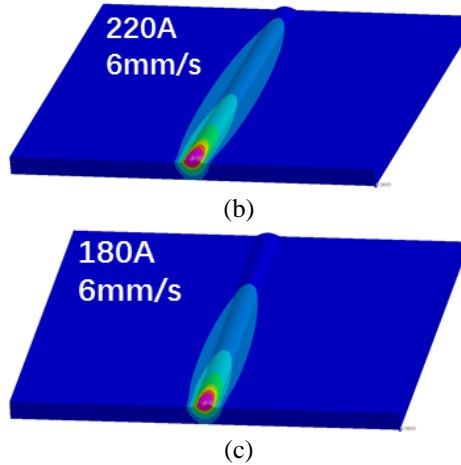

(a)

(b)

(c)
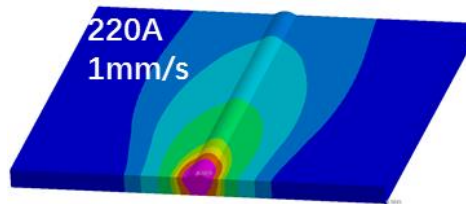
Figure 6.   Morphology of weld pool and heat-affected zone under different welding process parameters

3) Reference for selection of welding process parameters

How to select the speed is always a difficult point in the selection of welding process parameters. In actual production, the experienced welders usually evaluate whether the speed is too fast or too slow by observing the state of molten pool. But for the students, they often prefer to obtain specific values, so as to be more operable. It is pointed out in reference[9] that in the process of welding carbon steel by SMAW, the appropriate value range is 1770~1890℃. According to (2), if the welding current is determined, the specific value of welding speed can be determined. Based on this idea, the curve between molten pool temperature T and welding speed v" is fitted when the welding current is 150A, 160A, 170A and 180A, as shown in Fig. 7.
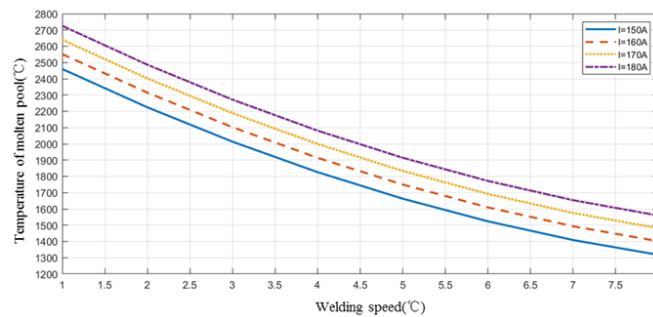

Figure 7.   Relationship curve between molten pool temperature and welding speed

The welding speed can be accurately determined by a cluster of curves in Fig. 7. For example, when welding the backing layer, low current and low molten pool temperature are required to avoid burning through the root and affecting the welding of subsequent layers. The current is set as 150A, and the molten pool temperature is expected to reach about 1800 ℃, so the welding speed can be 4.2mm/s.For another example, when welding the filler layer, a higher

current is required, and the temperature of the molten pool is also expected to be as high as possible to ensure full fusion, respectively set at 170A and 1890 °C. In this case, the speed value needs to be 4.5 mm/s.

3 A VIRTUAL TRAINING COURSE ASSISTED BY VR TECHNOLOGY

Selecting suitable welding process parameters is the preparation work before welding, and is one of the necessary conditions to achieve ideal welding effect. After theoretical study and process parameter selection, students will start the welding training, which is the most important part of welding learning. In the practical training link, the students should apply the theoretical knowledge and technical essentials learned in the theoretical course into practice, and improve the welding skills through repeated welding practical exercises to reach a certain level. In this process, due to the special environment of the welding training site, high training cost, the difficulty for teachers to observe and guide in detail in the whole process due to factors such as fierce arc light, and the difficulty in quantifying the key parameters in the technical essentials, such as welding voltage (i.e. arc length), welding speed, electrode angle, etc., the training efficiency is low and the training effect is poor. Virtual reality (VR) technology, which has emerged in recent years, has built an effective bridge between theoretical teaching and practical teaching. Virtual reality technology uses computers to build a highly simulated 3D virtual simulation environment. After wearing VR devices, users can interact with the scene through body movements in the virtual environment to obtain an immersive experience. As a modern information technology means, virtual reality technology has been concerned and recognized by colleges and training institutions, and has been applied in teaching. It effectively promotes students' understanding of knowledge and improves students' interest in learning.

3.1 Selection of welding methods and training items

The virtual welding equipment developed by relevant professional companies and applied to teaching can usually simulate the operation of SMAW, MAG, TIG and other common welding processes, and provides welding training for various materials, including low-carbon steel, alloy steel, stainless steel, aluminum alloy, etc. For different materials, users can practice flat welding, butt joint welding, T-joint welding, tube-sheet welding and other typical welding joints in different thickness. And by adjusting the direction of the workbench the flat welding, horizontal welding, vertical welding, overhead welding and other positions can be realized. So by selecting different materials, plate thicknesses, welding joints and welding positions in the training system, dozens of training items can be trained and assessed, thus covering all welding training items required in the syllabus.

For the training project in this case, which is low carbon steel plate V-groove flat welding, the training method and training project in the system can be selected as "SMAW" and "10mm low carbon steel V-groove butt joint (flat welding)".

3.2 Virtual welding training

Before virtual training, students should select welding parameters according to the welding specification manual and the welding speed selection method introduced previously of this

paper, and pay attention to real-time inspection, comparison and adjustment during virtual training. Repeated practice can effectively improve welding practical skills, laying a solid foundation for the subsequent practical training. For the convenience of beginners, the training system can also use the "guidance mode" for training. The system will provide the correct position and angle of the welding gun in the form of a translucent three-dimensional model, so that trainees can better follow and experience, as shown in Fig. 9.
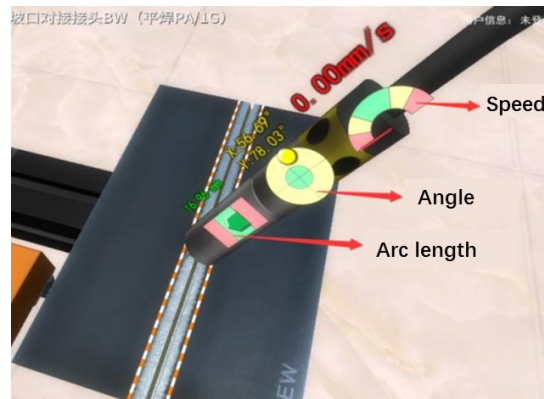

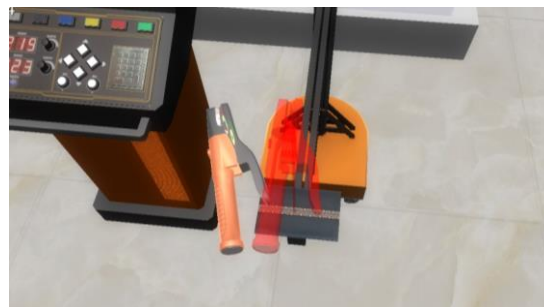**Figure 8.**   Real time display of welding operation status data

Figure 9.   Guidance mode

3.3   Scoring and summary

After the virtual welding project is completed, the system will give scores to the operator's operation process and results, so that the operator can summarize the welding process. The scoring interface is shown in Fig. 10, in which the torch angle, arc length and travel speed at each moment in the whole welding process are given, and the possibility of defects in this operation is evaluated.

The teachers can find the shortcomings for the students according to the scoring situation, and then a new round of training can be carried out, which can be more targeted and effective. After repeated training, the students will become more familiar with the welding practice environment, form a deeper understanding and experience of the theoretical knowledge,

operation process and operation essentials, and a certain muscle memory for the operation skills as well. At this time, it will be more suitable for the welding practice training to be carried out, and the students will get into the state faster. Through a certain amount of training, the welding skills can be improved more effectively.

Figure 10. Scoring interface

4 IMPLEMENTATION OF WELDING PRACTICAL TRAINING

After the preliminary theoretical knowledge learning and virtual welding training, finally the learning and training effects will be applied to the welding skill training, so as to improve the welding operation level more effectively. Welding training should highlight the key points and improve the training effect from three aspects: scientific, practical and competitive.

1) Scientific

The whole process of training should be scientific. In the arrangement of time, the proportion of theoretical teaching, virtual training and practical training should be reasonably arranged. And during the training, the correctness and stability of welding speed, torch angle, arc length, electrode manipulation method and other key points should be continuously emphasized by the teachers, so that students can gradually improve their skill in continuous practice and experience. After training, analysis, discussion and summary should be organized for the defects of welding work, and relate them with the process parameters which is previously learned, so that students can have a clearer understanding of their own shortcomings. In view of the shortcomings of students, teachers can give classified guidance in the next round of training to help students improve pertinently.

2) Practical

The whole training course consists of different welding training items, which are selected from the common work contents in production and maintenance practice, including welding of various welding joints at different positions. Before the training of each training project, students should be informed of the actual products and scenes that the project is mainly applied to, and students can also think about where the objects involved in this training project can be seen in their lives according to the characteristics of welding joints. Corresponding to the actual

product, it can enable students to have a clearer understanding of the application situation of the welding joint, and also enhance their interest in the welding training process and their sense of achievement and acquisition after welding, so as to improve the training effect.

3) Competitive

When a period of time or a unit of practical training is completed, some welding skill competitions can be carried out. The students can be divided into groups, and the contents of the competition can be obtained by teachers' direct proposition or by drawing lots to determine the topic. The competitions between groups can be carried out as a way to promote the training effect. Each group of students need to work out the process parameter scheme by discussion and manual checking, and complete the welding work with a correct process. Teachers will give scores and comments on the correctness of the process, weld appearance and quality, while safe production and post welding site arrangement, etc., and each group will also give mutual evaluations.

5 SUMMARY

This paper explores the application of numerical simulation method and virtual reality technology in welding training teaching, forming a welding teaching process combined with theoretical, virtual and practical, as shown in Fig. 11.
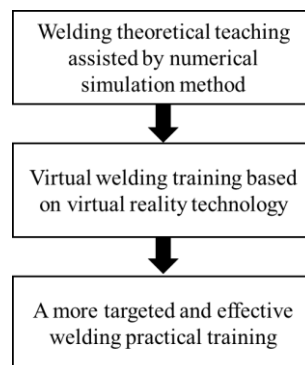

Figure 11.   The welding teaching process

Recently, this method and process was carried out to the students who major in mechanical manufacturing. We randomly selected some training items and conducted a questionnaire survey about the degree of interest and effectiveness on the participating students. The survey results showed that most of the students in the class felt that this method could greatly enhance their learning interest, and also gave great help to master knowledge and skills. The statistical results are shown in Fig. 12, in which Fig. 12(a) is an investigation on the improvement of interest, while Fig. 12(b) is an investigation on the improvement of training effect.

QUESTION: Does the introduction of numerical simulation and virtual reality technology in the course enhance your learning interest and initiative?

(a)
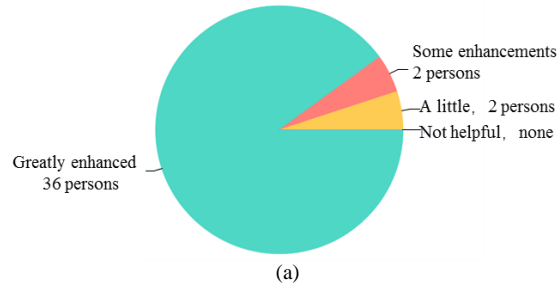
QUESTION: Is the introduction of numerical simulation and virtual reality technology in the course more helpful to master knowledge and skills?
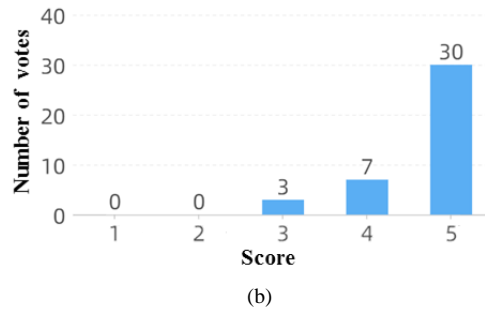

(b)

Figure 12.   Results of questionnaire survey

6 CONCLUSION

In view of the common problems in welding teaching, this paper explores a solution with the help of numerical simulation method and virtual reality technology, and the following conclusions can be obtained through exploration:

1) Adding numerical simulation technology in the theoretical teaching to simulate the welding process can deepen students' understanding of the welding process and process parameters, and assist in the selection of some process parameters.

2) Let the students carry out simulating training based on virtual reality technology between theoretical teaching and practical training as a transition can stimulate students' interest in learning and improve their basic welding skills.

3) Numerical simulation and virtual reality technology can be added to welding practical teaching, which is proved to be able to effectively improve the students' learning and training autonomy and practical skills.

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