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Effect of welding sequence on welding deformation in seal cylinder

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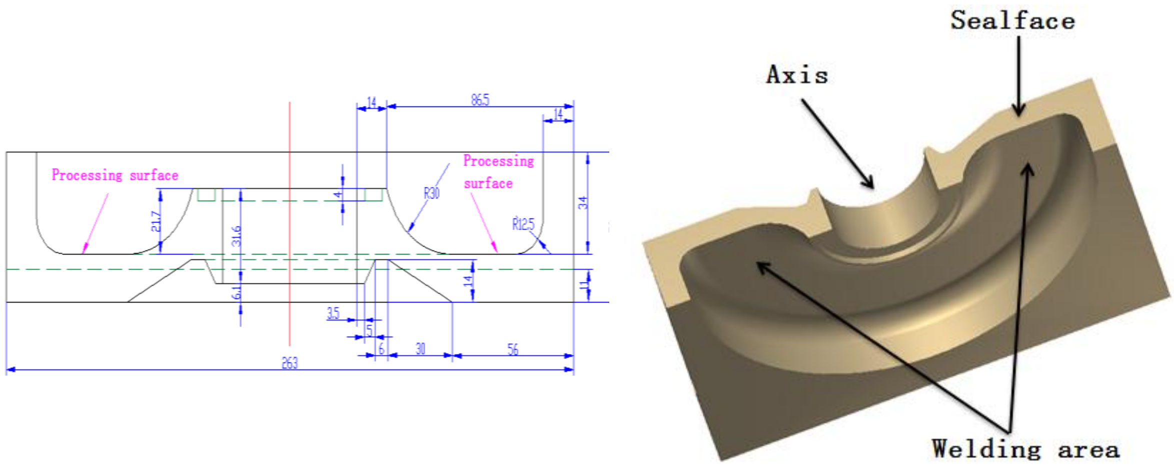
Abstract. The method of numerical simulation and experiment is used to calculate and analyze the post-weld deformation. The results show that the numerical simulation can quickly calculate the amount of welding deformation under different welding sequence, different welding meat size and different heat input, so as to optimize the welding process, control and reduce the welding deformation. The finite element results are less than the experimental results, which verified the accuracy of finite element calculation.

1. Introduction

When the manufacturing error appear in the work-piece surface, the surfacing[1,2,3] is usually selected to build welding in order to meet the size requirements, and improve the strength of the work-piece as the surface of the work-piece meet the corrosive media. In many projects, the welding area is often a complex surface, so surfacing quality has very strict requirements. If the welding quality is good, you can omit the machining process, otherwise it will make the manufacturing process more complicated, resulting in increased manufacturing costs, or even weld scrapped situation. The welding sequence has a great influence on the deformation of the welding, so the study of the welding sequence has far-reaching significance in solving practical engineering problems. In this paper, the method of combining finite element with experiment is used to analyze the influence of welding sequence on the welding deformation of seal cylinder[4].

2. Surfacing model of the sealing cylinder

There are two upper and lower seal cylinders in the engine[5]. The size requirements on the sealing end are extremely strict in pairs. At the same time, there is the corrosive gas in a sealed cylinder, and we found the middle area has the outer drum phenomenon of different level in the process of casting, surfacing of thickness 1mm is required in the outer drum area. As shown in Figure 1, surfacing in the welding area on both sides of the sealed cylinder. The welding process is a local fast cooling after the heating process, which is accompanied by the production of welding deformation, the whole sealing cylinder will scrap if the welding deformation makes two upper and lower sealing face produce the error of the size, so we need to verify the effects of surfacing on seal face size.



（a）The size of the sealed cylinder （b）Sealed cylinder model

Figure 1. The sealed cylinder structure

3. Finite element simulation method[6]

3.1. Finite element model

During surfacing, there is deformation and heat conduction in the surfacing area. Therefore, the surfacing area expands downward by 3mm and expands to both sides by about 10mm. The new surfacing area is the elastic zone. It is regarded as the plastic zone away from the new surfacing zone. For the accuracy of calculation, the elastic area with hexahedral mesh should be refined as much as possible. The plastic region should be tetrahedron. The connecting region between the tetrahedron and the hexahedron mesh should use Tie, so as to ensure the node correspondence. The finite element model of sealed cylinder is shown in Figure 2.

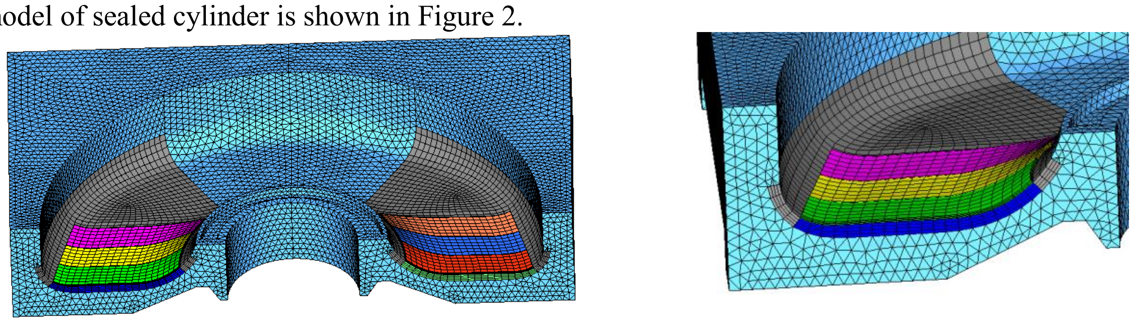


Figure 2. The finite element model of sealed cylinder

3.2. Choice of welding heat source

There are three welding heat source loading methods in welding numerical simulation, Gaussian distribution function, double ellipsoid distribution function, life and death unit method[7,8], respectively. In this study, the life-and-death unit method was used to simulate the formation of welding seam and the movement of welding heat source. Before calculation, kill all the units in the weld equivalent to the pre-weld assembly. During the calculation, the "killed" cells were "born" sequentially, simulating the filling of the weld metal. At the same time, in different beads, a corresponding heat generation rate (HGEN) is applied to the activated cell and the action time of the heat load is equal to the actual welding time. After each step of calculation, the heat rate of this step will be deleted, and the calculation is re-entered into the next step[9,10]. The heat rate is calculated as:

$$HGEN = Q(A_{weld} \times v \times dt)^{-1}$$

Where $HGEN$ is the heat rate applied by each load step, W/m^3; Q is heat, $Q = \eta UI$,which η is arc thermal efficiency, its value is 0.7～0.9; A_{weld} is cross-sectional area of weld; v is welding speed; dt is time step for each load step, s.

3.3. Boundary conditions

For surfacing process, preheat treatment is required to meet the welding process requirements in surfacing area, so the bottom of the surfacing layer is individually selected to complete the heat treatment. The single-pass weld heating time and cooling time distribution is set to 3s and 10000s, set up a brief heat treatment process after the last weld, which insulation time is 100s, and finally cooled to room temperature in preheat treatment process. The heat transfer coefficient is set to 8, the body heat source is applied and the heat flux density is set to 1.1e7. To overcome the rigid body movement, the bottom of the sealed cylinder is fixed by using a symmetrical constraint during loading.

Heat flux density: $$q_i = \eta U I V_H^{-1}$$

Where η is arc thermal efficiency, U is Arc voltage, I is welding current, V_H is heat source volume.

4. Results of finite element analysis

4.1. The choice of welding sequence in figure 3.

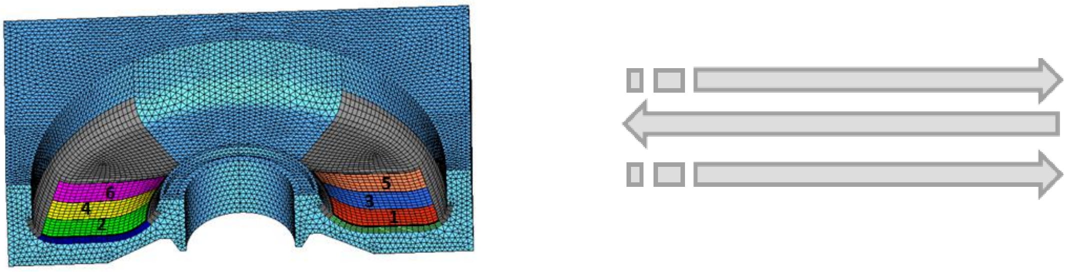
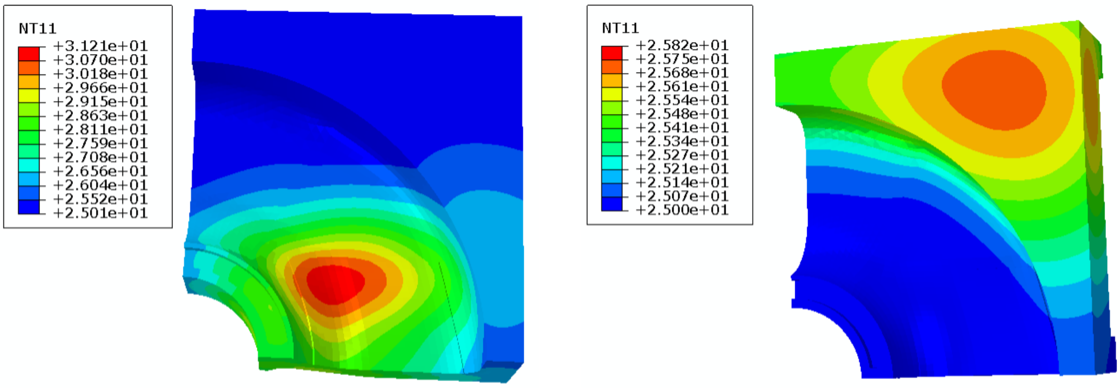


Figure 3.The welding sequence

4.2. Welding temperature field calculation results

Figures 4 (a) and (b) show the temperature distribution at the end of welding and cooling to room temperature, respectively.



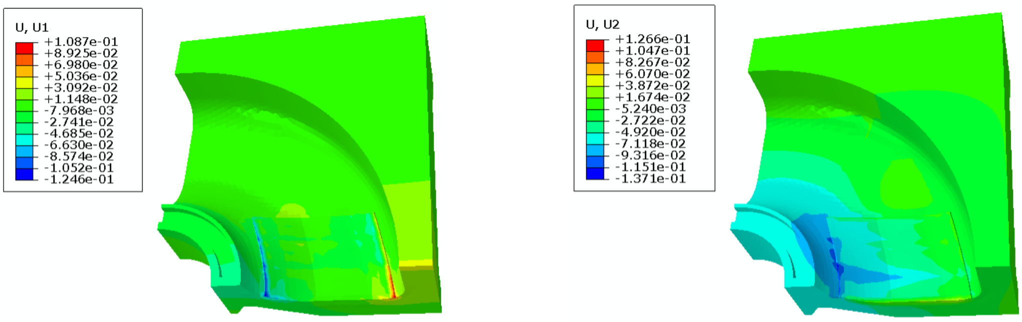
（a）Temperature distribution after the welding

（b）Temperature distribution after cooling to room temperature

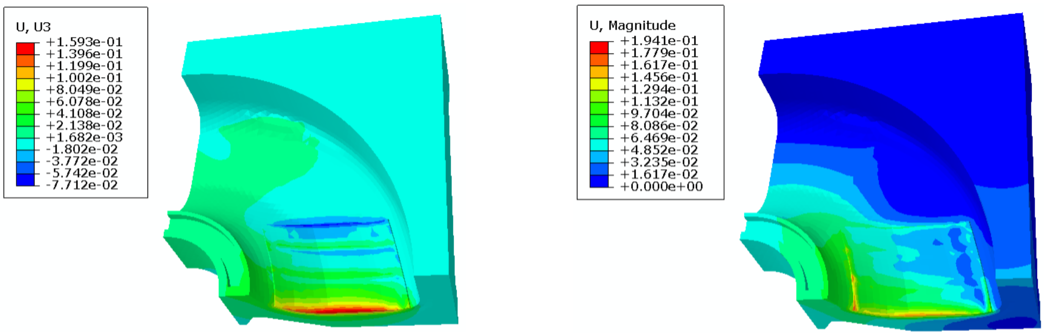
Figure 4. The welding temperature distribution cloud

4.3. The calculation results of welding deformation

The deformations in XYZ directions are shown in Figure 5. Figure 5 (a) shows the amount of deformation in the X direction, which is the flatness of the work-piece after surfacing. And then by measuring the average deformation between the work-piece and the constraint surface to get the mid-face warping deformation on selecting six points in the corresponding position of the middle face. The maximum deformation of which does not exceed 0.11 mm. Figure 5 (b) is the deformation in the Y direction with the maximum deformation less than 0.13 mm. Figure 5 (c) is the deformation in the Z direction, the maximum deformation value is less than 0.16mm.



（a）The deformation in X-direction （b）The deformation in Y-direction



（c）The deformation in Z-direction （d）Total deformation

Figure 5. Figure with surfacing deformation distribution cloud chart

The key positions in the overlay welding process include the seal face size, span size and axial seal size. The dimensions of the seal cylinder model are selected from 1-1，to 6-6，, and the cross-section is shown in Figure 6. The calculation results of deformation are shown in Table 1.

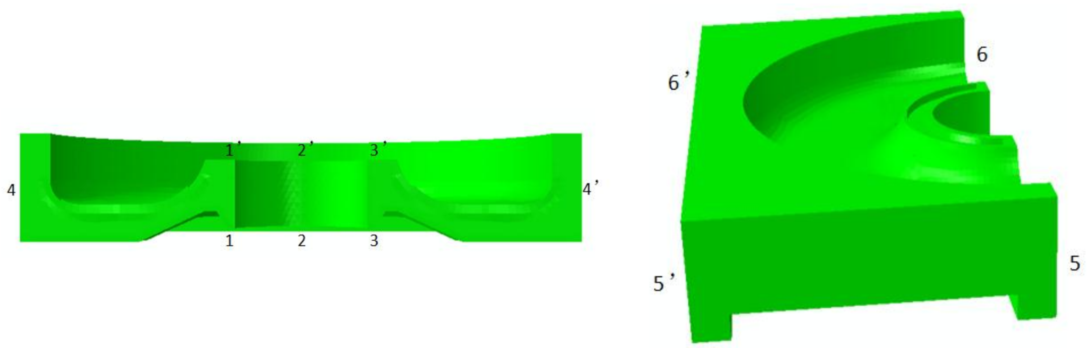


Figure 6. The key location size

Table 1. The deformation of the cross-section size

Cross-section	Direction	Before deformation （mm）	After deformation （mm）	Deformation （mm）
1-1′	Y-direction	33	32.972	-0.028
2-2′	Y-direction	33	32.956	-0.044
3-3′	Y-direction	33	32.932	-0.068
4-4′	X-direction	263	262.993	-0.007
5-5′	Z-direction	140	140.011	0.012
6-6′	Z-direction	140	140.009	0.009

The calculation results indicate the deformation in the axial direction (Y direction) is small, and the more axial deformation from the axis closer to the weld repair area through the section 1-1′ , 2-2′ , and 3-3′ , but the maximum value is not more than 1mm; section 4-4′ is the span size changes, the maximum deformation is less than 1mm. Unlike the deformation at the seal face, the farther away from the weld, the smaller the deformation appear; the cross section 5-5′ and 6-6′ are the deformation along the Z direction, and the deformation is smaller too.

5. Experimental results

In order to ensure the reduction of error, three models were processed. Before finishing welding, the welding position of the experimental part was determined. The MAG welding method was adopted. The welding base material selected was stainless steel and the welding material was Y316 welding wire. The welding current is 120A and the voltage is 10V. The measured position is consistent with the position of the finite element calculation model. Surfacing effect map of experimental pieces is shown in Figure 7.

Figure 7. The surfacing effect map of experimental pieces

The experimental results in the cross-section size deformation are shown in Table 2.

Table 2. The deformation of the cross-section size

Cross-	Direction	Before deformation	After deformation	Deformation

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section		（mm）	（mm）	（mm）
1-1'	Y-direction	33.02	32.94	-0.08
2-2'	Y-direction	33.027	33	-0.027
3-3'	Y-direction	33.02	33	-0.002
4-4'	X-direction	263.012	262.958	-0.054
5-5'	Z-direction	140.056	140. 072	0.012
6-6'	Z-direction	140.073	140.092	0.019

6. Conclusions

The following conclusions are shown from Table 1 and 2:

(1) Finite element calculation results and experimental calculation results have the same trend of deformation in all directions. The results obtained is more ideal in the finite element calculation, which values are less than the experimental results except for the finite element calculation cross-section 3-3' , and verify the accuracy of finite element calculation.

(2) The warping deformation of middle face in seal cylinder does not exceed the maximum 0.13mm. The sealed cylinder axial size is smaller too, and the maximum deformation is less than 0.2mm. The calculation results show that the scheme can be implemented.

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