Micro Component Heat Treatment Collecting Technology

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Abstract:

Funnel feeding tank and spiral pipe enable micro component evenly contact quenching oil and flow into system. Gas in the collecting tank blows micro component through filter so that won't be stuck in the filter, also removes quenching oil. This design facilitates collecting rate and yield rate reach 95%.

The objective of this study is to evaluate the heat treatment processes of micro-precision components using a continuous heat treatment equipment. To conduct this heat-flux coupling analysis, specific computational fluid dynamic models were established based on the Cradle/scFLOW, a commercially available software.

To maximize the productivity during the continuous heat treatment process, the ultimate goal is to uniformly heat up these micro-precision components, such as up to 1173 K, in the shortest process cycle and maximum conveyer speed. Two major tasks including the construction of the furnace heat up model and the feeding of the micro-component within the furnace were developed. The corresponding experimental tests were also conducted to ensure the reliability of the simulation models and consequently, to improve the processes by using these digital technologies. This study successfully established a finite-volume based computer aided engineering methodology and enabled the integration of virtual simulations and practical applications for the micro-component heat treatment industry. Through these simulation models, the thermal power from associated thermal resistances can be adjusted and managed properly. As a consequence, the concerns about high energy consumption can be reduced and the low carbon green energy manufacturing goal can be reached.

Keywords: *Micro component, Spiral pipe, Collecting rate, Computational Fluid Dynamics, Heat-flux Coupling Analysis, The Continuous Type Heat Treatment System Equipment for Micro Parts*

1. Introduction

Following the compact design of 3C products, their components become miniaturized, including carbon steel screw of mobile phone, small motor axis or small gear of fan. Heat treatment of these components by large traditional heat treatment equipment will encounter uneven heat treatment and mixing problems. The developed heat treatment collecting device uses the spiral design of oil tank, facilitating that the micro component quickly drops into collecting box. The micro component won't float at the surface or drift everywhere due to surface tension of quenching oil. Instead micro component will evenly cool off to increase the quality uniformity and further reach 95% of collecting rate. The collecting device combines the traditional oil tank and conveyor, meantime realizes the cooling of micro component and transporting. The flowing of quenching oil will quickly move the micro component to the collecting tank so that heat treatment collecting device will become miniaturized and reduce the equipment cost. The treated component, such as micro screw, the ferrite structure of core is less than 2% (that by traditional heat treatment is about 7%). The fracture torque of screw is larger than 1.2kg·cm (that by traditional heat treatment falls between 0.6 and 0.9), micro gear passed the test of assembly life more than 1,000 hours.

The main purpose of this research is to assist the Metal Industry Center to develop the CAE (Computer Aided Engineering, CAE) technology of the rotary continuous heat treatment process in order to complete the overall goal of developing the virtual and real integration technology of the rotary continuous heat treatment. The fine continuous heat treatment equipment is now The specifications are shown in Figure 1. The virtual-real integration technology developed by this research systematically integrates domain knowledge and process know-how, enabling the industry to achieve efficient heat treatment equipment development and optimization more conveniently and quickly, reducing the chance of human error and trial and error. Assisted in the development of the digital analysis model of the first rotary continuous heat treatment equipment in China by using virtual-real integration technology.

In the literature, Han et al. 1) developed a digital model for large-scale steel plates moving and heating in a reheating furnace. Due to the lack of software functions in the early 2010s, this study wrote C language and integrated FLUNET fluid analysis software for moving grids. Completed the evaluation of the temperature characteristics of the moving parts of the steel plate in the reheating furnace, as shown in Figure 2.

Gao, Qiang et al. 2) and Casal et al. 3-4) developed a CFD (Computational Fluid Dynamics, Computational Fluid Dynamics, CFD) model for large steel plate heat treatment continuous furnace, as shown in Figure 3, the movement of the steel plate in the furnace is Realized by the dynamic grid, the radiant tube is coupled with the furnace as a whole, and the indirect heat transfer in the furnace is realized through the radiant tube. The simulation results are stable with the experimental verification for the temperature field in the furnace and the heating process of the steel plate, as shown in Figure 4, this literature also identified the difference between the heat source contribution between the experiment and the numerical model, as shown in Figure 5.

Basol et al. [5-6] conducted a numerical analysis of the radiation heating effect of a glass continuous annealing furnace, using an industrial-scale continuous annealing furnace model, and using an in-house developed transient solver to solve the combined conduction-radiation heat transfer mode in the furnace. The convective heat transfer in the furnace was not considered due to its relatively low contribution to the heat transfer. The effect of the bottle row spacing on the radiation heating efficiency of the furnace is shown in Figure 6.

Recently, the research objects of digital models for heat treatment of continuous furnaces are all large objects, such as large steel plates, glass bottles, and glass cups. The target of this research is fine and small products (less than 2mm in size), and the development of digital models will be a big challenge. The ambient temperature stability of the product is particularly important, so the development of digital model analysis for the rotary continuous main furnace body, through the digital model of the furnace body, can fully understand its thermal temperature rise and temperature field distribution characteristics, which will help different Product requirements Efficiently and quickly adjust the heat treatment process, and also help the rapid development of new machines and equipment for different product requirements.

2. Experiment or Theory

After quenching, the micro component will flow into the collecting device. In the beginning, funnel feeding tank enables the micro component move into the same direction via gravity concentration. Afterwards the micro component will mix with the quenching oil after entering the pipe. Design of spiral pipe facilitates the micro component to be completely covered by quenching oil and flow along the spiral pipe so that micro component won't float at the surface of quenching oil to cause the uneven cooling. When micro component flows into the pipe, the device can adjust the length of path to control the flowing speed and improves the stuck problem of micro component. Then micro component will flow through filter to produce the pushing force toward micro component via introducing the feeding gas so that micro component won't be adhered to the filter. Finally, the micro component will flow into collecting tank.

This research will develop the thermal-solid simulation technology of computational fluid dynamics flow in the continuous furnace. The goal is to heat a large number of micro-products to a high temperature and uniformity in the shortest time, such as 1173 K, to maximize the speed of the furnace conveyor belt; in order to accurately simulate the heat treatment process and to confirm whether the temperature in the furnace reaches the target temperature, the temperature distribution measurement experiment and verification in the furnace space will be established, including the temperature distribution measurement at 1173 K in the furnace, to confirm the input of the environmental conditions before heat treatment and quenching, and to establish a heat transfer CFD analysis model to observe the overall temperature distribution.

This study mainly refers to the research methods of numerical analysis of heat treatment furnaces by Gao, Qiang et al. [2], and uses the high-value, high-precision heat treatment equipment for small and fine parts developed by our center as the carrier for research and experimentation, and carries out the overall technology development planning, with a view to establishing the digital process improvement technology required by the current domestic heat treatment industry.

The implementation planning of the plan is mainly as shown in Figure 7, and it is mainly carried out with two numerical simulation analyzes of the internal heating thermal field analysis of the chamber and the moving heating analysis of the work piece chamber. And each numerical analysis is supplemented by corresponding experiments to ensure the reliability of the numerical analysis model and results, and effectively introduce digital technology to improve the heat treatment process efficiency of important micro products such as tiny balls or micro probes.

2.1 Experimental Design and Planning

This study will carry out the analysis of the heating thermal field inside the chamber and the moving heating analysis of the work piece chamber. In order to verify the results of the numerical analysis and ensure the reliability of the analysis model, this study will plan to carry out the temperature rise measurement experiment in the furnace, the equivalent work piece intra-chamber mobile temperature rise measurement experiment, and plan the corresponding experimental design and process according to the experimental conditions and characteristics.

2.1.1 Experimental carrier and equipment

The carrier used in this research is the high-value and high-precision heat treatment equipment for the heat treatment of fine and micro products. As shown in Figure 8, this equipment can be mainly divided into two systems integration of quenching furnace and tempering furnace, and each integrated system is composed of feeder, receiver, cleaning machine, oil tank, heating chamber and control system. Forming a set of equipment that can fully automatic done the heat treatment process for fine products. In this project, due to the demand for experimental and analytical data, relevant experiments will be mainly carried out on the quenching furnace system, in order to provide relevant data to improve the reliability of the numerical analysis model.

2.1.2 Experimental design of temperature rise measurement inside the chamber

Since the accurate temperature rise curve in the furnace will directly affect the energy consumption of the overall process, it is very important to use experiments to identify the actual temperature rise curve in the furnace. In this experiment, it is mainly divided into two parts and carried out simultaneously. The first part is shown in Figure 9. Using a camera and a personal computer, the ammeter and voltmeter in the heating zone of the quenching furnace are recorded in the form of video during the experiment, and then use the method of manual identification to record the voltage and current values per unit time, and calculate the wattage of the heating zone at each time point during the heating time based on it, and finally substitute this condition into the numerical analysis model solve in.

The second part uses the furnace measurement fixture provided in the center, fixes the thermocouple on the fixture as shown in Figure 10, and then puts it into the furnace after the continuous temperature measurement system is set up. And in the first part, the experiment is carried out simultaneously, and the temperature readings corresponding to each measurement point and each time point are obtained to provide a numerical analysis model comparison.

As for the initial conditions of this experiment, because the actual application of the experimental carrier in the industry is to preheat at 673 K before starting to heat up, and the target temperature of the other carrier micro balls in this research is 1173 K before quenching, so the arrangement of this experiment is to carry out the experiment in the situation where the temperature starts to rise from 673 K to 1173 K.

2.1.3 Experimental design of moving temperature rise measurement in work piece chamber

When it is determined that the inside of the quenching furnace chamber will reach the target temperature, the product will be continuously fed into the chamber through the feeding system, and the product will be heated after moving slowly in the chamber. However, due to the requirements of the heat treatment conditions of the product, it is necessary to ensure that the product reaches the target temperature when it moves to the end of the chamber through the feeding system and falls into the quenching oil due to the influence of gravity, so as to ensure that the mechanical properties after quenching meet the corresponding requirements. Therefore, the main body of this experiment is to design a thermocouple that has been calibrated on the fixture, and cooperate with the continuous temperature measurement system, in the corresponding speed scenarios of the frequency conversion speed of the feeding system 10 Hz, 20 Hz, 40 Hz and 60 Hz The experiment is carried out below, the relative speed is shown in Table 1, and the temperature history changes of the individual test pieces are monitored when they move inside the chamber, and the results are compared with the corresponding numerical analysis results. The fixture design and feeding into the furnace are shown in Figure 11 shown.

2.2 Establishment of digital analysis model

This study will carry out the following two kinds of numerical analysis: the analysis of the heating thermal field inside the chamber, and the analysis of the moving heating in the chamber of the work piece. The analysis of this research uses the commercial numerical analysis software scFLOW to effectively integrate digitization and visualization technology, improve the traditional time-consuming process improvement method based on experimentation, shorten the process improvement time and reduce the corresponding cost, so that it can be applied to It can bring significant benefits to the industry. Therefore, it is quite necessary to carry out the corresponding analysis above in this study.

2.2.1 On-site mapping and establishment of chamber 3D CAD model

In this study, there is quite a lack of relevant drawings of the quenching furnace, so we can only rely on the traditional practical surveying and mapping method to carry out rather limited measurements and draw sketches, and then compare the cross-sectional view of the quenching furnace with the values and sections of the practical measurement sketches The way of taking proportional lines for the view is limited to verify the correctness of the surveying and drawing. As shown in Figure 12, the heated work piece enters through the furnace mouth, moves to the right through the conveyor belt at a set speed and is heated to the iron phase temperature of Austenite, then falls into the oil cooling tank at the vertical turning point for quenching. Only by integrating the data can the 3D model be established, which will be imported into each analysis model for gridding and setting of related conditions.

2.2.2 Analytical model of heating thermal field inside the chamber

In the quenching process related to tiny balls, how to accurately and efficiently control the temperature rise state in the chamber before the feeding system transports the work piece into the chamber, so as to achieve a uniform thermal field effect under the target temperature, so that Accurate and controllable prediction of the heating situation of the work piece when it moves in the chamber is an indispensable analysis.

And because the quenching furnace body is designed as a semi-open furnace body, the position of the feed port will convect with the air, and then the place where the work piece falls is also in contact with the quenching oil surface, so the gas in the chamber will also exchange heat with the feed port, and then locally affect its thermal field results. As for the temperature rise in the chamber, the temperature rise effect is similar to the temperature rise of the material in the furnace proposed by Hosseini et al. [7]. The multiple heating rods on the upper and lower sides conduct heat to the shell of the chamber through the effects of heat convection and heat radiation, and then the shell of the chamber absorbs the heat radiation from the wall through the gas in the chamber and heats the work piece input into the chamber.

Therefore, this analysis needs to take into account the influence of radiation, convection and conduction on the temperature rise of the work piece, and also needs to consider the heat exchange effect of the semi-open furnace body at the inlet and outlet. This analysis is currently designed as a flow-heat coupling in scFLOW. State analysis, and its various settings are shown in Figure 14. This analysis will consider the above-mentioned fluid-thermal coupling to solve and select the corresponding solver. In terms of transient analysis, it is also based on the current experimental carrier The heating time is used to set the total length of the analysis, and the part of the analysis time step. After many experiments to solve the problem, it is determined that the analysis time step is set to 0.2 seconds per step, which is relatively ideal for the current solution convergence situation. In addition, because this analysis will also have the influence of thermal radiation, the thermal radiation coefficient is also defined here, and the heat exchange effect at both ends of the furnace mouth is considered, so the initial temperature of the air is also considered to simulate the impact of the ambient temperature on the furnace. The influence of the heat exchange field. As for the heating source condition setting for the analysis of the heating thermal field inside the chamber, the total heating power monitored by the experiment is currently set at 15.5 kw, and the actual measured power history is distributed to the thermal resistances in each area, and the heating power is set according to each unit time. The output is heated, and the temperature of the chamber shell is raised by heat convection and heat radiation. Finally, as shown in Figure 13, the work piece moving in the chamber is heated.

Then, it is necessary to import the CAD model of the furnace body completed in the previous section into the analysis pre-processing software, as shown in Figure 15, use algorithms such as Bollinger arithmetic to determine and establish the solid and flow fields, and establish a set to distinguish There are four fluid areas, including the pipeline fluid area in the chamber, the heating resistor heat radiation area, the chamber body fluid area, and the central chamber area of the heating resistor, so as to facilitate the subsequent definition of various material properties and boundary conditions.

At the same time, continue the geometric distinctions in the previous paragraph, and define the material properties as shown in Figure 16. According to the real characteristics of the experimental carrier and the environment, the materials used in this analysis can be roughly divided into two parts: solid and fluid. For the solid part, the material used in the chamber and the main structural parts is SUS-310S, the heating resistor part is nickel-chromium alloy, and the parts outside the resistor, such as refractory bricks, are defined by the heat transfer properties of the heat insulating material. For the fluid part, this analysis is defined by the heat flow properties of incompressible air in the pipeline in the chamber, the chamber body, and the chamber area designed to avoid the shielding of heat radiation by the heating resistor (heating resistor heat radiation area).

In the various initial conditions of this analysis, the external ambient temperature is set at 298 K. In response to the actual use of the high-value, high-precision, small and fine parts heat treatment equipment in this study, it is usually kept at 298 K except for annual repairs or overhauls. 673 K, so under the condition of stable temperature distribution of 673 K at the thermal resistance, start to heat up. In the inlet part of the chamber, it is also set according to the actual process application situation, as shown in Figure 17(a), the inlet pressure is set to 0 pa, the temperature is set to room temperature (298 K), the fluid state Then set it to Turbulence. The part below the chamber that contacts the quenching oil surface is 298 K, as shown in the left of Figure 17(b), so that it can conduct heat exchange reaction with the heat field in the chamber in the form of heat conduction in the overall analysis. In addition, for each surface that will be in contact with air, the boundary conditions for contact with room temperature are also set as shown in Figure 17(c).

Meshing-related settings, because the software solver used in this analysis is based on the Finite Volume Method (FVM) as the theoretical basis, the difference between the characteristics of the mesh processing requirements and the finite element method is that Because the evaluation of each node depends on the difference calculation between nodes, instead of relying on the designation of various element shape functions (Shape function) to map to the same type of elements in the form of isoparametric transformation like the traditional finite element method, and then use Galio The solution is based on the Galerkin method. The advantage of this for numerical analysis is that it effectively reduces the dependence of the algorithm's solution accuracy and convergence on the grid quality, and can use the octree grid (Octree) to establish a global volume discrete grid, and then use the polyhedral grid (Polyhedron) performs geometric approximation on the constructed octetree grid, and then obtains an efficient grid result suitable for finite volume method operations. In this analysis, the overall model will first be divided into octet tree grids. In addition to limiting the size of the global grid, the geometry and connections that need to pay attention to accurate calculation results, such as heat source areas, are also given to perform grids. refinement. The result after the grid is established, as shown in Figure 18(a), ensures the generation of fine grids in the heat radiation area of the heating resistor and the conveyor belt area inside the chamber, providing the basis for establishing a good polyhedral grid at the back end Favorable conditions. After the octet tree grid is completed, it can be used as a basis to generate a polyhedral grid. Due to the characteristics of the polyhedral grid, the quality of the grid is good, and the quality of the connection with the surrounding grid is good, and there are few grids with a large distortion rate. Effectively ensure the convergence of transient analysis. At the same time, due to the local refinement characteristics of the previous step octree grid, the important calculation areas in this analysis are shown in Figure 18(b), which have good quality of refinement grid and can ensure relatively accurate Solve the result.

2.2.3 Analysis model of moving heating in work piece chamber

In this study, in addition to constructing a numerical analysis method that can effectively predict the temperature rise inside the quenching furnace chamber, due to the actual process application conditions, the micro products are quenched with a certain temperature rise condition in the chamber through the feeding system through the conveyor belt Therefore, when the conditions in the furnace are effectively known, it is used as the initial condition of the thermal field inside the heating furnace body that is equivalent to the work piece moving in the chamber, and the temperature of the work piece before quenching is simulated in the real process. For the subsequent The analysis of heat treatment mechanical properties is an important initial condition that must be provided.

This analysis takes into account the influence of radiation, convection and conduction on the temperature rise of the work piece, as well as the heat exchange effect of the semi-open furnace body at the entrance and exit. Because the process condition is that the work piece will continue to heat up during the process of moving in the chamber, so this analysis in scFLOW, in addition to a transient analysis of fluid-thermal coupling, also needs to consider the dynamic grid characteristics of the work piece movement, and must Consider the thermal radiation effect of the work piece position at each time step to ensure the reliability of the simulation results. Its various settings are shown on the left side of Figure 19. This analysis will use the above-mentioned dynamic mesh flow-thermal coupling to solve and select the corresponding solver. In terms of transient analysis, it also refers to the frequency conversion speed of the feeding system Table to set the total length of the analysis, after many experiments to solve the problem, it is determined that the analysis time step is set to 0.1 seconds per step is relatively ideal for the current solution convergence situation. In addition, because the moving work piece in this analysis will also have the influence of thermal radiation, it is also necessary to substitute into the VF algorithm to recalculate the area affected by thermal radiation at a specific time step.

The analysis model can be mainly divided into the following parts: the external flow field, the moving work piece, the heat transfer belt, and the chamber. The 3D CAD model is imported into the pre-processing software and the flow field geometry is established, as shown in Figure 20, with the same logic as the previous analysis, after importing the 3D CAD model, the corresponding flow field model is generated through the Boolean operation and its internal specific algorithm.

In terms of material properties, the solid is only equivalent to the part of the moving work piece, and its material properties are SUS-310S. The fluid part, the flow field inside and outside the chamber and the part of the heat transfer zone are the same as the previous analysis, and the heat transfer properties of incompressible air are also used for related settings, as shown in the right of Figure 19.

In terms of initial conditions, as shown in Figure 20, the ambient temperature of all components is the same as the setting of the external flow field, which is 298 K, and the temperature of the quenching oil surface in contact with the lower edge of the chamber is 298 K, and the flow field in the chamber The part of the belt is set at 1173 K, and the specially divided part of the heat transfer belt is set at 723 K to avoid excessive temperature gradient of heat transfer.

The flow field conditions of the intake air in the chamber are also the same as the previous analysis. According to the actual process application conditions, the settings are shown in Figure 21. The intake pressure is set to 0 pa, and the temperature is set to room temperature (298 K). In other cases, the fluid state is set to Turbulence. The speed of the moving grid part that simulates the movement and heating of the work piece into the chamber is defined by the frequency conversion speedometer of its feeding system to define its moving distance per second.

Grid setting, as shown in Figure 22, first perform the octet tree network grid division, and set the local refinement for the moving mesh work piece and the moving path area, and then use the divided octet tree grid to establish a polyhedral mesh, which is also the same between the moving mesh work piece and the moving path area Moving the location has the effect of local mesh refinement.

3. Results

3.1 Analysis and experimental verification of the heating thermal field inside the chamber

As shown in Figure 23, it is the thermal field analysis of the temperature inside the chamber at 60 seconds, 300 seconds, and 600 seconds of the temperature field distribution in the furnace. It is observed that the internal temperature presents a gradient distribution, mainly for the ring temperature of the upper furnace mouth and the lower furnace. The mouth oil temperature is caused by low temperature, and there are still conveyor belt mechanisms and carbon potential tube mechanisms in the furnace. Corresponding to the three thermocouple temperature points in the experiment, the positions marked in Figure 23 are: (1) close to the furnace mouth, (2) close to the furnace wall, and (3) in the middle position. The simulation analysis is compared with the time history of the experiment. The results are as follows as shown in Figure 24, the temperature distribution curve of the digital model in the heating process is consistent with the experiment, which verifies the reliability and rationality of the digital model.

3.2 Analysis and experiment of moving heating in work piece chamber

This study assumes that the thermal field in the furnace is evenly distributed, and after substituting the known conditions for the dynamic grid transient flow heat coupling analysis, it is found that the moving work piece is in the non-uniform temperature field due to the heat exchange between the air inlet and the external flow field as shown in Figure 25 below. After the moving work piece has completely passed through and exchanged heat with it, and after the moving work piece enters the stable target temperature thermal field, the temperature change rate of its heating has been greatly reduced, as shown in Figure 26. In the experiment, the temperature rise curve of the work piece under different conveyor belt speeds has been measured, as shown in Figure 27; the digital model will continue to be verified in the future to improve the process efficiency and effectively consider the area of the heat exchange field and the moving work piece The optimization of the travel speed in the chamber ensures the process optimization benefits.

4. Discussion

The reliability and rationality of the digital model depends on the accuracy of the 3D geometry of the analysis vehicle and reasonable analysis input conditions, initial conditions, and boundary conditions. At present, the digital analysis model of micro continuous heat treatment equipment has been established, and it has been verified robustly and experimentally. This reliable and reasonable digital analysis model will help:

(1) Thoroughly understand the thermal temperature rise and temperature field distribution characteristics of the equipment.
(2) Efficiently and quickly adjust the heat treatment process in response to product size changes and changes in the total amount of product blanking.

(3) Quickly develop new machines and equipment for different product requirements.

5. Conclusions or Summary

After component is miniaturized, if micro component is treated by large traditional heat treatment equipment, the quality will be uneven, the collecting rate is not good and mixing problem will be produced. As such, heat treatment collecting technology is an important part of heat treatment system. The advantage uses the spiral design in the oil tank to facilitate the micro component quickly drops and is collected. Micro component evenly, completely contacts the quenching oil in the process and thus decreases the temperature. In addition, micro component won't float at the surface of quenching oil or spread everywhere due to surface tension of quenching oil. Introducing of feeding gas in the filter of cooling tank will decrease the adherence of micro component toward filter, facilitating that the collecting rate and yield rate of micro component reaches more than 95% (those by traditional heat treatment is about 50%). This design also combines traditional oil tank and conveyor, facilitating that the heat treatment collecting device could be miniaturized and the equipment cost is thus decreased.

6. Acknowledgements

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7. References

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8. Appendix

Figure 1 Current Specifications of Micro Continuous Heat Treatment Equipment

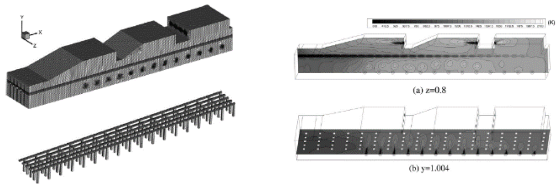


Figure 2 Numerical Analysis Model of Large Steel Plate Reheating Furnace [1)]

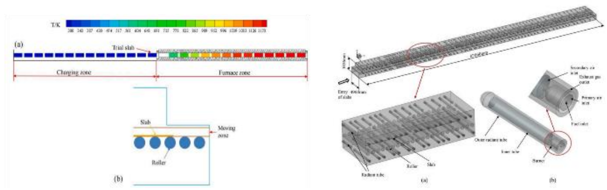


Figure 3 Analytical Model of Continuous Heat Treatment Furnace for Large Steel Plate [2)]

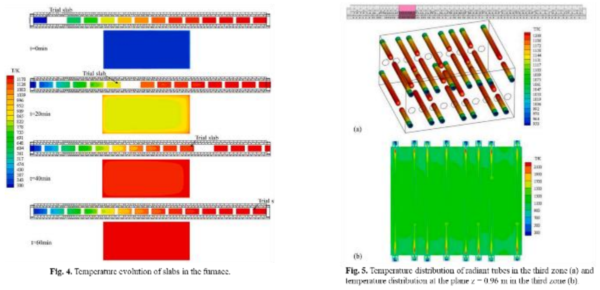


Figure 4 Analysis Results of Continuous Furnace for Heat Treatment of Large Steel Plate [2)]

Figure 8 Physical photo of the heat treatment equipment for high-value and high-precision small and fine parts developed by MIRDC

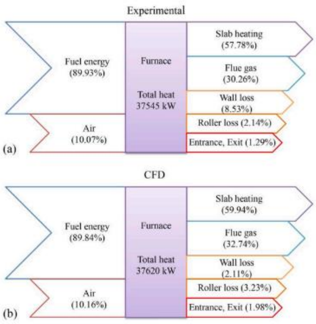


Figure 5 Heat Source Identification of Continuous Furnace for Heat Treatment of Large Steel Plates by Comparison Between Experiment and Numerical Model [2)]

Figure 9 The current and voltage video monitoring diagram of the temperature rise measurement experiment in the furnace

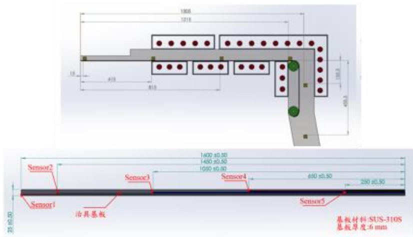


Figure 10 Schematic diagram of the measurement layout of the temperature rise measurement experiment in the furnace

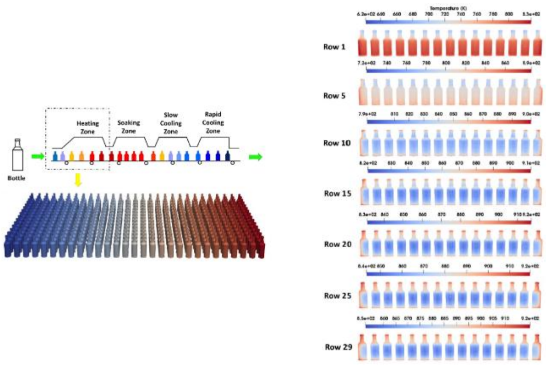


Figure 6 Numerical Analysis of Radiation Heating Effect in Glass Continuous Annealing Furnace [5)]

Figure 11 Tools design and experimental conditions

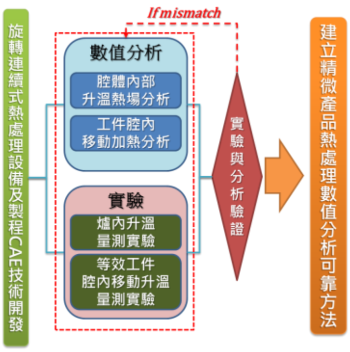


Figure 7 Research flow chart

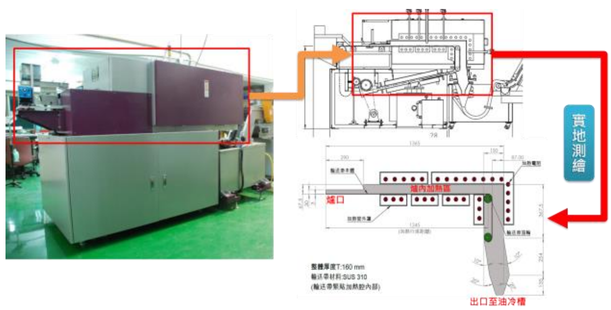


Figure 12 Schematic diagram of building a 3D model of a continuous furnace

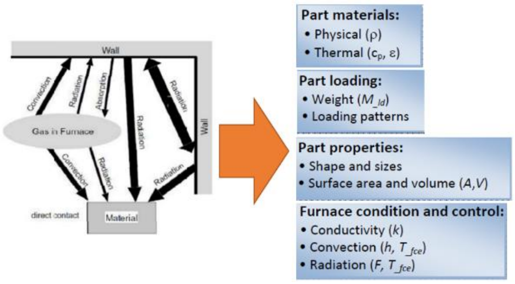


Figure 13 Schematic diagram of the heating mechanism of the work piece in the furnace and related influencing factors [7)]

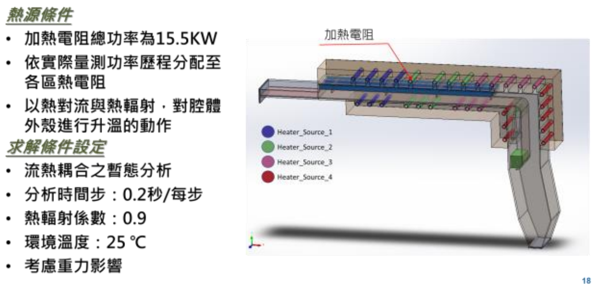


Figure 14 Relevant settings for solving the thermal field analysis model inside the chamber

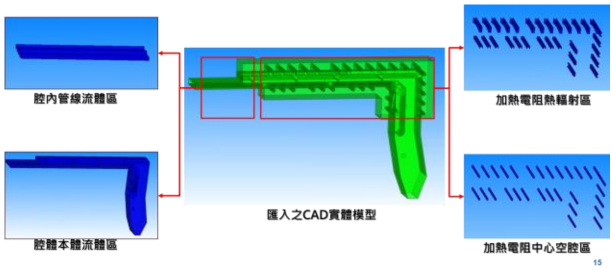


Figure 15 Schematic diagram of the solid-fluid region for the thermal field analysis of the temperature rise inside the chamber

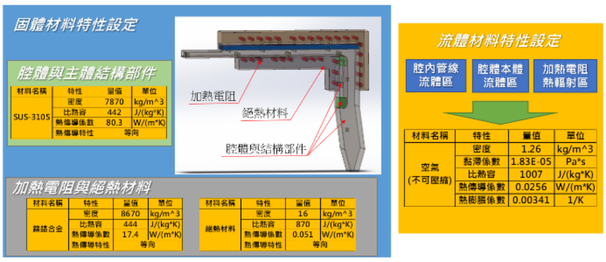


Figure 16 List of various material properties of solid and fluid in the analysis of the heating thermal field inside the chamber

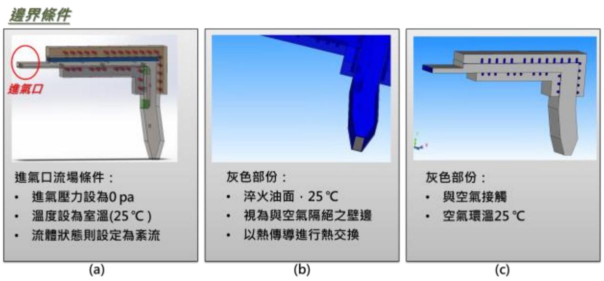


Figure 17 Setting of Boundary Conditions for Thermal Field Analysis of Chamber Internal Heating

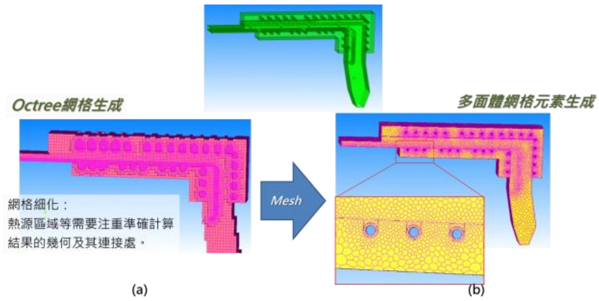


Figure 18 Mesh setting for analysis of heating thermal field inside the chamber

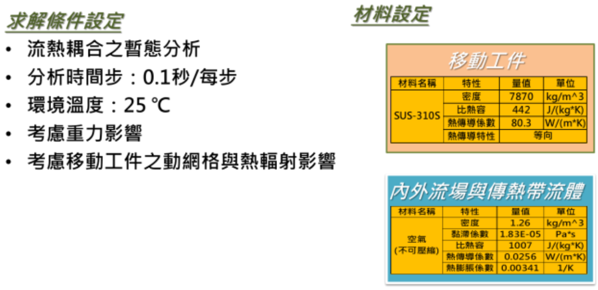


Figure 19 Solution and Material Setting of Moving Heating Analysis in Work piece camber

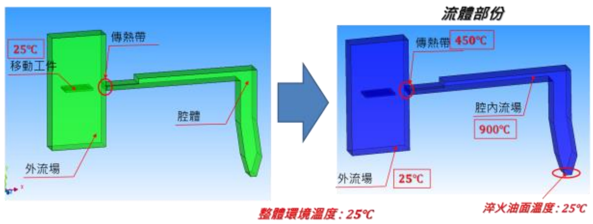


Figure 20 Overview of Solids and Fluids for Mobile Heating Analysis in the Work piece Chamber

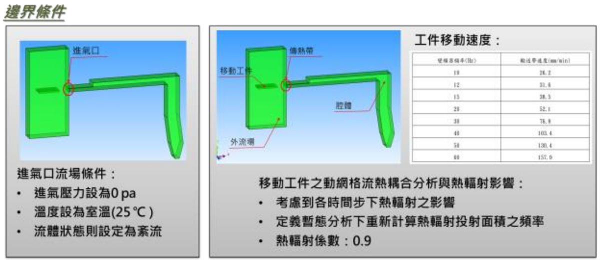


Figure 21 Boundary Conditions and Moving Mesh for Analysis of Moving Heating in Work piece Chamber

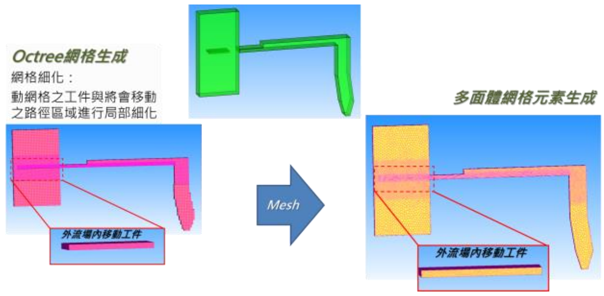
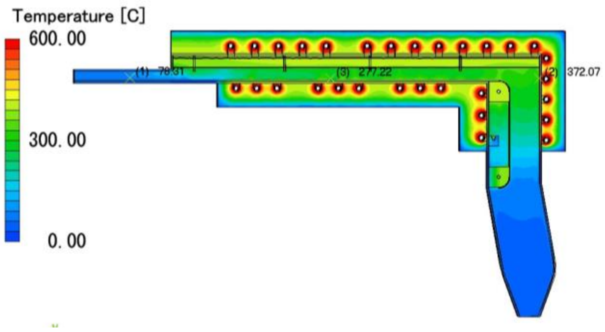
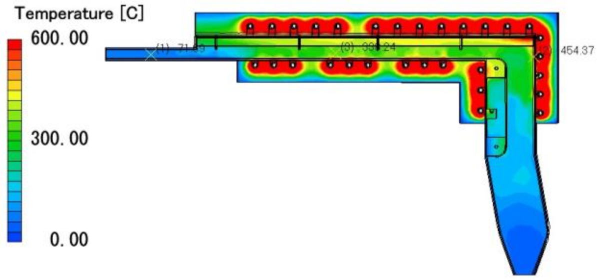


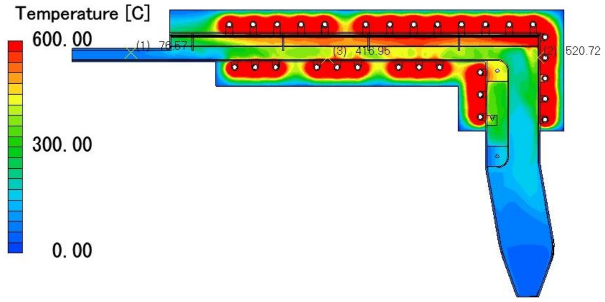
Figure 22 Mesh Setting for Moving Heating Analysis in the Work piece Chamber



(a) 60 seconds

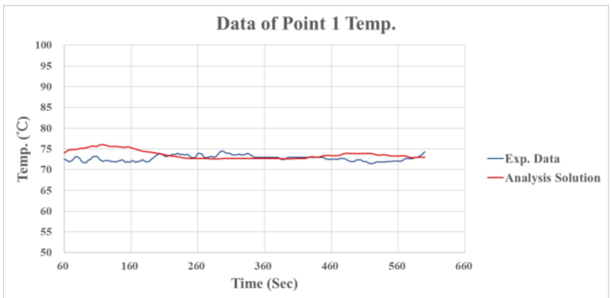


(b) 300 seconds

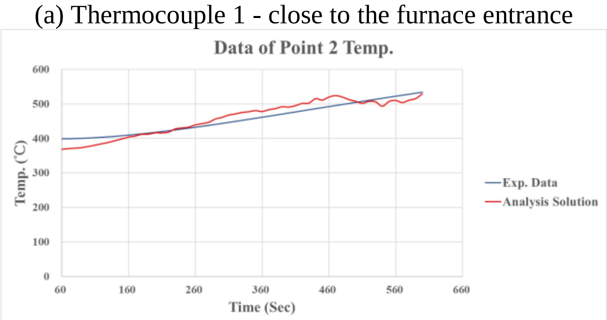


(c) 600 seconds

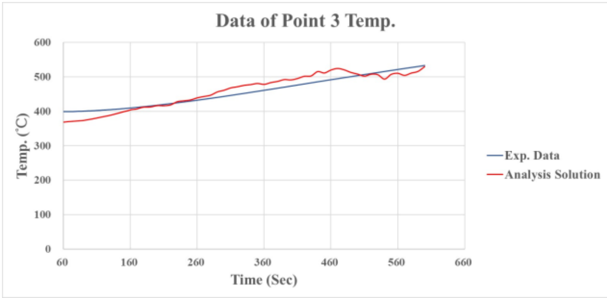
Figure 23 The temperature distribution of the thermal field analysis of the heating inside the chamber (a) 60 seconds; (b) 300 seconds; (c) 600 seconds



(a) Thermocouple 1 - close to the furnace entrance



(b) Thermocouple 2 - close to the furnace wall



(c) Thermocouple 3 - middle position

Figure 24 Comparison and verification of the temperature history of the internal heating thermal field analysis of the chamber

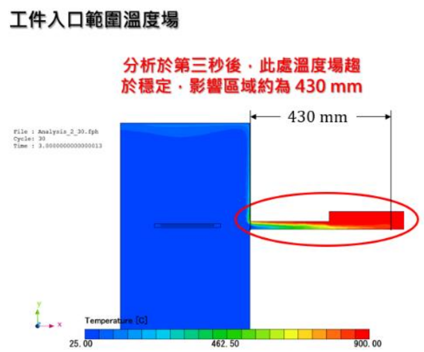


Figure 25 Heat exchange field at the entrance of the quenching furnace

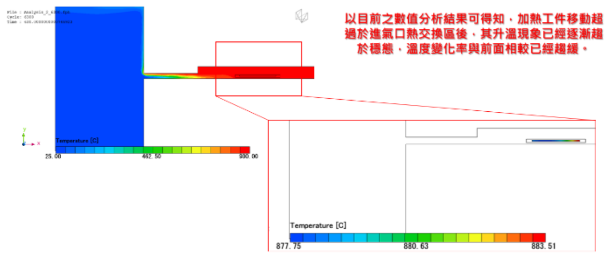


Figure 26 The result of moving the workpiece through the heat exchange field at the entrance to increase the temperature

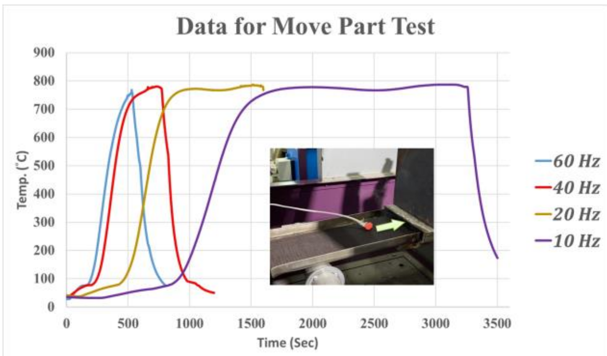


Figure 27 Experimental results of moving temperature rise in the work piece chamber

Table 1 The frequency of converter corresponding conveyor speed table of feeding system

Frequency, Hz	Conveyor speed , mm/min
10	26.2
20	52.1
40	103.4
60	157.9