Modeling of the Glaze Layer Thickness Distribution Formed by the Air Spray Oriented to Glaze Spray Process Parameters

Zhao Botai[1, a *], Feng Hao[2b] , Cao Ligang[3,c] and Yu Shengrui[4,d]

the school of mechatronics, Jingdezhen ceramic institute , Jingdezhen , Jiangxi , China

[a]illgoon@qq.com, [b]fenghao@jci.edu.cn, [c]5013392@qq.com, [d]ysr.hotdog@163.com

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Abstract. In order to improve efficiency of modeling glaze layer thickness distribution via air spray, a novel fast modeling method was developed which oriented to glaze spraying process parameters. According to analysis of the affecting factors of glaze layer formation, apply the software of the Fluent was utilized to simulate, the glaze layer was simulated through the orthogonal experiment method, and the regression analysis method was used to build the mathematical relationship model between the main parameters of the glaze spaying and the glaze layer thickness distribution structural parameter. Given any a group spray glazing process parameters, and the model and the experiment were applied which can get the glaze layer thickness distribution structural parameters respectively. By comparing analysis that the relative error is within 5%, the accuracy of the model was verified. Therefore, the method oriented to glaze spraying process parameters has a certain engineering application value.

Introduction

Now most of spray models could be divided into conical spray torch and elliptical conical spray torch. The coating thickness distribution models of conical spray torch include uniform distribution[1]、β distribution[2] and combined distribution[3,4], etc. The coating thickness distribution model of elliptical conical spray torch include Cauchy distribution[5], Gaussian distribution[6], elliptical double β distribution[7], elliptical β distribution[8] and Gaussian sum distribution[9], etc. Those models which can't be applied to all considerations were supposed some conditions remain the same. When the conditions were changed , the models must be rebuilt and amended by the experiment every application. Wang[10] had taken the factors affecting the formation of the coating into consideration, using BP neural network to analysis the glaze layer thickness distribution. But the main disadvantages of the model was lack of Mathematical expressions which lead to hard to understand and quote the model. In order to solve the above problems, this paper analyzes the factors affecting the formation of the coating, determining 4 main factors, then using Fluent[11] software to do orthogonal experiment simulation, getting the glaze layer thickness distribution, utilizing regression analysis to establish the relation model between the glaze spraying process parameters and glaze thickness distribution structural parameters and verifies the model by glaze spraying experiments.

Analyses of the Affecting Factors Formation of Glaze Layer

In the process of glaze spraying, the main factors affecting the formation of the glaze layer conclude Atomization pressure, diaphragm pump pressure (glaze flux rate), spray distance, spray time, spray posture, spray medium and so on. Atomizing result depends on the atomizing pressure. Diaphragm pump pressure determines the glaze flux rate. Spray distance affects the glaze adherent rate on spray surface; Spray time depends on the binding character of ceramic body and glaze; spray posture requires air spray gun vertical to spray surface; spray medium should be selected according to physical properties such as density, viscosity ,surface tension and so on. This paper mainly takes the Atomization pressure P, diaphragm pump pressure (glaze flux rate Q), spray distance d, viscosity μ into consideration, and the other factors are permanent.

Simulation of Glaze Spraying

Geometric Modeling. Establishing the geometric model in Gambit, air spray gun channel and nozzle external flow field are shown in Fig.1 and Fig.2. The models show that: spray gun channel is the atomizing air channel in spray gun; nozzle external flow field is the downstream field which is out of nozzle. External flow field is open field which is defined as closed frustum of a cone in the simulation.

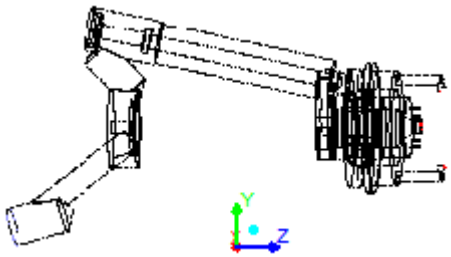

Fig.1. Air spray gun channel

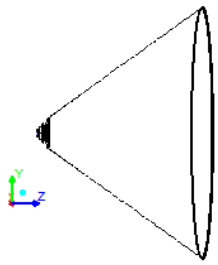

Fig.2. Nozzle external flow field

Glaze spraying simulation.(1)Select calculation models. According to the characters of air flow, selecting the RNG κ–ε mode which is based on the standard κ–ε mode. Chose the method of Euler-Lagrange proposed by C.T Crowe and L.D Smoot is to calculate the glaze particle equations of motion. Nozzle model requires the air assisted nozzle model and linear unstable liquid film model proposed by Schmidt. Taking Collision and aggregation into consideration in the simulation of glaze spraying, getting the critical value according to Rourke , judging Collision or aggregation which critical value is a function of Weber number, aggregating atomizing tube radius and glaze drop radius. Glaze broken model is Taylor broken model, getting the vibration and deformable in anytime by calculating particle vibration equation and deformable governing equation.

(2) Set simulation parameters.Pre-processing the mode by meshing geometric model which is imported into the Fluent software and set up the simulation parameters as follows: atomization pressure is 0.2MPa or 0.3Mpa, spray distance is 225mm or 250mm,initial mass flux rate is 0.006kg/s or 0.009kg/s, viscosity is 0.647 Pa· s or 0.740Pa·s,and the other factors are constant. Setting the discrete boundary as follows: the spray surface as wall-film, the exit and entrance as escape ,other surfaces as reflect. Setting the Iteration time step as 0.00001s, step number as 200000.

(3) Set orthogonal experiment parameters. According to the reason of glaze layer formation, defining the main parameters are atomization pressure, spray distance ,glaze mass flux rate and viscosity. Chose two levels of every parameter, shown in Table 1.Taking interaction effect into consideration, according to the orthogonal table $L_8(2^7)$ is to simulate glazing spraying.

Table 1. Glaze spraying process parameters and horizontal table

Parameters / levels	Atomization pressure (MPa)	Spray distance (mm)	Mass flow rate (kg/s)	viscosity （mPa· s）
1	0.2	225	0.006	647
2	0.3	250	0.009	740

Analysis of the simulation results. Dealing with simulation results, first, processing the data of glaze layer thickness; then ,establishing the mathematical model which contains spray glazing process parameters and glaze layer thickness distribution structural parameters. Those are shown as follows:

(1) Processing method of glaze layer thickness data

(a) Contour of glaze layer thickness distribution which is obtained in orthogonal experiment is shown in Fig.3.

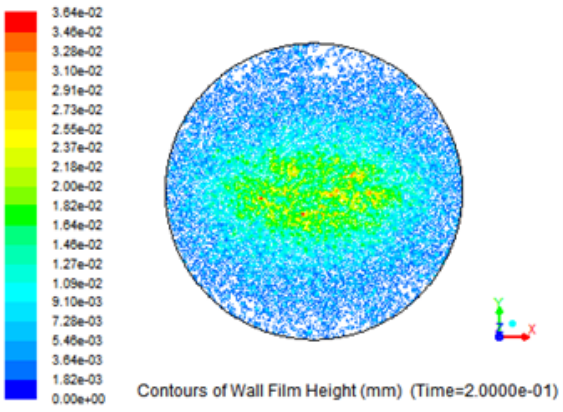

Fig.3 Contour of glaze layer thickness

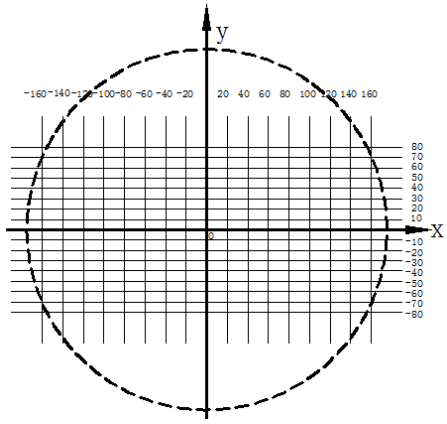

Fig.4 Diagram of extraction sections

The Fig.3 shows that: spray span is similar to elliptical distribution. The closer to spray axis, the thickness becomes bigger. For those experiments, contours are almost similar to each other, the main differences are maximum value of layer thickness and spray span.

(b) Schematic diagram for extracting glaze thickness data in sections are shown as Fig.4. Setting the center of paint field as the origin of coordinates, the major axis is x axis, the minor axis is y axis. The spray span is divided into 17 sections that sampling interval is 10mm in direction of parallel to x axis, from x=-80mm to x=80mm.In a similar way, spray span is divided into 17 sections that sampling interval is 20mm in direction of parallel to y axis, from x=-160mm to x=160mm,then extracting glaze thickness data from the junctions of cross sections.

(2)Analysis of glaze layer thickness distribution

Elliptical double β model[7], Genetic Algorithm and the Least Squares Method are used to fit the section glaze layer thickness data of 8 glaze spraying experiments. The fitness function is defined as quadratic sum of differences between actual values and fitted values. The structural parameters of glaze thickness distribution are obtained as Table 2.

Table 2 Structural parameters of glaze thickness distribution

Item / No.	Semi-major axis a(mm)	Semi-minor axis b(mm)	Max thickness z_{max} (μm)	Distribution Value β_1	Distribution Value β_2
1	126.1283	46.5312	196.113	2.4136	4.7953
2	129.7613	49.6251	217.134	2.2361	4.8216
3	163.9327	63.2457	252.638	5.2316	6.3842
4	169.4357	66.1716	281.326	5.4161	6.7062
5	131.5967	54.7366	175.652	4.9638	5.8642
6	136.5651	56.7623	219.888	5.1236	6.3761
7	177.4898	70.5585	133.279	2.3607	4.3612
8	178.8653	76.0126	166.042	2.1862	4.1537

SPSS(Statistical Package for Social Science) is used to do multiple linear regression analysis. Assume the process parameters is defined as $G=[P, d, Q, \mu,1]^T$, the structural parameters of distribution is defined as $M= [a,b,z_{max},\beta_1,\beta_2]^T$, and the transition matrix is defined as $Z_{5\times5}$. The relationship is as follows:

$$Z_{5\times5} \times G_{5\times1} = M_{5\times1} \tag{1}$$

Substitute transition matrix, process parameters and structural parameters into Eq.1. The mathematical model of relationship between glaze spraying process parameters and structural parameters of glaze thickness distribution is eventually obtained, and specific expression is as follows:

$$\begin{bmatrix} 88.1473 & 1.6567 & -892.875 & 41.6126 & -285.948 \\ 81.2410 & 0.6833 & -150.9333 & 36.2892 & 146.1807 \\ -630.875 & 0.2450 & 18078 & 340.6129 & -67.0050 \\ -1.6578 & 0.0046 & 961.5417 & -0.0207 & -4.1279 \\ -4.8802 & -0.0025 & 599.9083 & 1.7546 & 1.5350 \end{bmatrix}_{5\times5} \times \begin{bmatrix} P \\ d \\ Q \\ \mu \\ 1 \end{bmatrix}_{5\times1} = \begin{bmatrix} a \\ b \\ z_{\max} \\ \beta_1 \\ \beta_2 \end{bmatrix} \tag{2}$$

According to the Eq.2, the structural parameters of glaze thickness distribution can be acquired when the glaze spraying process parameters are set.

Verification of Mathematical Model

Application of Mathematical Model. Set a set of main process parameters: atomization pressure is 0.3MPa, spray distance is 250mm, glaze mass flux rate is 0.009kg/s, viscosity is 0.647 Pa· s, and simulation time is 2s. Other parameters qualify production demand and remain. The structural parameters of glaze thickness distribution are obtained through Eq.2.

$$\begin{bmatrix} 88.1473 & 1.6567 & -892.875 & 41.6126 & -285.948 \\ 81.2410 & 0.6833 & -150.9333 & 36.2892 & 146.1807 \\ -630.875 & 0.2450 & 18078 & 340.6129 & -67.0050 \\ -1.6578 & 0.0046 & 961.5417 & -0.0207 & -4.1279 \\ -4.8802 & -0.0025 & 599.9083 & 1.7546 & 1.5350 \end{bmatrix}_{5\times5} \times \begin{bmatrix} 0.3 \\ 250 \\ 0.009 \\ 0.647 \\ 1 \end{bmatrix}_{5\times1} = \begin{bmatrix} 173.5639 \\ 71.1453 \\ 188.0560 \\ 5.1590 \\ 5.9756 \end{bmatrix} \tag{3}$$

The function of glaze thickness distribution is as follows:

$$z(x,y) = 188.0560\left(1-\frac{x^2}{173.5639^2}\right)^{5.1590-1}\left[1-\frac{y^2}{71.1453^2\left(1-x^2/173.5639^2\right)}\right]^{5.9756-1} \tag{4}$$

Glaze distribution based on experiment. Glaze spraying experiment system is consist of glaze spraying room, air spray gun, feeding glaze and so on. Glaze spraying room is main structure of the system and consist of rotating platform, spray gun fixture, cleaning glaze, recycling device and so on. After spray glazing on porcelain plate, the plate is cut into small strips per 20mm along the spray span major axis and per 10mm along the spray span minor axis. And those are measured the glaze thickness by digital microscope. In the experiment, the parameters are set as the same as above. After getting the data of glaze thickness, the distribution function of glaze thickness can be fitted through elliptical double β method and Genetic Algorithm.The result is as follows:

$$z(x,y) = 191.3167\left(1-\frac{x^2}{176.5261^2}\right)^{4.9173-1}\left[1-\frac{y^2}{71.3627^2\left(1-x^2/176.5261^2\right)}\right]^{5.7314-1} \tag{5}$$

Comparison of the distribution structural parameters. In the consistent of glaze craft parameters, compare the result of Eq.2 and experiment of glaze layer thickness distribution structural parameters are shown in Table 3. From Table 3 we can know that the difference of distribution structural parameters obtained by Eq.2 and experiment are less than 5%.

Table 3 Comparison the distribution structural parameters

distribution structural parameters	Acquire by（3）	Acquire by Experiment	Relative errors
Semi-major a (mm)	173.5639	176.5261	1.68%
Semi-minor b (mm)	71.1453	71.3627	0.30%
Max thickness z_{max} (μm)	188.0560	191.3167	1.70%
Distribution index β1	5.1590	4.9173	4.91%
Distribution index β2	5.9756	5.7314	4.26%

Conclusion

Glaze layer thickness data were simulated through the orthogonal experiment method and glaze layer thickness distribution were obtained by fitting, and using the regression analysis method to establish the relationship mathematical model between the main parameters of the glaze spaying and the glaze layer thickness distribution structure parameters. Given any a group glaze spaying process parameters, using the model that we can get the glaze layer thickness distribution structure parameters and by comparing analysis with the experiment method that the relate error is within 5%, so that we can verify the accuracy of the oriented to glaze spaying process parameters model.

Acknowledgments

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