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Numerical Analysis of Natural Convection inside Spray Coating Room on Temperature Distributions

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자연대류를 고려한 스프레이 코팅 룸에서의 온도분포 해석

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Abstract Zinc coatings are widely used because of their environmental friendliness and high performance. In general, the coating temperature is a major factor in determining the coating layer thickness and coating quality. In the case of a zinc coating, a uniform and appropriate coating temperature is required. In this study, a thermal flow simulation of the air flow was performed to analyze the temperature distribution of a zinc spray coating room in a natural convection state. Using SolidWorks, modeling was performed for two spray coating rooms, a preheating room, and a drying room, and a thermal flow coupled analysis was performed using ANSYS-FLUENT. As a result of the analysis, the temperature distribution characteristics in the spray coating rooms were determined. It was found that the present temperature was below the target temperature of 25°C. Simulations were conducted for two different boundary conditions (one with a heater added and another with the open part closed). The simulation results show that the method of closing the open part is better than adding the heater.

요 약 아연말 코팅은 친환경성 및 고성능으로 인하여 널리 사용되고 있다. 일반적으로 코팅온도가 코팅층 두께 및 코팅 품질을 결정하는 주요한 요소이며 아연말 코팅의 경우에도 코팅 룸 내 균일하며 적절한 코팅온도가 요구된다. 본 연구에서는 일반적으로 사용하는 자연대류 상태에서의 아연말 스프레이 코팅 룸의 온도 분포를 해석하기 위해 룸 내부의 공기 유동을 포함하는 열 유동 전산 시뮬레이션을 수행하였다. 3차원 CAD 프로그램인 SolidWorks를 이용하여 스프레이 코팅 룸 전체와 예열실과 건조실을 모두 고려한 모델링을 수행하였으며 ANSYS의 FLUENT 프로그램을 이용하여 열 유동 연성 해석을 수행하였다. 해석 결과 스프레이 코팅 룸에서의 온도 분포 특성을 파악할 수 있었으며, 현재의 상태로는 목표 온도 값인 25 °C에 미달하고 있었음을 알 수 있었다. 이에 두 가지 다른 경계조건 (히터를 추가하는 방법과 현재 상태에서 Open 부분을 닫는 방법) 에 대해 열 유동 시뮬레이션을 수행하였으며, 시뮬레이션 결과 히터를 추가하기보다는 Open된 부분을 닫는 방법이 더 좋은 결과를 나타내었다.

Keywords : Natural Convection, Spray Coating Room, Temperature Distribution, Thermal Flow, Zinc Coating

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1. Introduction

In accordance with the EU Restriction of Hazardous Substances Directive (RoHS), the use of hexavalent chromium (Cr+6), which is an environmental regulation substance, has been banned since 2007. Therefore, research on Cr-free coatings such as bolts and nuts is actively conducted [1-2]. Among them, the zinc-coated steel has excellent resistance to corrosion, which can withstand corrosion in the atmosphere, prolonging the life of steel, and being widely used throughout the industry due to its advantages such as low price, no smell and harmlessness of human body [3-4].

The spraying method is widely used as a method of the Zinc coating. In general, the coating temperature is an important factor in determining the coating layer thickness and coating quality [5-6]. Therefore, the optimal coating temperature is also required for spray coating. Temperature control for the uniform temperature distribution of the spray coating room is a very important process element. Kim et al. [7] analyzed the temperature distribution characteristics through the thermal flow analysis of the spray coating room and studied ways to obtain the optimal temperature distribution.

In this study, the temperature characteristics in the natural convection state, in which the fan is not operated due to the noise, as a part of the study on the improvement of the temperature distribution in the spray coating room was analyzed. The preheating room, the drying room and the partially open structure existing before and after the spray coating room were modeled, and the heat flow analysis in the natural convection state by the heater was performed.

2. Analysis Model

The process sequence of the spray coating is shown in Fig. 1. (a) to (d) are the preheating room, the first spray room, the second spray room, and the drying room, respectively. The preheating room (a) is a place where the heater can be used to preheat the air and to set the optimum temperature for the spray coating. In winter, the temperature of the coating object(substrate) is very low, which is not suitable for coating. The temperature is adjustable from approximately 150 °C to 190 °C. (b) and (c) are the first and second spray room, respectively, in which the coating material is sprayed on the substrate in spray form. (d) is a section for drying at 220 °C in order to evaporate the thinner attached to the substrate coated. In the figure, each room is partially open. In the preheating room (a) in Fig. 1, an inlet for charging the object is opened. Opener 1 & 2 are opened in the first and second spray rooms, and a drying chamber door (Opener 3) and an outlet are opened in the drying room. Fig. 2 shows the actual appearance of the mentioned open structure.

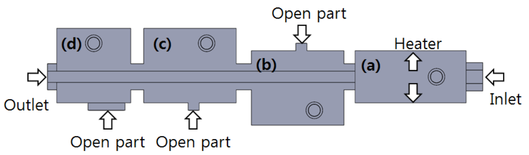


Fig. 1. Simple schematic figure of Zinc spray coating process; (a) Preheating room (b) First spray room (c) Second spray room (d) Drying room

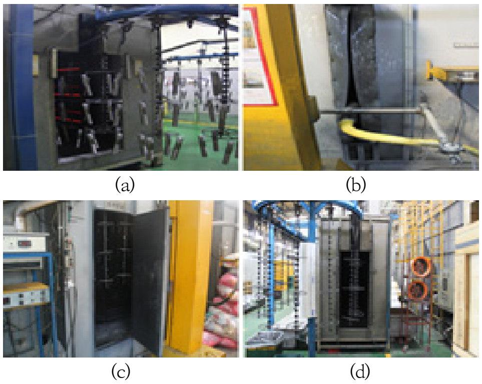


Fig. 2. Each opened portion of spray coating process; (a) Inlet of spray coating process (b) Entrance of spray gun (c) Drying room door (d) Outlet of spray coating process

Fig. 3 is a schematic view of a process in which the coating is spray coated. The substrate is suspended from the 3-stage round bar and transported by the rail. The transferred object is stopped at the spray gun inlet, and the coating operation is started. Simultaneously with the rotation of the round rod, the spray gun moves upward and downward to spray the coating liquid.

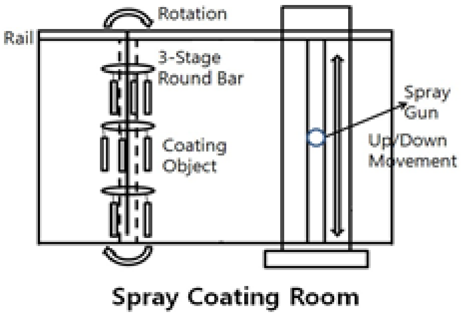


Fig. 3. Schematic figure of coating process in Zinc spray coating room

Fig. 4 is a model of the preheating room, the first spray room, the second spray room, and the drying room using the Solid Works program

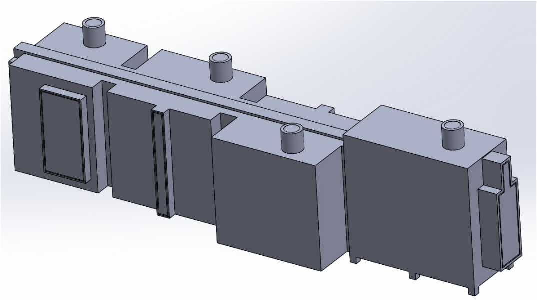


Fig. 4. 3-dimensional modeling of spray coating rooms

This study deals with the heat flow by natural convection. With fluid being Newtonian, three dimensional conservation equations for mass, momentum and energy are as follows.

$$\frac{\partial p}{\partial t}+\frac{\partial \rho u}{\partial x}+\frac{\partial \rho v}{\partial y}+\frac{\partial \rho w}{\partial z}=0$$

$$\rho(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z})=\rho g_x-\frac{\partial p}{\partial x}+u(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2})$$

$$\rho(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z})=\rho g_y-\frac{\partial p}{\partial y}+u(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2})$$

$$\rho(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z})=\rho g_z-\frac{\partial p}{\partial z}+u(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2})$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=\alpha(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2})$$

where u, v, w: x, y and z directional velocity

p: pressure

T: temperature

g_x g_y, g_z: x, y and z directional gravity acceleration

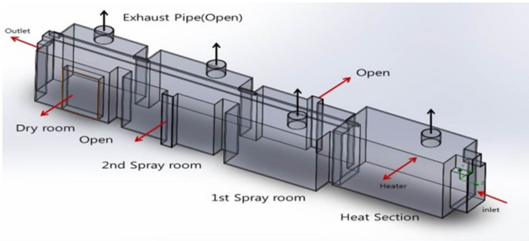
α: diffusivity.

The following three cases were considered as boundary conditions.

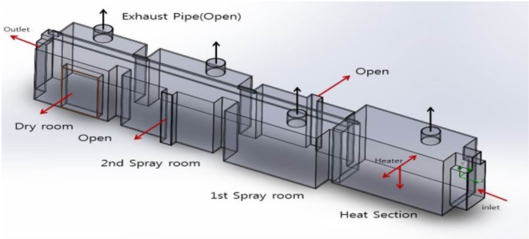
- Case 1: Considering the current state of use with open space
- Case 2: Same as case1 but a heater is added to the bottom of the preheating room
- Case 3: Changing the remaining open space except inlet outlet to closed

The outside air temperature was set at 5°C, which is the temperature in the winter factory.

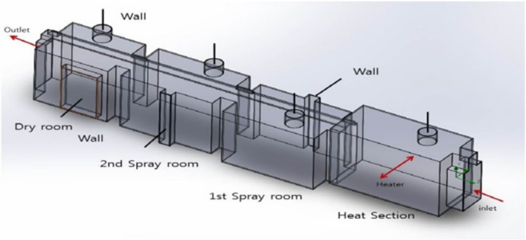
The boundary conditions of the three cases are given as shown in the Fig. 5.



(a) Case 1



(b) Case 2



(c) Case 3

Fig. 5. The boundary conditions of the three cases for numerical analysis of the heat flow in the natural convection state

3. Results and Reviews

ANSYS-FLUENT, the thermal flow analysis program, was used to investigate the heat transfer characteristics due to natural convection in a spraying room. Since the temperature distribution in the mid-vertical plane of each room (Fig. 6) is representative of the three-dimensional temperature distribution analysis through analysis, the result of the analysis shows the temperature distribution in the middle vertical plane.

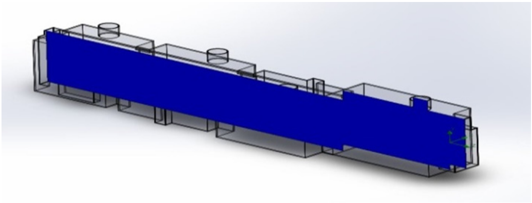
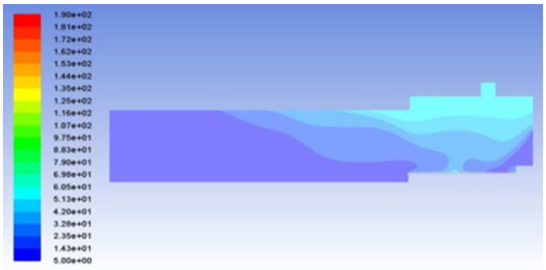


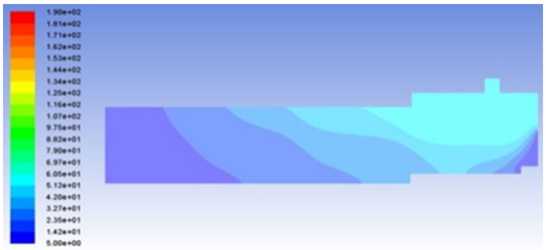
Fig. 6. The mid-vertical plane of each room.

Fig. 7's (a), (b), and (c), respectively, shows the result of the numerical analysis of the three boundary conditions (Case 1, 2 and 3) in Figure 5. All three analyses show the highest temperature in the preheating room and gradually heat transfer to the first and second spray rooms. This shows that the heat source in the preheating room is gradually transferred by natural convection. Fig. 7 (b) is the analysis that adds a heat source to the bottom of the preheating room, indicating that it improves the temperature of the preheating room and the temperature of the first and second spray rooms. Fig. 7 (c), with simply closed the open area without adding heat source to the preheating room, show the highest temperature distribution of both the preheating room and the first and second spray rooms. For all cases, we can see that the 1st spray room in both spray rooms is always higher than the 2nd spray room, which means that the 1st spray room is heavily influenced by the preheating room and there is less space open in the 1st spray room.

(a) Case 1



(b) Case 2



(c) Case 3

Fig. 7. Numerical results for temperature distributions of the boundary conditions of the three cases

Tables 1, 2 and 3 show the temperatures in Fig. 7 (a), (b), and (c), respectively, at the top, middle and bottom positions of the first and second spray rooms. All results show the highest temperature at the top position and the lowest temperature at the bottom position. It is also shown that temperatures of case 2 are higher than those of case 1 and temperatures of case 3 are higher than those of case 2.

Suitable temperature for spray coating is 25 °C. In the present state (case 1), the temperatures of the spray rooms are very low, indicating that it is not suitable for coating. Case 3 is the most suitable of the three boundary conditions. It can be seen that closing the open part is more effective than adding a heater to the preheating chamber.

Table 1. Temperatures of spray room for case 1 boundary condition

Position	1^{st} spray room	2^{nd} spray room
Top	18.7 °C	9.7 °C
Middle	16.1 °C	9.2 °C
Bottom	13.6 °C	8.6 °C

Table 2. Temperatures of spray room for case 2 boundary condition

Position	1^{st} spray room	2^{nd} spray room
Top	23.1 °C	12.2 °C
Middle	19.3 °C	11.1 °C
Bottom	15.6 °C	10.1 °C

Table 3. Temperatures of spray room for case 3 boundary condition

Position	1^{st} spray room	2^{nd} spray room
Top	33.8 °C	21.7 °C
Middle	30.9 °C	19.9 °C
Bottom	15.6 °C	10.1 °C

4. Conclusions

In this study, temperature distributions due to natural convection in the winter spray coating rooms were numerically analyzed. The following conclusions can be drawn from the study.

1. Numerical analysis of the heat flow distribution due to natural convection in the spray coating room was performed and the temperature distribution in the spray room was obtained. In the preheating room, the temperature rises due to the heater, and the temperature of the air passing through the preheating room is decreased by the external temperature(5 °C).
2. Both spray rooms show the highest temperature at the top, and the temperature decreases in the order of middle and bottom. We can see that the 1^{st} spray room in both spray rooms is always higher than the 2^{nd} spray room, which means that the 1^{st} spray room is heavily influenced by the preheating room.
3. For the three boundary conditions (current state, adding heaters to the preheating room, closing the open space), we found that closing the open space is a better method than adding heaters to the preheating room.

References

[1] J.K.Lee, H.K.Cho, M.J.Kang, D.J.Woo, S.H.Kim, S.J.Kim, "The Corrosion Comparision of the Bolt of Zinc Frake Coating in Line Test," Proceedings of the KISE Spring Conference, pp.147-148, 2011.

[2] S.S.Kim, A Study of Non-Chrome Flake Coating, Ph.D. Dissertation, Pukyong National University, 2010.

[3] J.R.Davis, "Corrosion: Understanding the Basics," ASM International, 2000.

[4] K.Y.Lee, K.W.Kim, "A Study on Numerical Analysis and Performance Improvement of Ventilation System in Coating Room," Journal of the Korea Academia-Industrial cooperation Society, vol.14, no.5, pp.2086-2091, 2013.
DOI: http://dx.doi.org/10.5762/KAIS.2013.14.5.2086

[5] J.W.Ha, H.Y.Park, "The Effect of Practical Size of Coating Powder and Coating Temperature on the

Thickness of Coating Layer Formed on Metal Surface," Journal of the Korean Industrial and Engineering Chemistry, vol.10, no.7, pp.1061-1065, 1999.

[6] K.H.,Seok, J.W.Ha, S.B.Lee, I.J.Park, H.J.Kim, "Surface Characterization of Poly(vinylidene fluoride) and Poly(methyl methacrylate) Blend Coatings Prepared by Dispersion Coating," Polymer, vol.37, no.2, pp.177-183, 2013.
DOI: http://dx.doi.org/10.7317/pk.2013.37.2.177

[7] N.W.Kim, K.Y.Lee, K.W.Kim, "Analysis of Temperature Distributions in Spray Coating Room." Journal of the Korea Academia-Industrial cooperation Society, vol.16, no.11, pp.7667-7671, 2015.
DOI: http://dx.doi.org/10.5762/KAIS.2015.16.11.7667

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