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TECHNIQUE TO IMPROVE PAINT UTILIZING EFFICIENCY OF WOODEN BOARD DURING ELECTROSTATIC SPRAYING PROCESS

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ABSTRACT

A technique to improve paint utilizing efficiency of wooden board during electrostatic spraying process was proposed. An experiment was carried out for verification of its feasibility. A finite element model for electric field between spray gun and wooden board was built by ANSYS software. Experimental results show that paint weight per square meter of wooden board surface after electrostatic spraying is increased significantly when the technique is used. Simulation results show that the electric field intensity between spray gun and wooden board is increased obviously when the technique is used.

KEYWORDS: Electrostatic spraying, finite element method, electric field, wood product.

INTRODUCTION

Wooden board is one kind of wood product. For example, wooden door, as the most familiar wood product, is the typical wooden board. In 2015, the total output of wooden doors in China had exceeded 50 million sets and the total output value had exceeded 120 billion RMB (Deng et al. 2015).

Electrostatic spraying has the advantages of high paint utilizing efficiency and low environmental pollution, which has been applied in wood product industry in recent years and is favored by wood product enterprises. In recent years, electrostatic spraying has been introduced into the coating process of wooden door (Deng et al. 2015). Paint utilizing efficiency is higher when metal workpiece is electrostatic sprayed. However, when wooden board is electrostatic sprayed, its paint utilizing efficiency is lower than metal workpiece, because of the insulation of wood. Therefore, improving paint utilizing efficiency of wooden board during electrostatic spraying process is an important research topic, which has remarkable social and economic benefits.

There are a lot of research results on electrostatic spraying process (Marchant 1985, Carlton and Bouse 1977, Kim and Hung 2007). Anestos (1986) developed a theoretical model which could predict the electric field distribution during air atomized electrostatic spraying process. An internal-corona (IC) gun operated at 1 Hz alternating polarity was used by Clements (1999) in an attempt to paint plastic plate. Theoretical and experimental results on electrostatic spraying of liquid insulators were presented by Woosley and Turnbull (1982). Giles and Law (1990) determined the passive effects of planar boundaries beneath idealized spray targets on the electro deposition of spray onto the targets. Surface potential of insulating plate coated by metallic paint had been investigated by Sugimoto et al. (2007). A novel technique for preparation of polymer coatings on electrodes was proposed by Hoyer et al. (1996).

Electrostatic spraying is also applied in pesticide spraying. Asano (1986) proposed the electrostatic spraying technology of liquid pesticide and made a thorough study about it. Maski and Durairaj (2010) studied the combined effects of electrode voltage, liquid flow rate and properties, which can enhance chargeability of electrostatic sprays for effective pesticide application. Zhao et al. (2005) found that the space charge does not affect the total current induced upon the liquid; rather, it affects the distribution between the space charge cloud current and electrode leakage current. Stover et al. (2003) found that environmental factors such as temperature, relative humidity, wind speed and wind direction also greatly influence spray deposition and drift. A numerical simulation technique was employed by Zhao et al. (2008) to model the charged droplet trajectories towards a spherical target for different droplet sizes, charge-to-mass ratios and nozzle-to-target distances.

In the field of wood industry, there is no related research about electrostatic spraying process. The electrostatic spraying process of wooden board has its own uniqueness, scientific and technical problems. Wood has its own special properties, which is different from metal, plastic or other. Wood painting is an important direction in the field of wood industry. The preparation technology of wood lacquer is more mature. The coating adhesion to the substrate, hardness and other coating quality are mainly determined by the performance of the wood lacquer. However, low utilization of coatings is an important problem in the field of wood products spraying. Low utilization of coatings is an important problem in the field of electrostatic spraying.

The electric field between wooden board and spray gun is weak and unstable, which results the lower paint utilizing efficiency during electrostatic spraying process. A technique to improve paint utilizing efficiency of wooden board during electrostatic spraying process was proposed. As shown in Fig. 1, there are two ways for the technique.

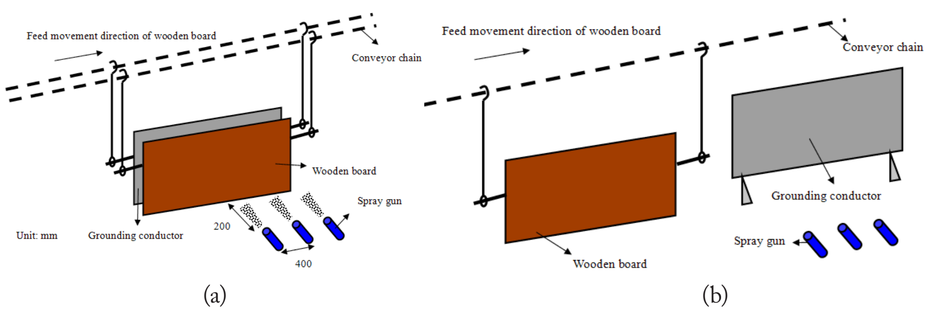


Fig 1: electrostatic spraying of wooden board with a grounding conductor. (a) way 1; (b) way 2.

One way is that the grounding conductor moves synchronously with wooden board. The other way is that the grounding conductor is fixed in front of spray guns. Wooden board is always between the grounding conductor and spray guns when it is under electrostatic spraying. The technique can enhance the electric field between wooden board and spray gun. The electric field force of charged paint particle is increased and the charged paint particle is more easily deposited on the surface of wooden board.

MATERIALS AND METHODS

Materials and equipments

Medium density fiberboard (MDF): 2000×800×25 mm. Moisture content of the MDF was about 8%~10%.

Decorative veneer: *Entandrophragma cylindricum*, 800×200×0.3 mm, with moisture content 8%~10%.

Aluminum foil conductive adhesive tape: 30000×800×0.2 mm. Aluminum foil conductive adhesive tape was used for grounding conductor, which can enhance the electric field between decorative veneer and spray gun.

Coating: X-7117 type UV (Ultraviolet curing) electrostatic spraying transparent primer, its main chemical component was acrylic. Diluent: US701 type UV electrostatic spraying diluent, its main chemical component was ethanol. The resistivity of diluted coating was about 30 MΩ•cm. Viscosity of the diluted coating was about 20 s using 4mm cup. JM20002 type electronic balance: measuring range 0~2000 g, precision 0.01 g.

Methods

The electrostatic spray equipment had three spray guns, which were arranged in horizontal direction with distance 400 mm, as shown in Fig. 1 (a). The spray gun was rotary cup type electrostatic spray gun and its diameter was 50 mm. Vertical reciprocating speed of spray guns was 40 m·min^{-1}. Horizontal feed speed of wooden board was 4.5 m·min^{-1}. Electrostatic voltage of spray guns was 60 kV. The distance between wooden board and spray guns was 200 mm.

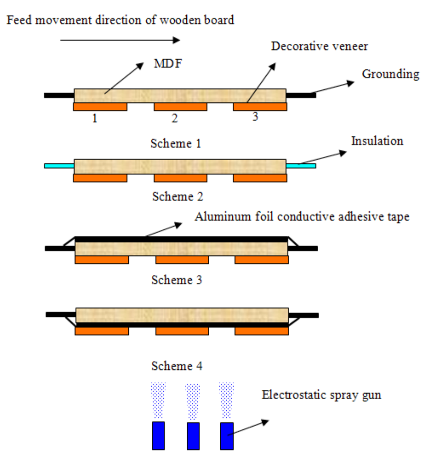


Fig. 2: Experimental scheme.

The decorative veneer was attached to the MDF. As shown in Fig. 2, there were four schemes for the experiment. Scheme 1 represented the traditional method. In Scheme 2, MDF was not grounded. Scheme 3 and 4 represented the technique proposed in this paper.

Decorative veneers of the 4 schemes were weighed before electrostatic spraying. The decorative veneers were spayed twice. After the first spraying, the decorative veneers were cured by ultraviolet and their weights were recorded. Then, the decorative veneers were attached to the MDF again. After the second spraying, the decorative veneers were cured by ultraviolet and their weights were recorded again. The real pictures of experiment were shown in Fig. 3.

(a) (b)

Fig. 3: Real picture of the experimental process.

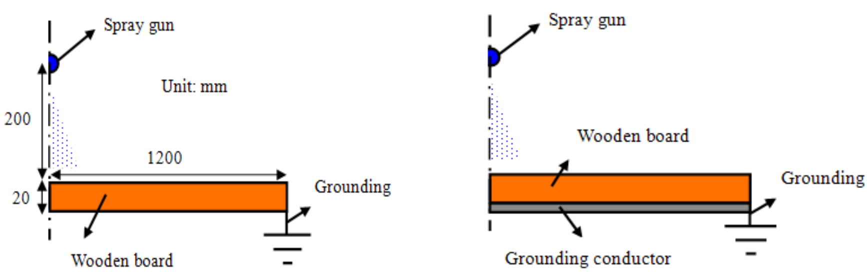
Establishment of the finite element model for electric field intensity

During electrostatic spraying process, the motion of paint particle is caused by electric field force, as shown below.

$$F = Eq \tag{1}$$

where: F - electric field force of paint particle (N),
E - electric field intensity (N/C),
q - the charge of paint particle (C).

The electric field intensity between wooden board and spray gun is the main factor to determine the paint utilizing efficiency. Therefore, two finite element models for electric field were built based on ANSYS software. One was about the traditional electrostatic spraying method. The other was about the technique proposed in this paper, as shown in Fig. 4. The geometry of spray gun was ignored and modeled as a sphere.



(a) (b)

Fig. 4: Simulation models of two electrostatic spraying methods.
(a)Traditional electrostatic spraying method, (b) New electrostatic spraying method.

Under normal temperature and humidity, the relative dielectric constant of wood is about 2~8. The relative dielectric constant of wood was set to 6 neglecting the effect of anisotropy of wood material. The relative dielectric constant of air medium between wooden board and electrostatic spray gun was set to 1. The finite element model after meshing was shown in Fig. 5.

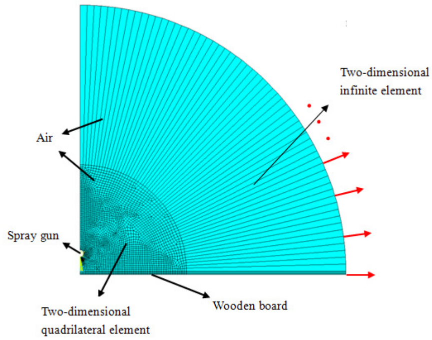


Fig. 5: Finite element model after meshing.

The boundary conditions of the two models were shown in Fig. 6. The electrostatic spray gun was a negative high voltage terminal, the voltage was 60 kV. In the traditional method, the end of wooden board in the length direction was grounded, with voltage 0 kV, as shown in Fig. 6 (a). In the new method, the grounding conductor on the back of wooden board was grounded, with voltage 0 kV, as shown in Fig. 6 (b).

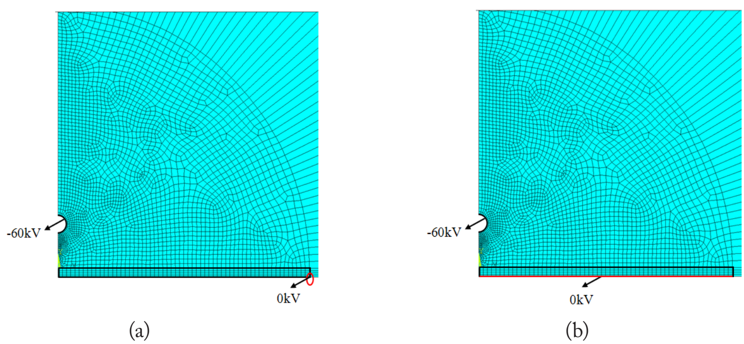


Fig. 6: Boundary conditions of two electrostatic spraying methods.
(a) Traditional method, (b) New method.

RESULTS

Experimental results

As shown in Tabs 1, 2, 3 4, the weight of decorative veneers of the four schemes was increased during electrostatic spraying process. As shown in Fig. 7, the average weight increase of decorative veneer of Scheme 1 was about 10.48 g after the first spray and 24.42 g after the second spray.

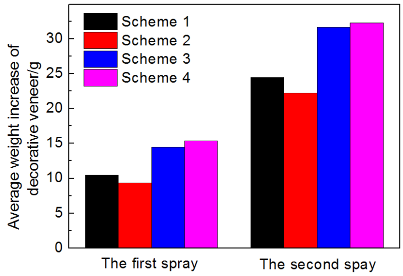


Fig. 7: Average weight increase of decorative veneer in four schemes.

The average weight increase of decorative veneer of Scheme 2 was about 9.35 g after the first spray and 22.21 g after the second spray. The average weight increase of decorative veneer of Scheme 3 was about 14.45 g after the first spray and 31.61 g after the second spray. The average weight increase of decorative veneer of Scheme 4 was about 15.35 g after the first spray and 32.28 g after the second spray.

The coating adhesion to the substrate, hardness and other coating quality of the four schemes are the same, because the wood lacquer is not changed during the whole experiment. The above phenomenon has been repeatedly verified by the industrial tests. Therefore, the research on the surface properties of coating during electrostatic spraying process is not described in this paper.

Tab. 1: Weight of sample after spay of Scheme 1.

Number of decorative veneer	Initial weight (g)	Weight after the first spay (g)	Weight after the second spay (g)
1	42.64	52.91	66.32
2	42.45	53.08	67.21
3	42.08	52.62	66.91
Average	42.39	52.87	66.81

Tab. 2: Weight of sample after spay of Scheme 2.

Number of decorative veneer	Initial weight (g)	Weight after the first spay (g)	Weight after the second spay (g)
1	43.19	52.46	65.02
2	43.09	52.68	65.65
3	43.11	52.30	65.35
Average	43.13	52.48	65.34

Tab. 3: Weight of sample after spay of Scheme 3.

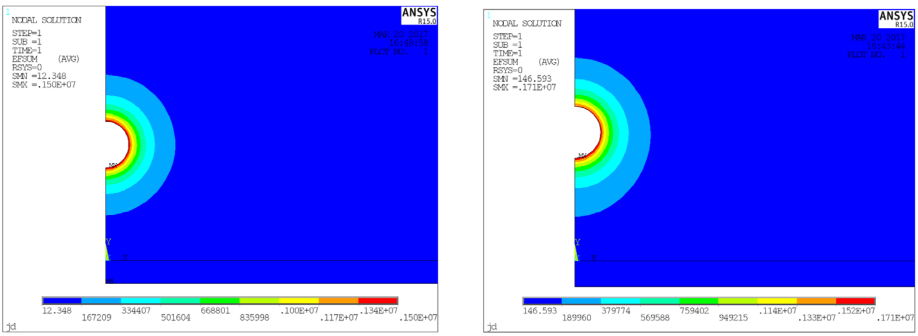
Number of decorative veneer	Initial weight (g)	Weight after the first spay (g)	Weight after the second spay (g)
1	43.54	57.58	75.66
2	42.47	57.21	73.33
3	43.41	58.00	75.28
Average	43.14	57.59	74.75

Tab. 4: Weight of sample after spay of Scheme 4.

Number of decorative veneer	Initial weight (g)	Weight after the first spay (g)	Weight after the second spay (g)
1	42.03	57.52	73.72
2	42.24	58.61	73.83
3	42.21	56.41	75.78
Average	42.16	57.51	74.44

Simulation results

Electric field intensity was shown in Fig. 8. Compared with traditional method, the electric field intensity of the new method was increased obviously. The peak of electric field intensity was increased from 1.5×106 V·m^{-1} to 1.7×106 V·m^{-1}, with an increase of about 13%.



(a) (b)

Fig. 8: Electric field intensity of two electrostatic spraying methods.
(a) Electric field of traditional method, (b) Electric field of the new method

The electric field under electrostatic spray gun was shown in Fig. 9. Compared with traditional method, the electric field intensity of each position between spray gun and wooden board was increased with the new method.

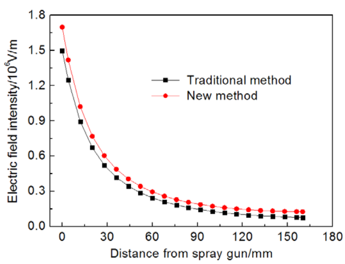


Fig. 9: Electric field intensity distribution under the electrostatic spray gun.

In the vicinity of electrostatic spray gun, the paint particle is fully charged and further atomized. With the increase of electric field intensity, the atomization and electrification effect can be enhanced. It makes the paint particle easier to move on the surface of wooden board under electrostatic field force.

DISCUSSION

As shown in Fig. 7, the paint utilizing efficiency of Scheme 4 was the highest because the electric field between decorative veneer and spray gun was the strongest. The aluminum foil conductive adhesive tape attached to the back of wooden board is the same as grounding conductor. It always maintains a 0 potential because of its excellent electrical conductivity. The potential difference between spray gun and aluminum foil conductive adhesive tape is increased. The charged paint mist is more easily adsorbed on wooden board.

Compared with Scheme 4, the paint utilizing efficiency of Scheme 3 was slightly lower. It is because the aluminum foil conductive adhesive tape attached to the back of wooden board in Scheme 4 is closer to spray gun than that in Scheme 3. The electric field between decorative veneer and spray gun is increased when the distance between aluminum foil conductive adhesive tape and spray gun is decreased.

The paint utilizing efficiency of Scheme 1 was the third highest. The paint utilizing efficiency of Scheme 2 was the fourth highest. The experimental results proved the feasibility of the technique proposed in this paper.

Scheme 1 represented the traditional method. Scheme 3 represented the technique proposed in this paper. The enhancement of electric field between wooden board and spray gun is the most important reason for the increase of paint utilizing efficiency. The simulation results clearly demonstrate this point, as shown in Figs. 8 and 9. Both theoretical and experimental results prove the feasibility and innovativeness of this technique, which is the main content and core of this paper.

There are two main factors that influence the electric field intensity between wooden board and spray gun, as shown below. Tepper et al. (1977) agreed that the surface of an insulated object has a definite electric potential when it is under high voltage electrostatic field. Sugimoto et al. (2007) also pointed out that the charge of paint mist also accumulates on the surface of insulated object during electrostatic spraying process, which will further increase the surface potential of insulated object. Potential difference between the surface of insulated object and spray gun is decreased because of the electric potential increase on the surface of insulated object. The decrease of potential difference directly leads to the decrease of electric field intensity. Clements (1999) pointed out that insulated plastic plate can be electrostatic powder sprayed with metal backing. Although he just mentioned it without any research on its mechanism and effect, he indirectly proved the argument in this article. Therefore, in order to alleviate the above adverse effects during electrostatic spraying process of wooden board, the grounding conductor is set behind the wooden board, which will increase the electric field intensity between the wooden board and spay gun.

The area of decorative veneer in the experiment was 0.16 m^2 (800×200 mm). The paint weight per square meter of Scheme 1 was about 65.5 $g \cdot m^{-2}$ after the first spray and 152.63 $g \cdot m^{-2}$ after the second spray. The paint weight per square meter of Scheme 3 was about 90.31 $g \cdot m^{-2}$ after the first spray and 197.56 $g \cdot m^{-2}$ after the second spray.

Take wooden door as an example, if the average area of wooden door is 2.0 m^2 (2000×1000 mm), then it will save about 90.0 grams of paint after two times of spraying. Take China as an example, Deng et al. (2015) pointed out that 50 million sets of wooden doors had been made in 2015. If the technique can be widely used in the spraying of wooden door, it will save about 4.5×10^6 kg paint every year.

CONCLUSIONS

(1) A technique to improve paint utilizing efficiency of wooden board during electrostatic spraying process was proposed in this paper. Its key point is that the wooden board is always between a grounding conductor and spray gun when it is under electrostatic spraying.
(2) Experimental results show that the paint weight per square meter of wooden board is increased from 65.5 $g \cdot m^{-2}$ to 90.31 $g \cdot m^{-2}$ after the first spray and from 152.63 $g \cdot m^{-2}$ to 197.56 $g \cdot m^{-2}$ after the second spray with the technique proposed in this paper.
(3) Simulation results show that the electric field intensity between spray gun and wooden board is increased obviously with the technique proposed in this paper.

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