

PAPER • OPEN ACCESS

Optimization of welding process for box-type structural parts with complex spatial orientation

To cite this article: Xuemei Zong *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **218** 012048

View the [article online](#) for updates and enhancements.

You may also like

- [Mathematical Optimization of the Spatial Distribution of Platinum Particles in the Catalyst Layer of Pemfcs](#)

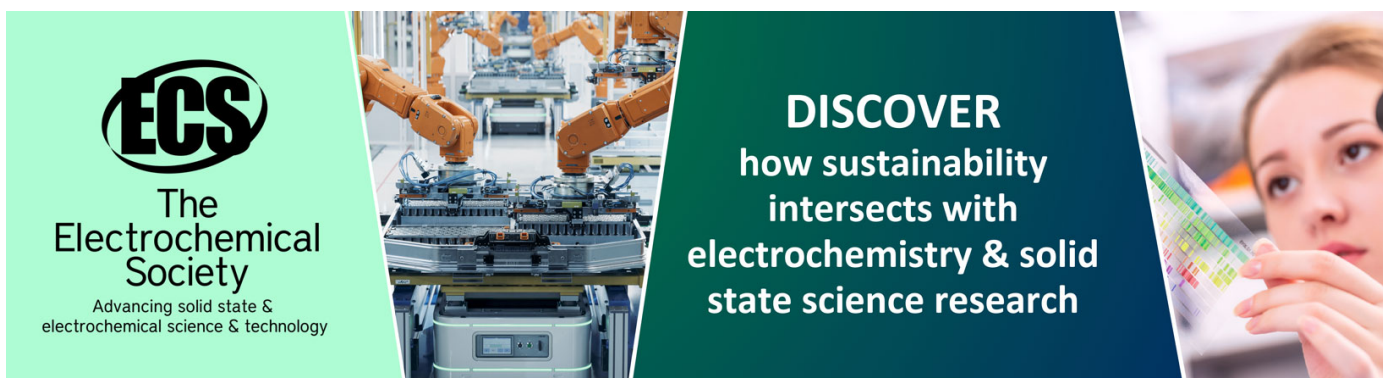
James Lamb, Grayson Mixon and Petru Andrei

- [Optimization of metal belt continuously variable transmission pulley based on multi-island genetic algorithm](#)

Jianfei Cheng, Hangyang Li, Bing Fu et al.

- [An optimization design method for aerodynamic configuration of high aspect ratio wing](#)

Ning Zong, Jing Sun and Meijuan Dong



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

Optimization of welding process for box-type structural parts with complex spatial orientation

Xuemei Zong^{1,2}, Yuanbin Fang^{1,2*}, SongHuang^{1,2} and CanWang^{1,2}

¹XCMGJiangsu Xuzhou Engineering Machinery Research Institute, Xuzhou, J S 221004, China

²XCMG Xuzhou Mining Machinery Co. Ltd, Xuzhou, J S 221004, China

*Corresponding author's e-mail:fybflying@163.com

Abstract. To solve welding process optimization of the complex box structure with spatial weld seam distribution, the finite element model is established in this study. The accuracy of the model is verified by the detection of the key position. As the characteristics of the process, the welding sequence is used to optimize the welding process. The results show that the maximum value is 1.714mm. The deformation near the two sides of the vertical plate is about 0.51mm. The deformation of the front and back Z plates is not consistent. There are 5 peaks in the strip, and the deformation ranges from 0.08mm to 0.12mm. The deformation comparison between the simulation and the measured result can meet the requirements of the engineering application and prove the correctness of the model. Through the optimization of the turning sequence, the deformation of the key position is reduced by 18.6%. By the optimization of the turning and the long-short weld seam, the deformation of the key position was reduced by 26.3%. By the sequence of the turning, the long-short and the key position weld seams optimized, the deformation is reduced by 34.6%. After the optimization of the sequence, the deformation range is between 0.1mm and 0.75mm. The average value is 0.36mm. The average value of welding deformation is at least 40.89% lower than that of the original process. The deformation of the key position controls below 1mm to achieve the implementation of the optimization plan expected that can effectively guide the production.

1. Introduction

With the continuous improvement of manufacturing level, the upgrading and replacement period of the product is gradually shortened. The application demand is higher requirements for the continuous optimization and improvement of traditional technology. To effectively control residual deformation caused by welding, many researches have been carried out. By the measurement results of deformation and residual stress, Fricke W. et al. [1] considered the difference between small samples and large components. The test results under the cyclic loading of small samples were transferred to the large parts. Tian Y. H. et al. [2] analyzed welding process parameters such as welding energy, speed, and the effect of pre-deformation on deformation. The study showed that pre-deformation had a certain effect on the deformation of molten pool, but not as much as welding energy and speed. Shen J. F. et al. [3] studied the effect of welding sequence changes on the stress and deformation of welded joints. As the analysis results of welding spot, a reasonable welding sequence could be made to reduce the deformation and provide a theoretical basis for the production.

The above research is mainly from the analysis of the deformation control method. The new technology will increase the cost. At the same time, the test method needs long time and heavy workload,



and the effect is difficult to guarantee. For this, welding simulation is predicted to make up for this shortage. To solve calculation efficiency and accuracy, experts have studied the research. Fang H. Y. et al. from Harbin Institute of Technology, carried out theoretical and applied research on the influence of the cluster heat source and welding sequence on the control of deformation, and proposed a method [4] for effective control of welding deformation. Zhao H. Y., Tsinghua University, used the local-integral finite element method to analyze the large thin wall cylinder. The results were in agreement with the results of the thermo-elastic finite element method. The calculation time was only about 1/6 [5] of thermal elastic plastic. It was of practical significance for the application of simulation technology in the engineering of large structure. Ma N. X. et al. [6], Osaka University, combined the thermal elastic-plastic method and the inherent strain method. They used the thermal elastic-plastic method to get the inherent strain of the weld seam, and loaded the inherent strain into the weld seam to calculate welding deformation.

To sum up, a reasonable grid transition and suitable material high temperature performance parameters can be used to predict welding deformation of large-scale engineering structures, so as to ensure the high precision and efficiency of the model. At the same time, the effective modeling method can shorten the welding process optimization cycle of engineering structures and guide production.

2. Methodology and Methods

The sample material involved in this research is Q345 steel. Q345 steel has excellent mechanical properties and good weld ability at room temperature. The box structural ironing plate is made by carbon dioxide gas shielded welding. The welding power is the Fronius 5000 welder. The welding wire is ER50-6 and the diameter is 1.2mm. The ironing plate is shown in Figure 1.

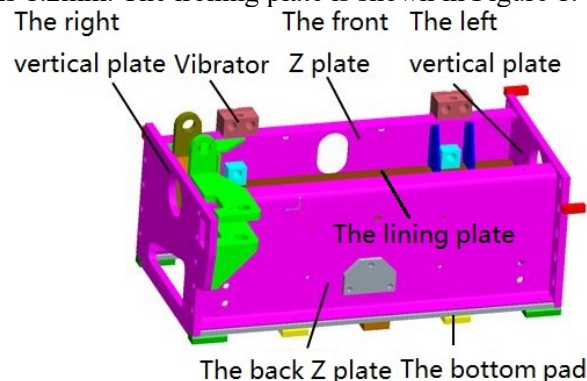


Figure 1. The ironing plate

The weld seams are flat welded, and the height of the fillet weld seam is 6mm. The single track is welded. In the process of field welding, there is no welding tooling, and the flipping welding is used to complete the welding after 5 turns, and all the weld seams are flat welded in every turning position.

In this paper, the study object is the ironing of a paver with a total number of 153 weld seams, a total length of 13837mm and a staggered spatial distribution. The finite element model of the ironing plate can be effectively predicted welding deformation based on the thermal elastic plastic finite element method. In view of the box structure characteristics, the welding sequence is optimized based on the whole factor optimization strategy. The optimization scheme is tested and verified.

3. The establishment of finite element model

3.1 The establishment of finite element model.

To effectively control freedom of the finite element model, mesh transition method is adopted. Complete integration is used for hexahedral elements. The mesh size of the weld seam is 3mm, and the total number of grids is 389166, of which the minimum value of Jacobian is 0.5. The finite element model is established, as shown in Figure 2. It can be seen from the filled grid of all the weld seams that there are many intermittent and complicated spatial orientation.

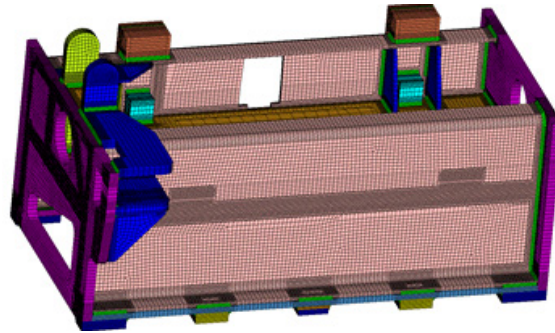


Figure 2. The finite element model

3.2 The establishment of related parameters.

With reference materials [8], the related parameters of Q345 steel for simulated materials are obtained. The double ellipsoid heat source model is considered to be the most reasonable heat source model for carbon dioxide gas shielded arc welding. The parameters of heat source are determined by macro metallographic analysis. The joint specimen takes into account one or both sides of the joint to measure the weld seam size.

To avoid rigid body displacement, the surface is set up on the contact plane of the platform at the bottom pad. A number of nodes are selected in the middle position of the front and back Z plates to limit the direction of Y and Z. A number of nodes are selected on the bottom of left and right vertical plates to limit the X direction.

3.3 Simulation results analysis.

The distribution trend of the overall deformation is calculated, as shown in Figure 3.

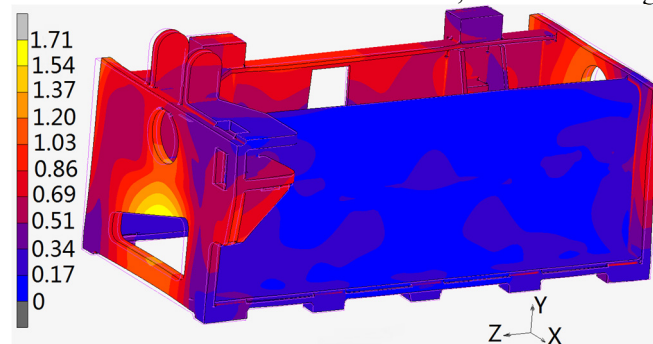


Figure 3. Welding deformation distribution (mm)

From Figure 3, the maximum deformation is at the center of the left and right vertical plate. The peak value is 1.71mm. The bottom pad deformation of the left and right vertical plate is about 0.51mm, which is bigger than that of the middle position that is about 0.34mm. The maximum deformation of the front Z plate is 0.51mm, which is smaller than that of the back Z plate that is 1.2mm.

To verify the key position of the ironing plate, the deformation is extracted at the side boundary of the long strip along the length direction. The deformation is from the right vertical plate to the left end plate, and the measuring points are named 1-3 at the bottom pad position. The Y direction at the 1-3 measuring point is shown in Figure 4. The bottom pad length of the point 1 is 95mm. The distance of the point 2 between the starting point and the right vertical plate is 685mm, and the length of the bottom pad is 70mm. The distance of the point 3 between the starting point and the right vertical plate is 905mm, and the length of the bottom pad is 95mm.

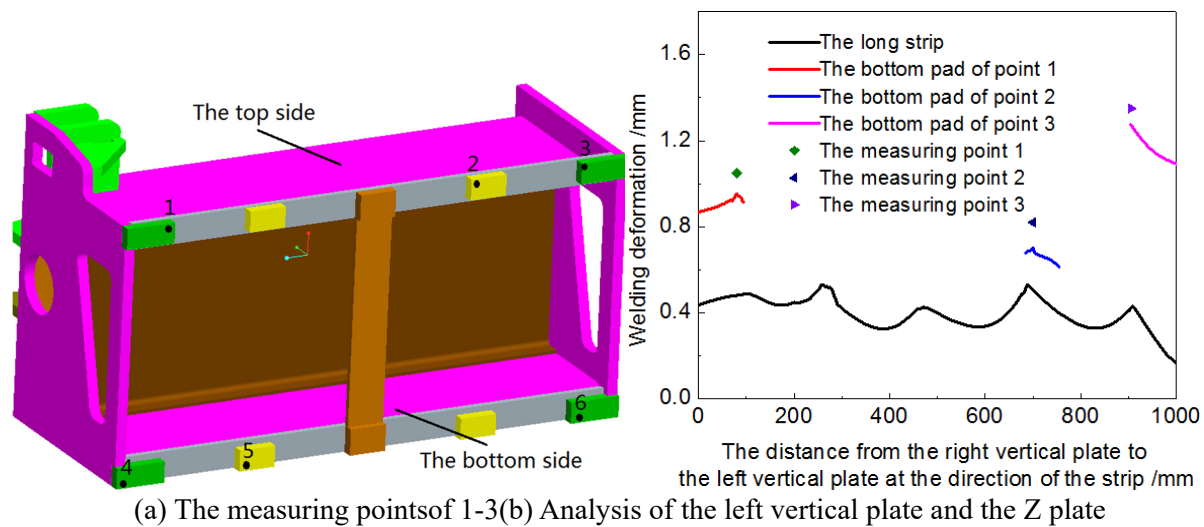


Figure 4. Comparison and analysis of the measuring points 1-3.

From Figure 4, the long plate has wavy deformation, and the curve of the bottom pad at the point 1-3 is consistent with the trend of the strip deformation. There are 5 peaks in the deformation of the long strip, and the deformation ranges from 0.08mm to 0.12mm. The wave deformation of the long strip is mainly related to the bottom pad, the long strip and the back Z plate. The results show the deformation trend of the ironing plate and the comparison results of the measuring points can meet the requirements of the engineering application, and prove the correctness of the finite element model effectively. There can be used in the next welding sequence optimization.

4. Discussion

4.1 Analysis of welding sequence optimization method.

The welding deformation in the vertical direction of the bottom pad and the length direction of the vertical plate connected with the ironing plate have a significant influence on the overall flatness of the bottom, which is the key research variable.

Based on the optimization strategy of the full factor test, the welding sequences including the long-short weld seams and the weld seams near the key position, and the change of the turnover sequence are simulated. The optimization scheme of the welding sequence is determined. Considering the factors of reducing welding deformation such as symmetrical welding, hopping welding and back welding, the welding sequence suitable for low deformation of the box structure is analyzed.

4.2 Optimization of the turnover sequence.

The turnover original sequence of the ironing plate is set to 12345, and the turnover sequence is variable. The original welding sequence is not changed in each turning condition. A single factor full factorial optimization test is carried out on the turning sequence. The experiment is divided into 24 groups. The full factorial test scheme is designed, and the results are calculated and extracted. Several schemes for maximum welding deformation are compared in Table 1.

In the table 1, when the turnover sequences are 21435 and 43215, the maximum deformation is 1.66mm. The maximum deformation is reduced by 3%. In engineering applications, 1.6626mm and 1.6631mm achieve the same effect.

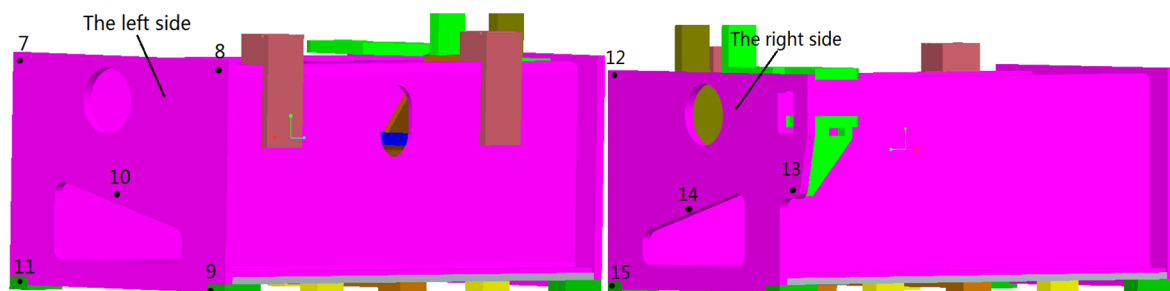
On the basis of the above schemes, the optimization of the key position is still needed to be analyzed. The position of the measurement point is shown in Figure 5.

In the sequence of 43215, the welding deformation of each key position is extracted, and the contrast data are obtained. While focusing on the optimization of deformation at all key locations, we should analyze the comprehensive optimization effect of deformation control. Therefore, the optimization effect of all key positions is averaged to evaluate the effect of comprehensive optimization.

The ironing plate cannot ensure that the welding deformation of the key positions can be controlled within 1mm. The variation range of the optimized scheme measurement point in the direction of Y is 0.31mm~1.15mm, and the variation range of the optimized scheme measurement point in the direction of Z is 0.12mm~1.66mm. The deformation of the key positions is reduced by 18.6%.

Table 1. Comparison of maximum deformation with different turnover sequences

The scheme	12345	21435	12534	21543	34125	43215
The maximum deformation /mm	1.714	1.6626	1.6814	1.6840	1.6690	1.6631



(a) The measuring points of 7-11 (b) The measuring points of 12-15

Figure 5. Comparison residual stress of the lap joints

4.3 Optimization of the long-short weld seam sequence.

At the same time, considering the turnover sequence, two methods are used to adjust the sequence of weld seam, including the short after long hopping welding and the long after short hopping welding. The total scheme contains 240 kinds. The comparison of the maximum deformation between the optimization scheme and the original scheme is calculated in Table 2.

Table 2. Comparison of maximum deformation with the turnover and long-short weld seam sequences

The maximum deformation	12345	12534	21534	34512	43215	53215
The long after short /mm	1.714	1.687 1	1.687 6	1.67	1.64	1.682 3
The short after long /mm	1.714	1.669	1.669 6	1.679 7	1.637	1.667

In the table 2, the best turnover sequence is 43215, and the welding deformation is almost the same between the long after short and the short after long hopping welding. The welding deformation of the ironing plate is the smallest under the turnover sequence, and the value is 1.64mm. The maximum welding deformation is reduced by 4%. At the same time, in the other turnover sequence, the long-short weld seam affects the deformation. Similarly, in the turnover sequence of 43215, the deformation of each key position is extracted, and the comparison data are obtained. The optimization scheme cannot guarantee the deformation of the key positions within 1mm. The deformation range of the measuring point 1-6 in the direction of Y is 0.13mm~1.12mm, and the deformation range of the measuring point 7-15 in the direction of Z is 0.13mm~1.64mm. With the optimization of the long-short weld seam sequence, the welding deformation of the key position is reduced by 26.3%.

The best turnover sequence is 21435 and 43215 in the case of the turnover sequence only. The optimum turnover sequence is 43215, considering the two factors of the turnover sequence and the long-short weld seam. It indicates that one factor cannot be considered in isolation, but the comprehensive factors should be taken into consideration. Therefore, other optimization factors should be considered to optimize welding process.

4.4 Optimization of weld seam sequence in the key position.

On the basis of the above optimization analysis, on the turnover sequence of 43215, the control deformation method is long-short weld seam. The deformation is controlled by optimizing the weld seams near the key position. The weld seams at the key position are mainly the weld seams between the bottom pad and the long strip. The weld seams of the Z plate, the long strip and the bottom pad are mainly adjusted and optimized. The weld seams at the key position are shown in Figure 6. The welding sequence schemes are followed.

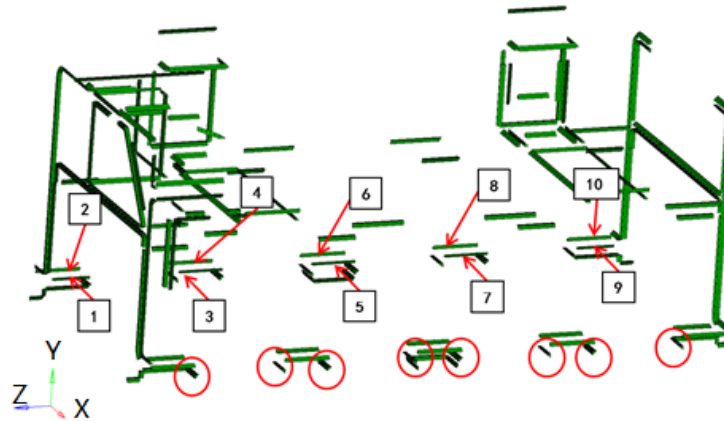


Figure 6. The weld seam distribution of the key position.

(1) The optimization scheme for welding sequence of the long strip and the Z plate. The weld seams named 1-10 are adopted interrupted welding, as shown in Figure 8. The scheme for welding sequence of interrupted welding is shown below.

Sequence named A is used from middle to two ends symmetrically, which is started from the center of the ironing plate to both ends in turn; Sequence named B is used subsection retreating. Sequence named C is used hopping welding to reduce the heat input in one position of the ironing plate.

(2) It is determined the optimization sequence of the bottom pad and the long strip. The weld seams are fillet weld, only the positions of both sides are welded, that is identified the location of the red circle as shown in Figure 8. The proposed plan is as follows.

Sequence named D is used parallel symmetric welding. Sequence named E is used back welding.

The plan of A, B, C, D and E is arranged and analyzed, and welding simulation is carried out. There are 5 optimization schemes. The calculation results of maximum deformation are extracted, as shown in Table 3.

Table 3. Comparison of maximum deformation with weld seam sequences of the key position

The scheme	AD	BD	CD	AE	BE	CE
The maximum deformation /mm	1.628 6	1.637 7	1.628 4	1.629 4	1.638 7	1.633 2

In table 3, on the basis of the optimization of the turnover sequence and so on, the Z plate and the long strip is welded by hopping welding, and the bottom pad and the long strip is parallel symmetrical welding. The total deformation of the box structure is the smallest that is the CD scheme shown in Table 5. To analyze optimization effect on key position, deformation is extracted and contrasted.

The deformation of each key position is within 1mm. The deformation is reduced by 34.6% by optimizing the welding sequence of the turnover sequence, the long-short weld seam and the weld seam in the key position.

4.5 The formulation of welding process optimized.

As the optimized scheme, the data of welding sequence and welding process parameters are extracted and converted into welding instructions for the ironing plate welded. The optimization scheme is applied to production and manufacture. After the ironing plate is welded, the deformation of the sample

is measured by the tape, and compared with the measured value and the simulation predicted value of the original process. The comparison of the measured values is shown in Table 4.

In table 4, after welding process optimization, the deformation range is 0.1mm~0.75mm, and the average of measured point is 0.36mm. The maximum deformation occurs at the bottom pad near the bottom side of the right vertical plate, with a maximum deformation of 0.75mm. The original measurement points 2, 3, 7, 8 are smaller than 0.05mm. If the value is calculated as 0.05mm, the average deformation of the ironing plate is at least 40.89% lower than that of the original process. The deformation of the key position is controlled below 1mm, so as to achieve the anticipation of the optimization plan.

Table 4. Comparison of maximum deformation with weld seam sequences of the key position

The point	1	2	3	4	5	6	7	8	9	10
The optimization /mm	0.5	0.1	0.15	0.65	0.25	0.75	0.1	0.15	0.35	0.6
The original /mm	1.35	<0.05	<0.05	1.15	1.65	0.49	<0.05	<0.05	0.45	0.8
The simulation /mm	0.261	0.165	0.174	0.324	0.235	0.328	0.132	0.148	0.262	0.395

5. Conclusions

In this research, the finite element model of the box structure with the space complex weld seams is established. Deformation is predicted according to the distribution characteristics of the weld seam, and the finite element model is verified. On this, by the whole factor test optimization strategy, the welding process optimization scheme is formulated with three kinds of variable comprehensive improvement measures that is the turnover sequence, the long-short weld seam and the weld seam of the key position. The process optimization scheme is tested. Through the study, the following conclusions are drawn.

(1) The maximum deformation occurs at the center of the vertical plate. The bottom pad is upwards "drum package", and the deformation of the front and back Z plate is not consistent.

(2) The deformation cannot be effectively controlled by the single variable optimization method. The welding sequence is optimized by the turnover, the long-short weld seam and the key position, and the deformation control effect of comprehensive three factors is good.

(3) After the optimization, the deformation of the key position is controlled below 1mm, which is expected to the optimization plan, and can effectively guide the production.

Considering the calculation of high performance computer, this research has not been able to carry out a detailed analysis in the efficient calculation method. It is carried out the research with the help of previous experience. Research can design parallel computing kernel number and other factors to carry out experimental design to further optimize computing efficiency and improve computing efficiency.

Acknowledgments

This work was financially supported by Jiangsu Natural Science Foundation (BK20180175) and Jiangsu Natural Science Foundation (BK20180176).

References

- [1] Fricke W and Feltz O 2013 *Fatigue Fract. Eng. M.* **36**(12) 1223-1231
- [2] Tian Y, Wang C, Zhu D and Zhou Y 2008 *J. Mater. Process. Tech.* **199**(1-3) 41-48
- [3] Shen J F, He Y J and Yu Y C 2016 *Key Eng. Mater.* **667** 168-172
- [4] Ji S. D., Fang H. Y., Liu X. S., Meng Q. G. (2005). Numerical simulation of stress field of manual swing welding on basis of cluster heat source. **26**(5) 46-48.
- [5] Zhao H Y, Wu J W, Lu X M, Jian B and Li H W 2017 *J. Tsinghua Univ. (Sci. Technol.)* **57**(5)

449-453

- [6] Ma N X, Ueda Y, Murakawa H and Maeda H 1995 *Trans. Jwri* **24**(2) 115-122
- [7] Fang Y B, Zong XM, Zhang HQ, Yin XQ and Zhang L J 2017 *T. Chin. Weld. I.* **38**(8) 45-49