Numerical Simulation of Wax Mold Assembly Welding Process

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Abstract: In the modern manufacturing industry, investment casting is widely used in aerospace, automotive, marine and other key areas by virtue of its near-net-shape characteristics, for the manufacture of such high-precision and complex structure parts as turbine blades for aero-engines. Complex structure wax mold cooling and shrinkage rate of each part of the large differences, coupled with the assembly, welding and other aspects of the impact of deformation is very easy to occur, resulting in casting dimensions over the difference, affecting production efficiency and increase production costs. In this paper, numerical simulation is innovatively adopted to improve the production efficiency of castings, to provide theoretical guidance for the reasonable design of shaping fixture and welding process.
Keywords: numerical simulation; Wax molding; Wax Mold Assembly Welding; investment casting

1 Introduction

In the production of investment casting, the stability of the wax mold size and the degree of deformation greatly affects the dimensional accuracy of the casting, so it is very important to control the deformation of the wax mold, the main factors of the deformation of the wax mold are: the cooling method, the combination of the wax mold program, the wax mold tooling, Hou Limeng[1] summed up the production experience and found that, when the assembly speed is fast and the temperature of the electric iron is high, the amount of deformation will be relatively small. And the soldering iron assembly process is suitable for a single gate or not easy to deform the thick and large fine castings (two gates) of the product, the use of the wax mold must be strictly monitored after the assembly of the amount of deformation. Jiang Shisheng [2] mentioned the wax mold production process in the production of Bonjour bell, the upper limit of wax temperature needs to be controlled within 200 ℃, and the part of the bell body requires high strength of the wax mold to ensure that the shell making process is not deformed. Yang Jieren [3] mentioned that the wax mold assembly process usually includes: wax mold trimming, inspection, using adhesive method and mechanical assembly, and cleaning the wax mold. Wax mold assembling is mainly studied experimentally, and there is no precedent for wax mold assembling simulation study. In the actual wax mold assembling process, the temperature control of the wax mold is the main factor affecting the amount of deformation of the wax mold. In the simulation study of wax mold combination in this paper, the soldering iron heat source is approximated as a double ellipsoid heat source, and the power of the heat source and the welding rate are studied as variables [4-7].

2 Experimental section

Since the wax mold combination process is generally examined by experimental methods with less simulation experience, this simulation experiment refers to the traditional rubber welding simulation study, using Simufact.Welding software: it is a simulation software developed specifically for welding process, with more professional and refined functions in welding simulation. It provides a wealth of welding heat source model, can more accurately simulate the heat input process under various welding methods, and has unique advantages in welding deformation prediction, residual stress analysis and weld microstructure simulation. It is more specialized for welding process design, and can improve the calculation speed by setting parallelism. It is suitable for wax pattern welding simulation with the main purpose of welding process optimization.

2.1 Wax mold material performance parameters

Due to less experience in the simulation of wax mold combination process, most of the software lacks the parameters required for wax mold combination process, after comparing the parameters required for other materials in the welding process, the thermophysical parameters and mechanical properties of the parameters are as follows, and after consulting the Moldflow software material library and collecting literature, the rheological curves of the wax mold materials are shown in Fig. 1, and the other parameters are shown in Table 2.

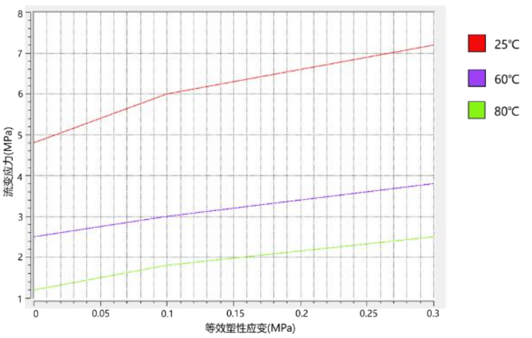

Fig. 1: Wax Mold Rheological Stress

Table 1. Key Material Parameters for Wax Molds

parameters	numerical value
Solid phase line temperature	48℃
latent heat of melting	80000
coefficient of thermal expansion	30
Loss factor (damping ratio)	0.9
densities	1100
thermal conductivity	0.159 W/(m·°C)
modulus of elasticity	2445
Poisson's ratio	0.38

2.2 Heat source modeling

During the actual welding process, the temperature is higher at the weld, and the heat spreads from the center of the weld to the vicinity, forming a temperature diffusion gradient. With the rapid movement of the heat source, the temperature of each point in the weldment undergoes a nonlinear change. The closer the heat source point temperature rises rapidly, the further away from the heat source point temperature rises slowly, the temperature field changes are more intense, especially in the vicinity of the weld seam, and the welding process also exists in the process of latent heat of melting and phase transition, so the welding process is a nonlinear transient heat transfer process. In the actual production of wax mold combination, generally use the heating of the soldering iron to carry out the wax mold combination, the heat source of the soldering iron is mainly concentrated in the soldering iron head and the contact parts of the weldment, the heat is conducted to the weldment through the contact.

According to the heating mode and energy distribution characteristics of the soldering iron, the double ellipsoid heat source model is chosen as Figure 1, which can better simulate the distribution of heat on the surface of the weldment. The double ellipsoid heat source is divided into two parts, the temperature gradient in the first half of the heat source center is large, and the temperature gradient in the second half is more moderate.

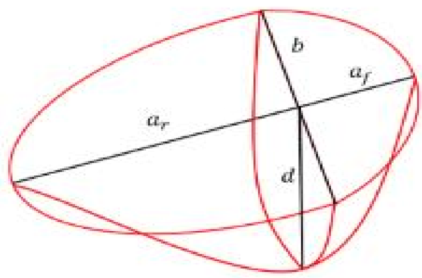

Fig.2: Double ellipsoid heat source model model

2.2 waxwork simulation

Due to the complex structure of large welded components and the large span of model dimensions, finite element models of large engineering components using solid meshes will have many nodes and meshes. The computational process of this finite element model is very time-consuming and the large number of meshes may make the computational process not easy to converge.Wang[8-11] et al. used solid and shell cells to simulate the localized seams of the ship hull, respectively. The nodes and mesh of the shell cell were reduced by 82.6% and 80.3%, respectively, compared to the solid cell. The maximum deformation difference between the shell and solid models is only 0.09 mm and the minimum deformation difference is only 0.5 mm. The weld depths of the three weld seams were measured and there were 40 points in total, of which 27 were for 4mm-6mm welds, 8 for 7mm-9mm welds, 8 for 12mm-13mm welds, and 5 for 12mm-13mm welds. Therefore, the weld thicknesses of 5mm, 8mm and 12mm are chosen to establish a simplified model for the simulation of welding combinations.

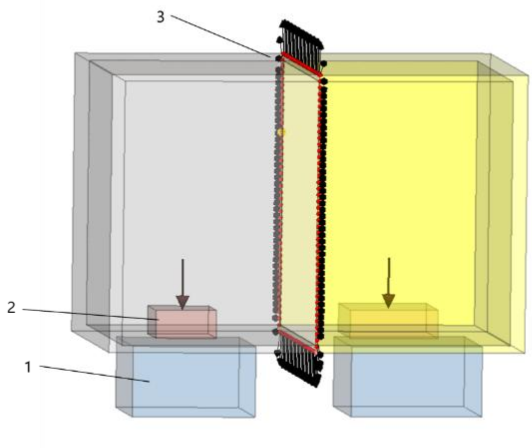

Fig.3: Schematic diagram of the simplified model

3 Results and discussion

3.1 Heat source model calibration

Wax mold welding process numerical simulation experience is less, there is no direct data basis, theoretically, wax mold welding power should be substantially less than steel, welding speed should not be too high, in order to validate the simulation model, the first heat source model calibration, to determine the corresponding range of welding power, to improve the simulation efficiency[12-15]. The following table shows the heat source power calibration simulation experiment.

Table 2. Calibration of heat source power parameters

Experiment number	Heating power	thermal efficiency	Welding speed
(a)	300W	0.5	400mm/s
(b)	100W	0.5	400mm/s
(c)	300W	0.5	100mm/s

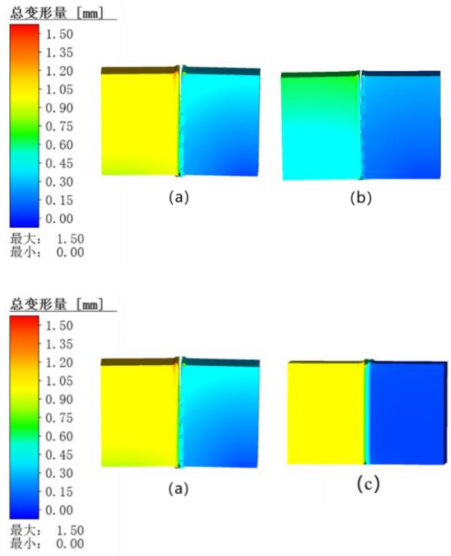

Fig.4: Wax mold deformation cloud map.

The deformation cloud diagram of the wax model under different heat source parameters is shown above, and the deformation magnification of 10 is enabled to visualize the deformation trend, so that the amount of deformation at critical locations can be better observed. Fig. (a) and Fig. (b) both show the presence of weld cracks, Fig. (a) also has a larger deformation due to the high power of the heat source, and there is more obvious cracking at the weld, and there is also a deformation of 1 mm at the shell in both cases. In contrast, Fig. (b), the deformation is smaller, and the deformation at the shell is under 0.6mm, which is easier to carry out the subsequent leveling work. Combined with the rheological curve, the reduction of welding power to reduce the temperature gradient, so that the stress becomes smaller, so the deformation is also smaller, combined with the actual production and simulation results, the heat source power is set at 100W or less. The welding cracks in Fig. (c) are obviously smaller, combined with the actual production, this is due to the heating time in Fig. (a) is too short, so that the wax molds do not have time to melt before entering into the cooling process, therefore, the welding speed should be slower than 400 mm/s.

3.2 Effect of different welding power on distortion for 5mm wax mold thickness

Combined with the actual production, wax mold combination of process parameters simulation experiments tentatively set the following table, welding power in three groups 80W, 50W, 30W to determine the minimum welding power, welding speed of 300 mm / s and 150 mm / s two groups, the two together to determine the melting situation under different power judgment. High power - low speed is likely to lead to high temperature residence time is too long, increasing the probability of cracking, low power - high speed can control the deformation in a very small range, but it will also lead to the depth of fusion is less than 20% of the thickness of the plate, resulting in inadequate welding, therefore, the welding power and welding speed should be considered in a comprehensive manner, in order to reduce the welding power as much as possible at the same time, improve the welding speed. Ensure that the melt-through rate at the same time, increase the welding speed, can reduce the stress, reduce cracks, but also reduce the total deformation, improve the quality of welding. After simufact welding software to simulate the wax mold combination process, the results are shown below[16-18].

Table 3. 5mm Simplified Model Welding Process

Experiment number	Heating power	thermal efficiency	Welding speed
(1)	80W	0.5	300mm/s
(2)	50W	0.5	300mm/s
(3)	30W	0.5	300mm/s
(4)	80W	0.5	150mm/s
(5)	50W	0.5	150mm/s
(6)	30W	0.5	150mm/s

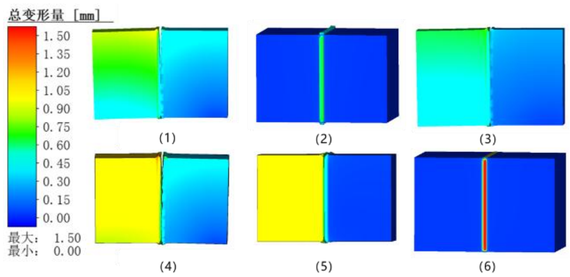

Fig. 5 Simplified model simulation experiment total deformation cloud map

The first and the fourth groups of simulation experiments showed more obvious cracks, which seriously affected the final results of the wax mold combination. The remaining simulated experiments are relatively flat at the weld seam, in which the second and sixth groups only have obvious deformation of the wax mold at the weld seam, and the deformation of the left and right shells is within 0.1mm, which indicates that the wax mold combination is relatively solid, and the overall stress is small and uniform as can be seen from the medium effect force cloud diagram in Fig. 10. The third and fifth groups of simulation experiments have obvious deformation of the left and right shells under gravity, indicating that there are cracks at the weld, resulting in stress transfer to the left and right shells. The fifth group of experiments has higher welding power and slower welding speed, combined with the stress cloud diagram in Figure 10, it can be seen that the equivalent force is larger at the weld, resulting in a larger deformation of 1.05mm in the left shell.

Wax mold deformation is mainly affected by the wax mold welding process stress changes, in the welding process, the stress evolution is mainly regulated by heat input parameters, specifically as follows: 1, welding power dominated by the heat input, the power increase will significantly increase the energy deposition per unit of time, resulting in the melting pool and the heat affected zone of the temperature field inhomogeneity intensified. When the power exceeds the critical value, the local high heat flux density will trigger transient thermal stresses and easily induce microcracks. 2, the welding speed increase will shorten the high temperature residence time, which will inhibit the heat affected zone, but the cooling rate will also be increased accordingly, resulting in poor core stress, so the welding power needs to be appropriately increased when the welding speed is increased.

In combination with the simplified model total deformation cloud diagram and the total deformation evolution curve at the center point, the welding effect is best when the welding power is 50W and the welding speed is 300mm/s.

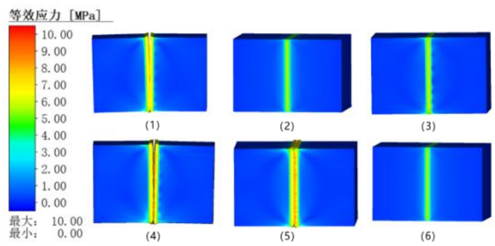

Fig. 6 Simplified model simulation of the experimental equivalent force clouds

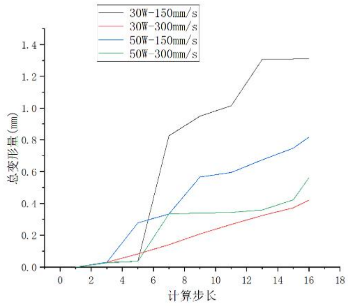

Fig. 7 Simplified model simulation experiment total deformation change cloud diagram

3.3 Process validation of different wax mold wall thicknesses

According to the heat input line energy calculation formula $Q = \frac{P}{V}$ (P: welding power, V: welding speed), the line energy directly affects the melting depth and deformation, the higher the line energy, the greater the melting depth and the greater the deformation. According to the relationship between penetration, different thickness of wax mold heat input and plate thickness is directly proportional to: $\frac{Q_2}{Q_1} = \left(\frac{t_2}{t_1}\right)^2$, the above chapter 5mm wax mold thickness of the best parameters for the welding power of 50W, welding speed of 320mm / s, the line input of about 0.156, according to the formula can be calculated, 8mm wax template plate material line input should be 0.4, 12mm wax template plate material line input is 0.9. According to the formula of the line input, line energy needs to be increased by increasing the power of welding, the line energy should be increased by increasing the power, the line energy needs to be increased by increasing the power, the line energy needs to be increased by increasing the power of welding. According to the formula of line input, it is known that the increase of line energy needs to reduce the welding speed while increasing the power, therefore, the simulation program is formulated as follows:

Table 4 Processes for combining wax molds of different thicknesses

Thickness of wax mold	Heating power	thermal efficiency	Welding speed
8mm	60W	0.5	150mm/s
8mm	80W	0.5	200mm/s
12mm	70W	0.5	80mm/s
12mm	100W	0.5	120mm/s

The following figure shows the simulation results of the simplified model of 8mm thickness wax mold, it can be seen that the two groups of experiments did not produce cracking phenomenon, from the weld morphology, the two groups of experiments on the outer surface of the deformation of the uniform, along the direction of the heat source in the center of the position of the highest amount of deformation to the sides of the uniformly low, the wax mold has no obvious deformation, cracks, weld seam integrity. This phenomenon shows that the line energy calculation is correct, but combined with the weld profile can be seen, welding power of 60W, the depth of fusion is only 4mm, only 50%, while the welding power of 80W, the depth of fusion of 6mm, the depth of fusion of 75%, and the weld is clean and complete, to meet the basic requirements[19-21].

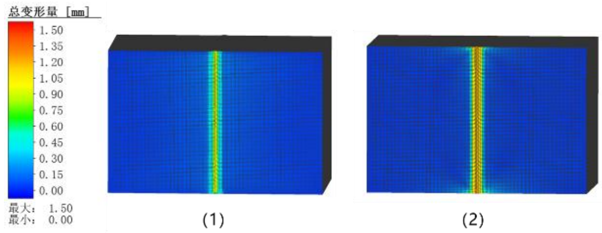

Fig.8 Simulation results of 8mm wax model with different powers

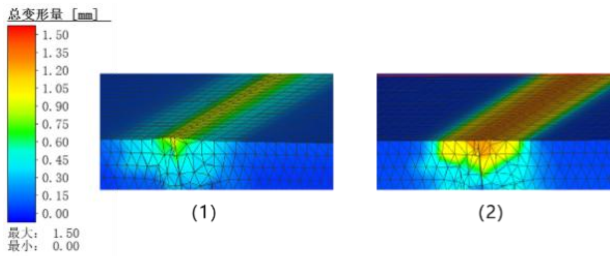

Fig.9 8mm wax pattern with different power weld profiles

The following figure shows the simulation results of the simplified model of the 12mm thickness wax pattern, and it can be seen that the weld profile is consistent with the simulation results of the simplified model of the 8mm wax pattern. Combined with the weld profile, it can be seen that when the welding power is 70W, the depth of fusion is only 5mm, which is only 41%, while when the welding power is 100W, the depth of fusion reaches 10mm, which is 83%, and the weld is clean and complete, which meets the basic requirements.

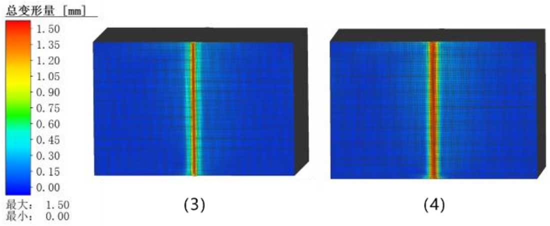

Fig.10 Simulation results of 12mm wax model with different powers

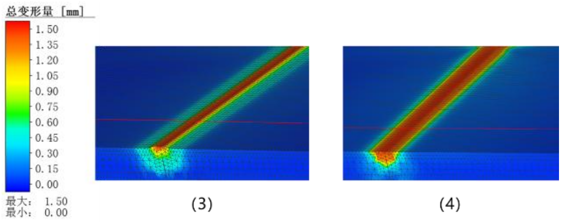

Fig.11 8mm wax pattern with different power weld profiles

4 Conclusions

In this study, Simufact welding finite element analysis software is used as a platform to simulate the deformation process of wax mold combination, and the following conclusions are drawn:

• Welding power and welding speed are the main factors affecting the deformation of wax molds. An increase in welding power leads to an increase in the temperature gradient, which intensifies the stress change and increases the amount of deformation. Welding speed affects the cooling rate by influencing the residence time in the high temperature region of the wax mold, the faster the welding speed, the smaller the deformation.

• Simulation of the wax mold model verified that cracking occurs at higher power, which is consistent with the deformation law of the simplified model. Using the simplified model to simulate the best process, the surface deformation of the wax mold is uniform and the deformation is small. It shows that the simplified model can reflect the change rule of the actual wax mold welding process.

• Simulation of different thicknesses of the simplified model reveals that the best welding process for the wax mold with wall thickness of 5mm is 50W and the welding speed is 2.2mm/s. For the wax mold with wall thickness of 8mm, the best welding process is 80W and the welding speed is 1.35mm/s. For the wax mold with wall thickness of 12mm, the best welding process is 100W and the welding speed is 0.81mm/s. The best welding process is 100W, The welding speed is 0.81mm/s.

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