Research on Pyrocondensation Parameters of Heat-shrinkable Tube Based on Numerical Simulation of Temperature Field

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Abstract. In this paper two different temperature fields of nozzles are simulated by Fluent software for molding process requirement of heat-shrinkable tube in spacecraft electronics assembly. And optimized molding process parameters of pyrocondensation are given by verification experiments. The results show that the nozzle type, blowing shrinkage time and shrinkage temperature are very important to the molding quality of heat-shrinkable tube.

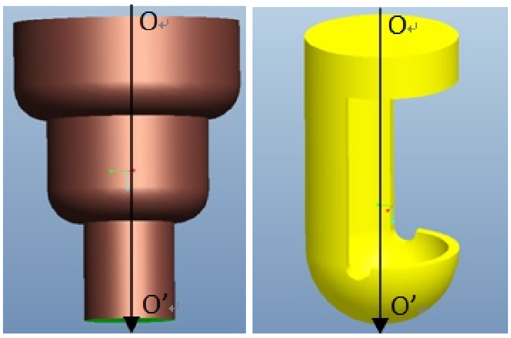
1. Introduction

Heat-shrinkable tube is a commonly used pyrocondensation protection material in the process of spacecraft electronic assembly. It is mainly used for the insulation protection of the welding spot after manual welding in the process of spacecraft electronic assembly [1].

As a kind of memory material, the memory effect of heat-shrinkable material is formed through the allotropy transformation of slow density polyethylene molecular structure. The molecular structure of memory material can be changed from linear structure into three-dimensional mesh structure under the effect of electron beam or cobalt radiation and has the memory function through the tensile or expansion processing methods [2]. To be specific, when heat is applied to the heat-shrinkable tube, the diameter of the tube will decreased rapidly and closely adheres to the surface of product being protected so as to guarantee the insulation of product. Since the hot air gun is the direct heat source in the process of pyrocondensation, the temperature distribution of the nozzle of hot air gun and heating time directly affect the forming quality and performance of heat-shrinkable tube [3]. Therefore, it is necessary to analyze the temperature field of the hot air gun in the process of pyrocondensation through the numerical simulation software to guarantee the thermal transmission performance and the thermal uniformity of the working surface, and finally study the reasonable and effective process parameters.

2. Numerical Simulation of Temperature Field

In this paper, mathematical models are established for the necking down nozzle and the backflow nozzle of HG-2310LCD type hot air gun, the temperature field and heat flow velocity are simulated numerically. The forms of nozzles are shown in Fig. 1.



(a) Necking down nozzle (b) Backflow nozzle

Figure 1. Three-dimensional modeling for nozzles.

2.1. Settings for Boundary Condition

In the finite element analysis and calculation process by using Fluent software, it is believed that the air inlet position is the air outlet position of the hot air gun in the calculation, the air flow direction is along the axis of the hot air gun nozzle. The air flow speed of the hot air gun is 2.5m/s, all other surfaces are set as pressure outlet and standard atmosphere pressure is 101,325Pa. Wall surface of heat-shrinkable tube is assumed to be fixed no-slip wall surface.

2.2. Mathematical Modeling

For the convenience of calculation, a cube whose computational domain is 1.5m×1.5m is established. The central position of a plane is defined as the outlet of the nozzle. At the beginning of calculation, the same temperature is set for the necking down nozzle and the backflow nozzle respectively. The entire computational domain is unstructured grid. And the number of grids at the top of the hot air gun is increased to about 650,000. The computational domain grid is shown in Fig. 2.

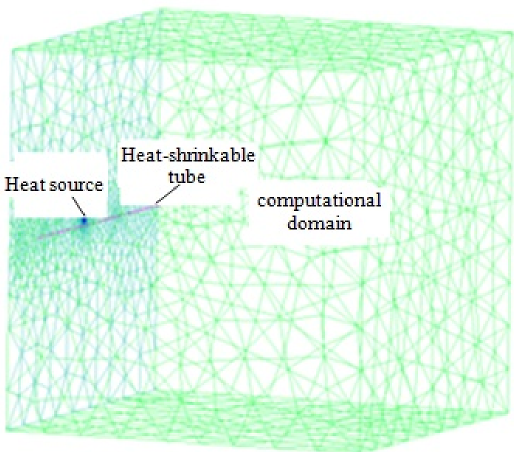


Figure 2. The computational domain grid.

2.3. Basic Assumptions

In the process of numerical simulation, it is necessary to simplify the heat transfer model of the heat-shrinkable tube. The simplified conditions are as follows:

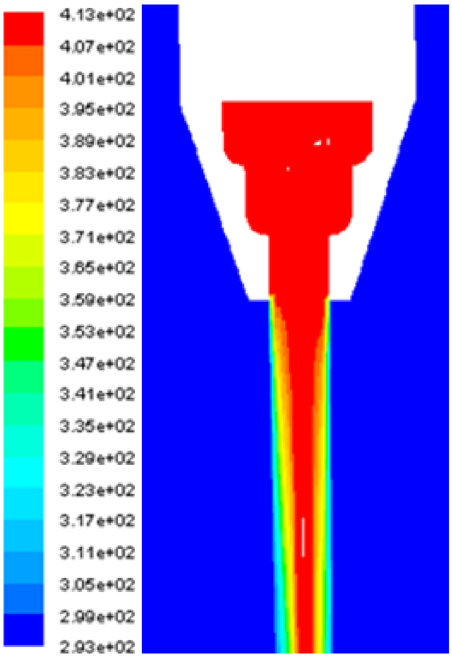
(a) Ambient air temperature is constant;
(b) Heating surface temperature of heat-shrinkable tube is uniform;
(c) Upper hot air inlet is set as velocity inlet;

(d) The thermo-physical parameters of high pressure polyethylene are constant in the range of test temperature;

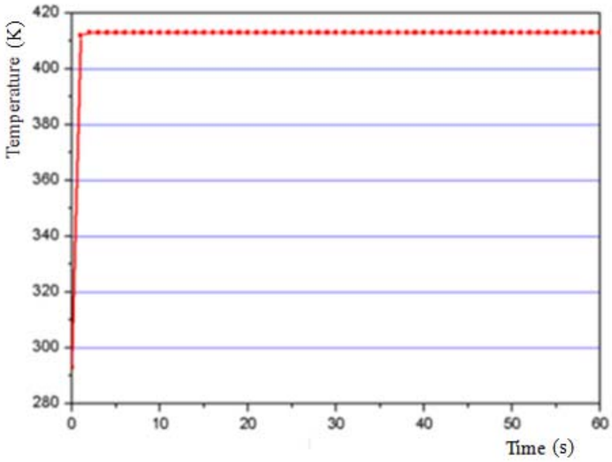
(e) Do not consider the radiation heat transfer in the heat transfer process.

2.4. Calculation Results and Analysis

The result based on Fluent temperature field analysis shows that the temperature field distribution gradient below the necking down nozzle is larger, the center temperature is high and close to the setting temperature, but the ambient temperature around central axis falls rapidly, the result is shown in Fig. 3.



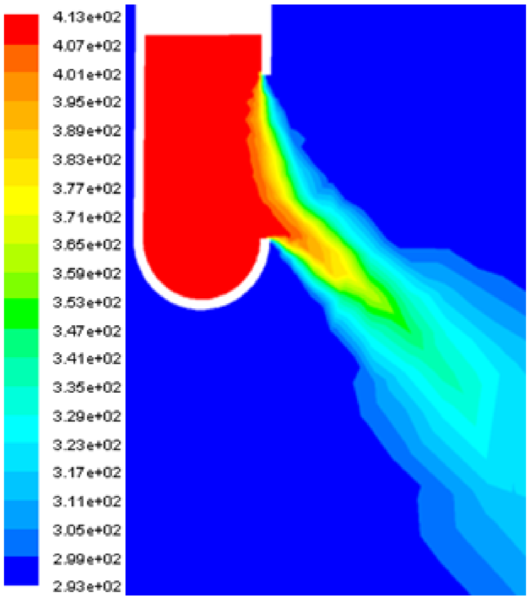
(a) Temperature field of necking down nozzle



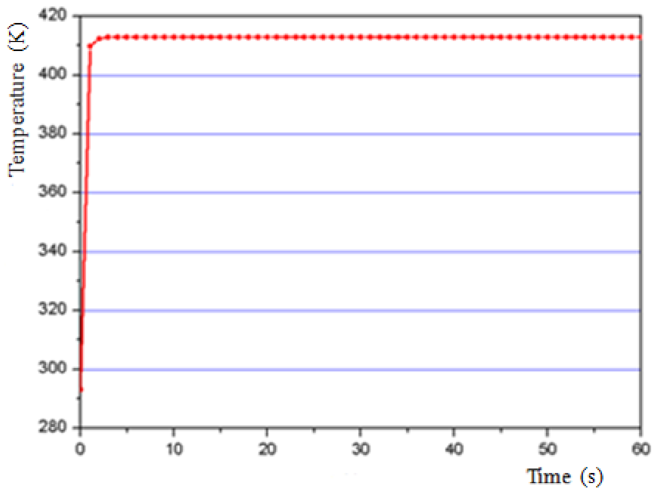
(b) Curve diagram of temperature field of necking down nozzle

Figure 3. Temperature field distribution of necking down nozzle.

In contrast the temperature field distribution gradient in the swirl chamber at the bottom of backflow nozzle is smaller, more uniform and has the characteristics of regional stability, the result is shown in Fig. 4.



(a) Temperature field of backflow nozzle



(b) Curve diagram of temperature field of backflow nozzle

Figure 4. Temperature field distribution of backflow nozzle.

It can be concluded from the curve diagram of exit temperature and time that the temperature in the temperature field of two different types of nozzles increases immediately after initial heating and both tend to be stable after two seconds.

The heat flow velocity of the two types of nozzles is simulated by Fluent software. It is known that the heat flow velocity in the central axis of necking down nozzle is high and the ambient speed is low. The result is shown in Fig. 5.

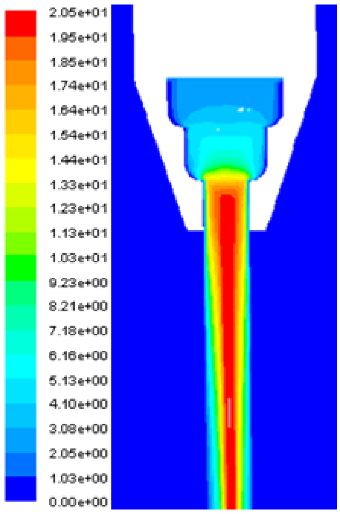


Figure 5. Heat flow velocity distribution of necking down nozzle.

However, the heat flow velocity in the swirl chamber of the backflow nozzle is affected by the bottom surface and presents a vortex distribution. The heat flow velocity in most areas below the nozzle is lower than the setting speed of the hot air gun. In addition, the velocity of heat flow at the bottom of the swirl chamber is lower because of cyclone formed by resistance as shown in Fig. 6.

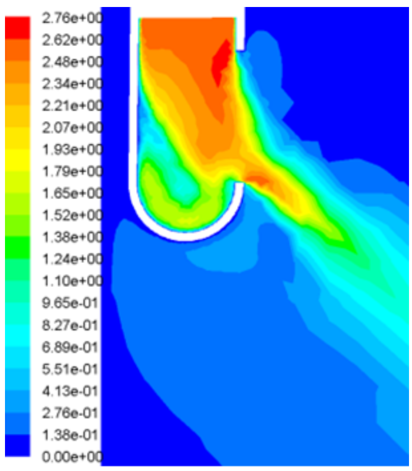


Figure 6. Heat flow velocity distribution of reverse flow nozzle.

Comparative analysis of two types of nozzles shows that the temperature field distribution in the cavity of backflow nozzle is more uniform. And because of the poor consistency of heat flow in direction, heat flow velocity is stable in most of the area in the cavity near the backflow nozzle. However, thermal gradient direction of necking down nozzle is single and heat flow tends to better consistency. Therefore, the backflow nozzle can make good heating uniformity on heating surface of heat-shrinkable tube, and it is not easy to produce fold and local displacement in shrinkage parts. Blow molding quality is better.

3. Design of experiment

3.1. Experimental Materials

The heat-shrinkable tube is mainly divided into two types: the single-wall heat-shrinkable tube without glue on the inner wall and the double-wall heat-shrinkable tube with glue on the inner wall. The double-wall heat-shrinkable tube is mainly used for the protection of electrical connector in the process of electronic assembly. The single-wall heat-shrinkable tube is mainly used for the protection of cable itself. In this paper blow molding technology of single-wall heat-shrinkable tube is mainly studied.

In the process of spacecraft assembly, high-pressure polyethylene is generally used as the main raw material. The thermal-physical parameters of heat-shrinkable tube made by radiation cross linking, heating and expansion are shown in Table 1.

Table 1. Thermal-physical parameters of high-pressure polyethylene.

No.	Item	Value
1	Density	0.91~0.92g/cm^3
2	Shore hardness	≥90
3	Tensile strength	≥15MPa
4	Elongation at break	≥300%
5	Volume resistivity	≥1×10^{13}Ωcm
6	Breakdown strength	≥20kV/mm
7	Restrictive shrinkage (shrink on mould core)	No cracks
8	Shrinkage temperature	110~140℃

3.2. Experimental Facilities

1) HG-2310LCD type hot air gun: The commonly used heat-shrinkable tube molding method is heating and shrinking with hot air gun, which has the advantages of simple operation and flexible use. Currently, hot air gun used in the process of spacecraft assembly is HG-2310LCD type, and its main performance is shown in Table **2**.

Table 2. Performance parameter of HG-2310LCD type hot air gun.

Rated Voltage	Power Consumption	Maximum Temperature	Temperature Adjustment Range	Adjustable Wind Speed
230~240V, 50Hz	2300W	650℃	50~650℃	150 ~500l/min

2) Pt100 platinum resistor: This experiment adopts the Pt100 platinum resistor (temperature measurement range -200℃~850℃) for real-time measurement of the temperature field near the hot air gun exit. Platinum resistor has a wide temperature measurement range as well as stable performance and repeatability, which is widely used for temperature measurement [4, 5]. The relationship between the resistance value and temperature is nonlinear. In this experiment, the relationship of the resistance value of platinum resistor and temperature is as follows.

In negative temperature zone (-200℃~0℃):

$$R_t=R_0[1+\mathrm{A}t+\mathrm{B}t^2+\mathrm{C}(t-100\ ℃)t^2] \quad (1)$$

In positive temperature zone (0℃~850℃):

$$R_t=R_0(1+\mathrm{A}t+\mathrm{B}t^2) \quad (2)$$

Where Rt means the resistance value at temperature t, Ω;

R_0 means the resistance value at temperature 0℃, Ω;

T means the temperature of medium, ℃;

A, B and C mean related division constant and their values are as follows:

A=5.00802×10^{-3}℃$^{-1}$;
B=-5.0195×10^{-7}℃$^{-2}$;
C=-4.27350×10^{-12}℃$^{-4}$.

3) Distance setting device: The distance setting device can reliably fix the hot air gun. The position between platinum resistor and the air outlet of the hot air gun can be adjusted continuously as well as the position between the heat-shrinkable tube and the air outlet of the hot air gun through the set screw so as to ensure that the heating surface of the contraction point is under the air outlet of the hot air gun and the position can be adjusted continuously.

3.3. Design of Process Parameters

The main physical parameters of the heat-shrinkable tube are:

(a) Shrinkage ratio;
(b) Lowest shrinkage temperature;
(c) Lowest complete shrinkage temperature;
(d) Tensile strength.

In this paper, according to the characteristics of heat-shrinkable tube and the results of Fluent finite element analysis, reasonable process parameters are selected and blow molding experiment of heat-shrinkable tube is carried out with single variable method [6].

In the various technological parameters affecting the quality of blowing shrinkage, the types of nozzles, heating temperature and time are mainly considered in this paper. The result based on Fluent finite element analysis shows that the heating temperature of hot air gun is correlative with the distance between shrinkage point and the outlet. The choice of the middle position in swirl chamber of backflow type nozzle is favorable for the heat uniformity of heat-shrinkable tube and good molding quality.

In this experiment, for convenient operation, Pt100 platinum resistor is used to convert temperature distribution near the nozzle to the distance parameter [7]. In this way real temperature of heat-shrinkable tube can be attained through a comparison table of distance and temperature. To fix the hot air gun a distance setting device is designed and its functions and usage are described in the previous section. At the same time for validation of finite element analysis results with Fluent software, experiment of temperature field distribution along the axis of backflow nozzle is carried out in this paper and the results are shown in Fig. 7.

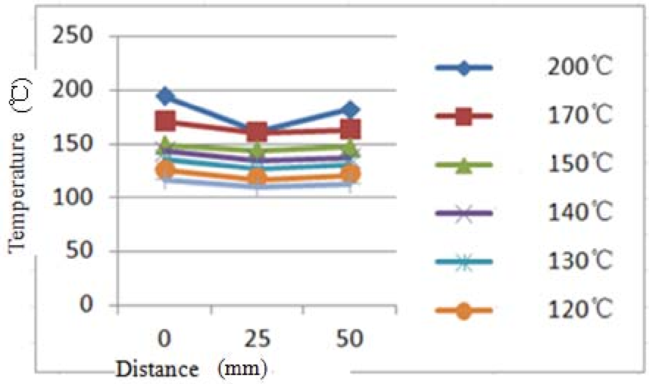


Figure 7. Temperature-distance curve of backflow nozzle.

The relationship between the distance and temperature near the outlet of the backflow nozzle is recorded [8]. The comparison datas are shown in Table 3.

Table 3. Temperature-distance comparison datas of backflow nozzle.

Setting Temperature (℃)	Distance from the Air Outlet (mm)	Resistance (Ω)	Corresponding Temperature (℃)
110	0	145	117
	20	142.3	110
	40	143.4	113
120	0	148.1	125
	20	145	117
	40	146.5	121
130	0	152	136
	20	149	127
	40	150.2	131
140	0	154.8	143
	20	151.6	135
	40	152.2	137
150	0	156.9	149
	20	155.2	144
	40	156.1	147
170	0	164.5	170
	20	161.2	160
	40	161.9	163
200	0	173.5	194
	20	161.5	161
	40	169	182

3.4. Experimental Results and Analysis
In accordance with the above process parameters and setting methods, necking down nozzle and the backflow nozzle are installed to the hot air gun outlet respectively for RSG Φ 22/10 heat-shrinkable tube for shrinkage experiment. Single variable method is used in the process to set the parameters. By setting different temperatures and different distances from 20mm to 40mm on the backflow nozzle compared with necking down nozzle, the forming quality of heat-shrinkable tube is analyzed under different process parameters. To assure operational consistency, the entire blowing shrinkage experiment is accomplished by the same people to eliminate the influence of operational factors on blowing shrinkage results. Each item is repeated three times and then takes the averages. Partial effective results are shown in Table 4.

Table 4. Results of blowing shrinkage experiment.

No.	Type	Distance (mm)	Temperature (℃)	Time (s)	Quality
1	Necking down nozzle	20	120	10	Small shrinkage, local displacement
2	Necking down nozzle	20	140	10	Even shrinkage, local displacement
3	Necking down nozzle	20	170	10	serious ablation, fold
4	Backflow nozzle	20	120	10	Small and even shrinkage
5	Backflow nozzle	20	140	10	even shrinkage, good blow molding
6	Backflow nozzle	20	170	10	serious ablation, fold
7	Backflow nozzle	20	140	15	surface ablation, fold

The blowing shrinkage experiment results indicate that, by using necking down nozzle, the surface of heat-shrinkable tube can't be heated unevenly because of the high velocity heat flow and large temperature gradient along the central axis. Too much axial shrinkage of heat-shrinkable tube results in displacement of the shrinkage parts. The shrinkage temperature raised up to 170℃ will lead to serious ablation, wrinkle and even singe damage.

Comparison analysis shows that heat flow in the swirl chamber form a cyclone because of blocking and has lower speed and relatively even distribution of temperature field. In most area within the cavity near the nozzle heat flow velocity is stable. At the position about 20mm from the outlet the heat-shrinkable cube shrinks evenly under the experimental condition of 140℃ and 10 seconds blowing shrinkage time. Blow molding quality is good with no fold.

At the same time, the experiment results also show that too short blowing shrinkage time and small heat input will lead to incomplete thermal shrinkage, and the heat-shrinkable tube will fall off easily. However, if the blowing shrinkage time is too long and the heat input is too large, it will lead to excess axial shrinkage, which will cause displacement, aging, uninsulation and even ablation of the already shrinkage parts.

The experimental results also verify the numerical simulation results of two types of nozzles. Namely, under the same distance and blowing shrinkage time, the backflow nozzle can make the heating surface of heat-shrinkable tube being heated evenly, better heating uniformity. And it is not easy to produce fold and local displacement at the shrinkage area, and the quality of blow molding is good.

4. Conclusion

In this paper, finite element analysis and experimental verification are performed on the blowing shrinkage process parameters of heat-shrinkable tube during the current spacecraft assembly process. Fluent software is used to simulate the temperature field of two types of nozzles of HG-2310LCD type hot air gun, platinum resistor is used to measure the temperature of temperature field, and combined with the simulation results, and the blowing shrinkage process experiment of heat-shrinkable tube is carried out. Results show that blowing shrinkage effect of high pressure polyethylene heat-shrinkable tube is strongly influenced by the nozzle type.

Because backflow nozzle has the effect of heat flux swirl and the temperature field distribution gradient in the swirl chamber is small, heat-shrinkable tube shrinkage is uniform, and it is not easy to produce fold and local displacement at the shrinkage area. At the position about 20mm from the outlet the heat-shrinkable cube shrinks evenly under the process parameter of 140℃ and 10 seconds blowing shrinkage time. Blow molding quality is good.

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