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EFFECTS OF SURFACE TREATMENT ON THE PROPERTIES OF UV COATING

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ABSTRACT

The influence of the surface treatment of raw medium-density fiberboard on the properties of 1st ultraviolet putty coating film and the effects of primer coating arrangement on the qualities of 1st ultraviolet primer film were investigated. With regard to surface roughness and the recorded adhesion of the coating film, there were significant variations when the surface treatment was modified or when the coating arrangement was changed. The findings led to the conclusion that there was a close relationship between the surface treatment as well as the coating arrangement and properties of the coating film.

KEY WORDS: Medium density fiberboard; UV filler; UV basecoat; surface treatment; coating film properties; roller coating.

INTRODUCTION

Ultraviolet (UV) curable resins have now been widely used in surface treatment, electronics, pigmentation, and adhesive fields due to their distinctive features of fast cure speed, energy-saving characteristic, and lower pollution potential (Jung et al. 1998). In wood industries, UV coating normally can be used in the surface decoration of woodwork. In previous works, various studies have been conducted to study the properties of UV curable resins, the usage of UV curable coating, and the quality of the final products of UV coatings.

Ali et al. (1997) researched the UV curing of epoxy coating on a wood surface. In their research, different formulated solutions of thin film were coated on a low-grade wood substrate, and then both of the UV-cured thin films and surface coatings were characterized. They concluded that high-density, quality wood can be acquired by using this low-grade wood substrate as a substitute in some cases.

Jung et al. (1998) conducted a series of experiments to clarify the effects of different polyols and acids on the properties of UV-curable, waterborne unsaturated polyesters for wood coating. It was shown that unsaturated polyester prepared with 60/40 (mol %) TMAn/THPAn and an equimolar mixture of ethylene glycol, diethylene glycol, and propylene glycol could acquire balanced coating properties. Irissin-Mangata et al. (2000) investigated the vapor permeability and other functional properties of bilayer films composed of wheat gluten film and UV-cured coating. The UV coatings chosen by the authors were found to reduce both the water solubility and the water vapor permeability of gluten film by half. Good adhesion was achieved between the UV coating and the gluten film, suggesting a need for further study of the usage of UV coating on original materials. Ali et al. (2001) evaluated new polyester acrylate resins from palm oil for wood coating applications. Palm oil-based acrylate polyester resins were synthesized and tested with respect to their curing rate and the physical-mechanical properties of cured products. Studies have indicated that oil-based resins can be used as radiation-curable coating materials for wood coating applications.

Simmons and Lowe (2004) conducted a study on adhesion and flexibility in radiation-cured coil coatings. In their study, the coil coating was applied to a flat metal sheet by both conventional thermally cured systems and radiation-curing systems. Differences between the two systems were demonstrated, and some conventional "paint tests" and surface analytical techniques were used to evaluate them.

Petry and Kent (2004) investigated the UV-curable formulations and matting agents on lacquer properties and drew the conclusion that the type of monomer and the organic treatment of the matting agent used played a significant role in the matting efficiency and foam.

Hwang et al. (2009) examined the effect of water-drying conditions on the surface properties and morphology of waterborne UV-curable coatings for engineered flooring. The results showed that sufficient drying played a significant role in the best application and ideal surface morphology of waterborne UV-curable coatings.

The aim of this paper was to investigate the effects of the surface roughness of raw MDF board and the coating times on the performances of UV putty and 1st UV primer. Surface roughness and adhesion were chosen to evaluate these performances.

MATERIAL AND METHODS

Material

The Medium Density Fiberboard (MDF) used in the series of experiments was provided by the Jiangsu Dare Global Wood Company (China). The surface density of these samples was 0.84 $g.cm^{-3}$, and the moisture content was 8.9 %. The size of samples for this UV roller coating test was 500 (length) × 200 (width) × 18 mm (thickness).

Both the UV putty (UK 8371) and UV primer (UF 8187-9004) tested were supplied by the Sherwin-Williams Company (Shanghai, China). The technical data of the UV putty and UV primer, tested by the company, are shown in Tabs. 1 and 2, respectively.

Tab. 1: Technical data of UV putty type UK 837.1.

Color	Specific gravity ($g.mL^{-1}$)	Viscosity (23°C)	Resin	Solvent	Coating way	Effective wavelength of UV curing	Radiation curing energy ($mJ.cm^{-2}$)
Grey White	1.44	18000 ~22000 mPa•s	Unsaturated Acrylic Ester	None	Roller Coating	UVB 280~320 nm	Partially Curing: 200 Fully Curing: 450

Tab. 2: Technical data of UV primert type UF 8187-9004.

Color	Specific gravity ($g.mL^{-1}$)	Viscosity (23°C)	Resin	Solvent	Coating way	Effective wavelength of UV curing	Radiation curing energy ($mJ.cm^{-2}$)
White	1.74	1800 ~2200 mPa•s	Unsaturated Acrylic Ester	None	Roller Coating	UVV 395~445 nm	Fully Curing: 500

Methods

To acquire different surface qualities, the MDF boards were sanded by a twin-head wide-belt sander (Impression Gold LL, HEESEMANN, Germany) with a feed rate of 3.5 $m.s^{-1}$. Then, a commercial UV putty coating machine (SAS-1300, BURKLE, China) was used for the putty coating process; the coating weight was 25 $g.m^{-2}$.

The coated boards were then dried by an industrial UV curing machine (UV2-1300, BURKLE, China), which contains two UV lamps (a Gallium Lodine Lamp with UV wavelength: 395-445 nm and a medium pressure Hg UV lamp with UV wavelength: 280-320 nm). To test the effects of UV putty coating times on the properties of the 1st UV primer, the coated putty was partly cured between putties and fully cured when the putty curing process was finished. The fully cured, putty-coated boards were then sanded using the twin-head wide-belt sander again with different sandpapers (320, 400, and 600 grit abrasive papers with a sanding thickness of 0.1 mm) and also cleared in the next step. Finally, the 1st UV primer was coated on the sanded and cleared UV putty, and the UV primer was fully cured.

Test of surface roughness

The sanded MDF boards were tested using a contact diamond stylus (Perthometer M2, Mahr, Germany) with a 5μm tip radius, where the cut-off length was 2.5 mm. The roughness parameter was characterized by the ISO 4287 (1997) standard, and the arithmetical mean deviation Ra was taken to assess the surface characteristics of the MDF samples (Aguilera 2011).

Coating film flatness was also tested by using surface roughness (also the arithmetical mean deviation Ra) to estimate the surface qualities of the 1st UV primer.

Test of coating film adhesion

The crosscut method was applied for measuring the adhesion of the UV-cured coating on the MDF surface. The greater chipped-off area, the worse the film adhesion. According to the Chinese standard GB/T 9286-1998, scribing a grid of lines (cutting length of 10 to 20 mm and width of 1 mm) through the coating in the pattern of 10 × 10 squares can generate sufficient forces to cause adhesion loss in some coatings. Following scribing, "Scotch Tape" was then applied and peeled off rapidly to lift off any loosely adhering particles (Simmons and Lowe 2004). The percentage of the particles peeled off relative to the 100 squares represented the adhesion of the coating film.

Plan of the experiment

Two full factorial experiments were conducted. The first one was to test the effects that the surface roughness of raw MDF boards has on the adhesion of 1st UV putty. Seven MDF boards were sanded using different configurations of sandpaper (seven levels: 0, 120, 180, 240, 320, 400, and 600 grid abrasive papers with 0.1 mm stock removal), and the surface roughness of each board was measured after cleaning.

Then, a second full factorial experimental design was established to determine the effects of the properties of the 1st UV primer, where the main variables were the UV putty coating times (three levels: 1, 2 and 3 times) and the configurations of sandpaper (three levels: 320, 400 and 600 grid abrasive papers with 0.1 mm stock removal), as shown in Tab. 3.

Tab. 3: Assignment of levels to factors.

Level	Times of UV putty coating	Configuration of sanding papers
1	1	320# / 320#
2	2	400# / 400#
3	3	600# / 600#

An analysis of variance (ANOVA) was performed using the Statistical Product and Service Solutions (SPSS version 20.0) software to study the influence of sanding paper configuration on the coating film adhesion of the 1st UV putty. The influence of UV putty coating times, sandpaper configurations as well as their interactions on the coating film properties (roughness and adhesion) of the 1st UV primer in the MDF UV pigment roller coating process were determined.

RESULTS AND DISCUSSION

Analysis of coating film adhesion of the 1st UV putty

Relationship between surface roughness of raw MDF and coating film adhesion of UV putty

Fig. 1 shows the changes in surface roughness (R_a) with the sandpaper configuration and the changes in coating film adhesion of the 1st UV putty with the surface roughness (R_a).

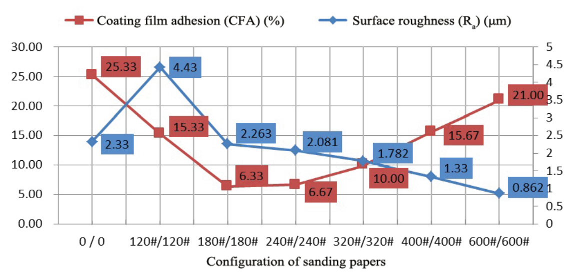

Fig. 1: Relation between surface roughness of substrate and coating film adhesion of UV putty.

As seen in Fig. 1, with the increase in grit abrasive papers, the surface roughness of the MDF boards was decreased almost linearly.

From Fig. 1, it can also be seen that the coating film adhesion of unsanded MDF board (0/0) was smaller than those of the sanded MDF boards. As reported by earlier studies, the painted wood could be described as a three-component system consisting of a wood section, a paint section, and the paint-wood interface. The contact zone between the wood structure (MDF in this paper) and the coating played a significant role in the properties of the coating for the long-term behavior (Dickie 1994; Rijckaert et al. 2001). Hence, the differences in adhesion could be explained by the following reasons: firstly, the MDF substrate is composed of several different types of organic materials, the principal components being cellulose, hemicelluloses, lignin and urea-formaldehyde thermosetting adhesive. Sanding would cause breakage of the original chains among the organic compounds and create more free radicals. As shown in the study carried out by Zeren and Huguenard (2004), under the influences of UV exposure, photoinitiators, and organic compounds, molecular cleavage and the initiation of chain reactions occur with unsaturated polyester, vinyl ether urethane, or (meth) acrylated prepolymers, which were used as binders. These highly active free radicals led to the ready creation of new chains with the resin used as an adhesive. Secondly, a cellular structure, characteristic of organic material itself, leads to a large amount space within the walls and cavities of the cells. The sanding process exposes many of the tiny interstices on the surface, which could be filled by the adhesive.

Furthermore, the adhesion of the coating film increased from 21 to 6.33 % with the increase in surface roughness from 0.862 to 2.263 µm. This confirmed the two reasons discussed above, which posited that the more irregular the contact area the larger the contact area, thus strengthening the adhesion of the coating film. However, excessive large surface roughness could also reduce the adhesion of the coating film. From Fig. 1, when the surface roughness increased from 2.263 to 4.43 µm, the adhesion of the coating film decreased from 6.33 to 15.38 %. This may be because the surface roughness was so large such that it reduced the ratio of internal spaces filled by the adhesive. The less completely filled interstices also caused a reduction in adhesion.

ANOVA for coating film adhesion of UV putty

An analysis of variance was performed to determine the statistical significance of the configuration of the sand papers, represented by surface roughness (R_a), on the adhesion of the coating film of the 1st UV putty in the UV pigment roller coating of MDF panels for a level of significance of 5 %.

As shown in Tab. 4, for the MDF roller coating, the surface roughness of the raw MDF boards showed statistically significant contributions to the adhesion of the 1st UV filler according to the F-value of greater than $F_{0.05}$.

Tab. 4: Results of ANOVA for coating film adhesion of the 1st UV Putty.

Resources	Sum of squares	df	Mean square	F	Sig.
Between groups	929.333	6	154.889	14.329	.000
Within groups	151.333	14	10.810		
Total	1080.667	20			

Analysis of coating film adhesion of the 1st UV Primer

Influence of UV putty coating times and sandpaper configuration on coating film adhesion of the 1st UV primer

Fig. 2 shows the adhesion of the 1st UV primer during changes in the roller coating process with the changing UV putty coating times and the sand paper configurations.

From Fig. 2, it can be seen that the adhesion of the coating film of the 1st UV primer decreased linearly with the increase in grit in the abrasive papers. This could also be explained by the principle that more flatness translates into less contact area between the UV putty and the 1st UV primer, and the smaller contact area would tend to weaken the adhesion of the coating film. The sanding process also increased the number of free radicals on the top of the cured putty film, which would reinforce the adhesion of the 1st UV primer film.

As the chemical bonds played a major role in the adhesion of the final film, the putty coating times had little effect on the adhesion of the coating film.

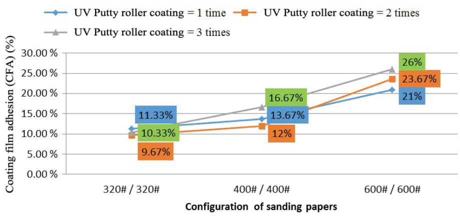

Fig. 2: Influence of filling times and sanding grit on adhesion of the 1st UV primer.

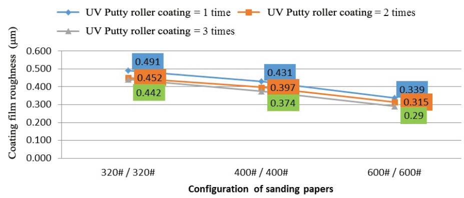

Fig. 3: Influence of filling times and sanding grit on roughness of the 1st UV primer.

ANOVA for coating film adhesion of 1st UV primer

An analysis of variance was considered for the determination of the statistical significance of the variables (times of UV putty coating, sandpaper configuration) and their interactions on the adhesion of the coating film in the UV pigment roller coating of MDF panels for a level of significance of 5 %.

As shown in Tab. 5, for the MDF roller coating, the surface roughness of the UV putty film had statistically significant contributions to the adhesion of the 1st UV primer according to the F-value being greater than the $F_{0.05}$. There was no significant effect demonstrated relative to the time of UV putty coating or for the interaction between UV putty coating times and sandpaper configuration relative to the adhesion of the 1st UV primer. This was in agreement with the conclusions stated above.

Tab. 5: Results of ANOVA for coating film adhesion of the 1st UV primer.

Source	Type III Sum of squares	df	Mean square	F	Sig.
Model	2610.569a	6	435.095	322.743	.000
TFC	19.193	3	6.398	4.746	.117
CSP	274.594	1	274.594	203.687	.001
TFC * CSP	9.070	2	4.535	3.364	.171
Error	4.044	3	1.348		
Total	2614.613	9			

a. R squared = 99.8 %; Adjusted r squared = 99.5 %

b. TFC = Times of UV putty coating; CSP = Configuration of sanding papers

Analysis of coating film roughness of the 1st UV Primer

Influence of UV putty coating times and sandpaper configuration on coating film flatness of the 1st UV primer

From Fig. 3 it can be seen that with the increase in grit of the abrasive papers, the flatness of the 1st UV primer increased linearly. The UV putty coating film was the coating substrate for the 1st UV primer coating. High-grit sandpapers led to a high flatness of the putty surface, and this offered a smoother surface as the base for the 1st UV primer.

Fig. 3 also indicated that UV putty coating times had a positive effect on the flatness, or surface roughness, of the 1st UV primer film, which means that the greater the putty coating time, the better the surface roughness. This could be because the UV putty filled the pores on the surface of MDF substrate and prepared a smooth surface for the 1st UV primer. Because of the mechanical properties as well as the viscosity of the adhesive, coating the MDF board onlyonce could not fully achieve the ideal surface quality for the further coating and would cause some problems. According to the study of Evans and Cullis (2008), there was a scraping blade located after the application roller of the roller coater, which forced the material into the surface voids and removed the excess coating adhesive. Because of the limited adhesive used in one coating process, coating the MDF board by using the UV putty repeatedly could solve the problems caused by the earlier step and improve the quality of the final surface.

ANOVA for coating film roughness 1st UV primer

An analysis of variance was conducted to determine the statistical significance of the variables (times of UV putty coating, sandpaper configurations and their interactions) on the flatness of the coating film of the 1st UV primer in the UV pigment roller coating of MDF panels for a level of significance of 5 %.

As shown in Tab. 6, for the MDF roller coating, the surface roughness of the UV putty film and the UV putty coating times showed statistically significant contributions to the adhesion of the 1st UV primer according to the F-value greater than $F_{0.05}$. However, there was no significant indication that the interaction between UV putty coating times and the sandpaper configurations had any influence on the adhesion of the 1st UV primer.

Tab. 6: Results of ANOVA for coating film roughness of the 1st UV primer.

Source	Type III Sum of squares	df	Mean square	F	Sig.
Model	1.422a	6	0.237	1001.422	0.000
TFC	0.228	3	0.076	321.442	0.000
CSP	0.032	1	0.032	135.451	0.001
TFC * CSP	6.792E-5	2	3.396E-5	0.144	0.872
Error	0.001	3	0.000		
Total	1.422	9			

a. R squared = 1.000; Adjusted r squared = 99.9 %

b. TFC = Times of UV putty coating; CSP = Configuration of sanding papers;

Sig = significance

CONCLUSIONS

1. Statistical results indicated that the surface roughness had a very significant influence on the adhesion of 1st UV putty coating layer. Sanding the raw MDF boards with a proper surface roughness could increase the adhesion of the putty film. Excessively large or small surface roughness would both decrease the film adhesion of the putty layer.
2. Statistical results indicated that the surface roughness of the UV putty film made a

statistically significant contribution to the adhesion of the 1st UV primer. With the increase in grit of the abrasive papers the adhesion of the coating film of the 1st UV primer decreased linearly.

3. Results indicated that the surface roughness of the UV putty film and the UV putty coating times made statistically significant contributions on the adhesion of the 1st UV primer. With the increase in grit of the abrasive papers, the roughness of the 1st UV primer increased linearly. The UV putty coating time had a positive effect on the surface roughness, of the 1st UV primer film, which signifies that the longer the roller coating times, the better the surface roughness.

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