Bonding Properties of Poly(vinyl chloride)-Based Wood–Plastic Composites Bonded with Epoxy Adhesive

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Received 23 November 2010; accepted 28 July 2011
DOI 10.1002/app.35385
Published online 17 December 2011 in Wiley Online Library (wileyonlinelibrary.com).

ABSTRACT: This article studied the bonding properties of poly(vinyl chloride) (PVC)-based wood–plastic composite (WPC) materials bonded with epoxy adhesive. The results show that the dry compression shear strength of bonded specimens glued with epoxy adhesive could reach 72% of the strength of the PVC-based WPCs themselves. That meant the bonding connection with epoxy resin was feasible in the application of PVC-based WPCs. The results show that the compression shear strength after the damp cycle was 0.981 times the compression shear strength without any treatment. In addition, the retention rate of the compression shear strength was 87.7% after the UV aging test process set in this study. In this study, the surface morphologies of bonded specimens glued with epoxy adhesive after a boiling–drying treatment and UV aging were observed by scanning electron microscopy (SEM). The results of SEM show that the glue line became rough in different degrees after the damp cycle and UV aging. © 2011 Wiley Periodicals, Inc. J Appl Polym Sci 125: 175–179, 2012

Key words: adhesion; ageing; poly(vinyl chloride) (PVC)

INTRODUCTION

A wood–plastic composite (WPC) is a new kind of material made from waste plastic and wood fibers or other fibers of natural plants. WPC materials have the advantages of plastic and wood and avoid their shortcomings, so now WPC has aroused great attention. Studies have been investigated by domestic and foreign scholars on WPCs.[1–8] The application ranges of WPCs are very wide [poly(vinyl chloride) (PVC)-based WPC materials are the most commonly used WPC materials]. They can be used in construction, vehicles, packaging and transport, landscape, home decoration industry, and so on. However, in the application of WPC materials, connection problems are often involved.

Nowadays, bolt connections are often used when WPC materials need to be connected. Although the bolt connection technology enables fast connections of WPC materials, it has some shortcomings: it can damage the WPC materials themselves because of predrilling and stress concentration during application, so the application range of bolt connections in the application of WPC materials is limited. Compared with bolt connections, bonding is a nondisruptive connection technology because the whole bonding interface bears the load; the overall load capacity could be increased, and the service life of the bonding assembly of WPC materials could be extended. In some cases, no gap connection was in urgent need, especially in the following fields: windows and doors, interior decoration, and furniture. Bonding connections can achieve the need of no gap connection, but bolt connections cannot. Therefore, it is necessary to explore bonding connection methods for WPC materials. Also, concerns about the long-term properties of bonded joints have been raised, so it is necessary to study the bonding durability of the bonded specimens of PVC-based WPCs. The purpose of this study was to investigate the strength and durability of the bonded assembly of PVC-based WPCs.

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Contract grant sponsor: National Natural Science Foundation of China; contract grant number: 30871980.

Journal of Applied Polymer Science, Vol. 125, 175–179 (2012)

EXPERIMENTAL

Materials

The WPC materials used in this study were commercially available foaming WPCs supplied by Sanus Synthesis Timber Science & Technology Co., Ltd. (Hang Zhou City, China). These WPC materials (PVC-based WPCs) were mainly composed of PVC and wood flour by an extrusion process. This

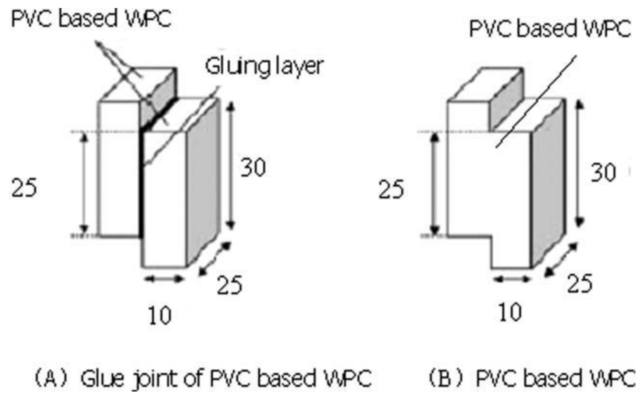

Figure 1 Dimension and shape of the specimens for compression shear strength (mm).

PVC-based WPC materials contained about 20% wood flour. The density of this PVC-based WPC was 1.183 g/cm^3, and its bending strength was 30 MPa.

The adhesive used in this article was a commercially available room-temperature curing epoxy adhesive supplied by a six-ring adhesive factory in Harbin City in China. The epoxy adhesive was composed of two components; one was epoxy resin, and the other was the polyamide resin as a curing agent. When used, epoxy adhesive should be applied immediately after its two components were mixed evenly according to a proportion of 1 : 1 in weight.

Determination of the compression shear strength

The adhesion properties of the PVC-based WPC bonded joint with epoxy adhesive were evaluated with a lap-shear test for the compression shear strength (Chinese standard GB/T 17517, "Determination of the Shear Strength by Compressing Loading").

PVC-based WPC materials were cut into samples 10 mm thick, 25 mm wide, and 30 mm long. The epoxy adhesives were calculated according to a rate of 120 g/m^2 on each surface of the two substrates (25 $\times$ 25 mm^2). The adhesive amount was weight-controlled to 0.0750 $\pm$ 0.0002 g. These adhesives were evenly spread during the gluing operation. Lap joints with epoxy adhesive (25 $\times$ 25 mm^2 overlap) for compression shear strength were prepared in accordance with Figure 1(A). The glue blocks were pressed under a pressure of 1.5 MPa for 24 h at 20–25°C.

After the bonded joints were kept at room temperature for 10 days to allow the curing of the epoxy adhesive, these bonded specimens were divided into three sets. One set of bonded specimens was directly used to test the dry compression shear strength without any treatment, and the other was treated by a damp cycle; another set was used for the UV aging test.

Tests for the compression shear strengths were performed on a Reger universal mechanical testing machine (Shenzhen City, China).

In addition, PVC-based WPC materials were sawn into specimens, shown in Figure 1(B), to test the compression shear strengths of the PVC-based WPC materials themselves.

Determination of the compression shear strength after the damp cycle

In applications, bonded specimens are often influenced by many factors; the most prominent factor is the combination action of humidity and heat.[8–10] So in this part, bonded specimens were treated in accordance with the test method of bonding strength in Chinese standard GB/T17657-1999 ("Test Methods of Evaluating the Properties of Wood-Based Panels and Surface Decorated Wood-Based Panels") before testing the compression shear strength. The specific treatment procedure was as follows: the bonded specimens were immersed in hot water at 100°C for 4 h and then dried in oven at 63 $\pm$ 2°C for 20 h; after that, the bonded specimens were immersed in hot water at 100°C for another 4 h and, then, were directly immersed in cold water to be cooled to room temperature. After this treatment, these boiled and dried bonded specimens were divided by two sets: one was used for testing the compression shear strength after the damp cycle; these boiled and dried treated joints were tested to destruction on the Reger universal mechanical testing machine with a crosshead speed of 5 mm/min. The other set was used for observation in scanning electron microscopy (SEM).

UV aging test

A UV aging test was used to accelerate the degradation processes. In this article, the artificial simulated UV weathering test was carried out in a QUV/SPRAY UV accelerated aging instrument (American Q-Panel Co., FEI Company, Hillsboro, Oregon).

The accelerated weathering procedure of the bonded specimens were set in accordance with ASTM G154 (8 h of UV irradiation, average irradiance = 0.77 W/m^2 at 340 nm, chamber temperature = 60°C) and 4 h of condensation (chamber temperature = 50°C) for 7 and 14 days, respectively.

The compression shear strengths of the bonded specimens after the UV accelerated weathering procedure for 7 and 14 days, respectively, were tested on the universal mechanical testing machine. The extent of degradation was determined from the reduction in the compression shear strength as a result of exposure to UV aging conditions.

SEM observation

The effect of the aging test on the morphology of the prepared joints was studied by SEM.[11]

TABLE I
Compression Shear Strength of the Bonded Specimens Glued with Epoxy Adhesive and Strength of the PVC-Based WPCs

Item	Bonded specimens glued with epoxy adhesive		PVC-based WPCs
	Dry condition	Wet condition	
Compression shear strength (MPa)	7.45	7.31	10.41
CV (%)	14.53	13.98	15.32

CV, coefficient of variation. The data are based on 10 replicates for each property.

The surfaces morphology of the samples was examined by a Quanta200 scanning electron microscope (FEI Co.). Bonded samples used for SEM observation, including boiled and dried samples, and exposure to the UV aging test conditions were stuck on the sample stage of SEM. An SCD005 ion-sputtering instrument made in BAL-TEC Co. (Switzerland) was used to sputter metal film on the bonded samples' surface to form a conductive surface for SEM observation, and then, these samples were observed under SEM.

RESULTS AND DISCUSSION

Determination of the compression shear strength

The compression shear strength of the bonded specimens glued with epoxy adhesive and the compression shear strength of PVC-based WPC are shown in Table I.

It can be seen from Table I that the compression shear strength of the bonded specimens glued with epoxy adhesive was 7.45 MPa, whereas that of the PVC-based WPC materials themselves was 10.41 MPa. That meant that the compression shear strength of the bonded specimens glued with epoxy adhesive could reach 72% of the strength of PVC-based WPC materials themselves. Otherwise, it can be seen from Figure 2 that joints for the compression shear strength were often destroyed at the substrate. These results show that PVC-based WPCs could be

Figure 2 Failure morphology of the specimen bonded with epoxy adhesive. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

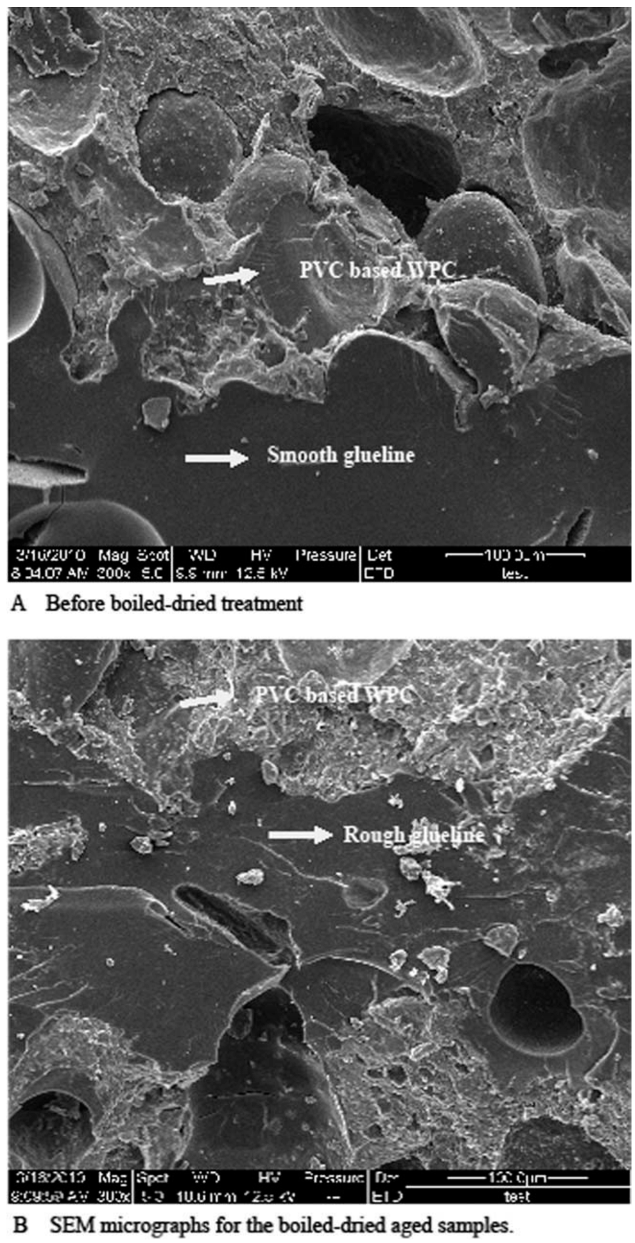

Figure 3 Differences in the glue line surface morphology of the specimen bonded with epoxy adhesive by the SEM before and after boiling–drying treatment.

TABLE II
Compression Shear Strength of the Specimens Bonded with Epoxy Adhesive Before and After UV Aging

Item	Control	After exposure to UV aging 7 days	After exposure to UV aging 14 days
Mean of the compression shear strength ± Standard deviation (MPa)	7.32 ± 0.98	6.86 ± 0.91	6.42 ± 0.87
Retention rate of the compression shear strength (%)	—	93.7	87.7

The data are based on 10 replicates for each property.

glued with epoxy resin and that the bonding connection with epoxy resin could be used as a kind of connection method.

Determination of the compression shear strength after the damp cycle

The compression shear strengths after the damp cycle of the bonded specimens with epoxy adhesive are listed in Table I.

The glue line of the bonded specimens did not split after the damp cycle by observation of the specimens treated by the damp cycle. It can be seen from Table I that the compression shear strength of the bonded specimens was reduced to 7.31 from 7.45 MPa after the damp cycle, and the retention rate of the compression shear strength after the damp cycle reached 98.1%. That means the bonding strength of the bonded specimens only decreased a bit after the damp cycle.

These results indicate that the bonded specimens still exhibited sufficient adhesion after the boiling–drying treatment.

Surface observation by SEM after the damp cycle

Figure 3 shows differences in the surface morphology of the specimen bonded with epoxy adhesive by the SEM after the damp cycle.

A smooth and shiny glue line before the damp cycle was observed from the SEM micrographs shown in Figure 3(A), although a little bit of a folded glue line after the damp cycle was observed from the SEM micrographs shown in Figure 3(B). That meant that little change occurred in these aged joints after the damp cycle. However, joints between the epoxy adhesive and the PVC-based WPC surface still adhered closely, as shown in Figure 3(B). These also could explain the reason that damp cycle treatment had little effect on the compression shear strength of the bonded joints.

Bonding properties after UV-accelerated weathering testing

Nowadays, PVC–WPCs are being used in many applications, including window and door frames, which are easily subjected to attack, typically by UV. UV radiation from sunlight was one of the factors that induced the degradation of the bonded specimens. The degradation of the bonded specimens induced from UV radiation needed to be estimated.

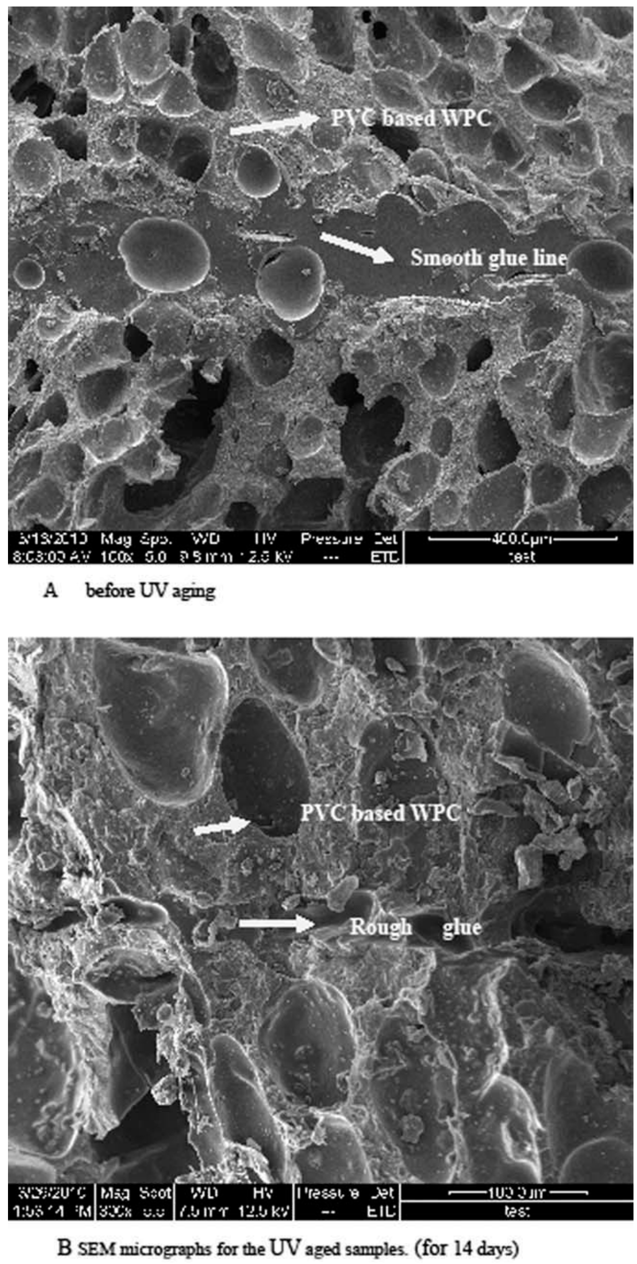

Figure 4 Differences in the glue line surface morphology of the specimen bonded with epoxy adhesive by the SEM before and after UV aging.

The results of the compression shear strength of the bonded joints before and after artificial accelerated UV aging are listed in Table II.

It could be seen from Table II that the compression shear strength of the bonded specimens with epoxy adhesive decreased significantly, from 7.32 to 6.42 MPa, after UV aging for 14 days, and the retention rate of the compression shear strength was 87.7% (UV aging for 14 days).

Surface observation by SEM after the UV aging test

SEM was employed to investigate the morphological changes of the bonded specimen with epoxy adhesive after UV aging.

Representative micrographs of SEM are shown in Figure 4. As reference, the surface appearance of the unaged sample is shown in Figure 4(A). One can see that the glue line before the UV aging test [Fig. 4(A)] had a smooth section; whereas the change in the surface morphology of the interface film after UV aging can be seen from the electron microscope image in Figure 4(B). The interface film after UV aging became rough, as shown in Figure 4(B). There appeared to be many more small fragments of the adhesive, shown in Figure 4(B), than in the control samples. The epoxy failed because of embrittlement caused by the UV, and this could be seen by many small fragments of the epoxy, shown in Figure 4(B).

Although there were some small fragments in the glue line of the epoxy after UV aging, it was evident from Figure 4(B) that the cured epoxy adhesive adhered closely to the PVC-based WPC; this implied that there was still compact adhesion between the cured epoxy adhesive and substrate, and this did not result in very poor bonding properties.

CONCLUSIONS

The results show that the compression shear strength of the bonded specimens of PVC-based WPCs glued with epoxy adhesive was 7.45 MPa, whereas the compression shear strength of the PVC-based WPC materials themselves was 10.41 MPa. The compression shear strength of the bonded specimens glued with epoxy adhesive could reach 72% of the strength of the PVC-based WPCs themselves. Otherwise, joints for the compression shear strength were often destroyed at the substrate. These results show that the PVC-based WPCs could be glued with epoxy resin, and the bonding connection with epoxy resin could be used as a kind of connection method.

The results show that the compression shear strength after the damp cycle was 0.981 times the compression shear strength without any treatment. In addition, the retention rate of the compression shear strength of the bonded specimens after the UV-aging test process set in this study was 87.7%.

SEM observation indicated that changes in the morphology of bonded specimens occurred at the bonding interface. There appeared to be many more small fragments of the adhesive, shown in Figures 3(B) and 4(B), than in the control samples. The epoxy failed a little, maybe because of the embrittlement caused by the moisture and head or UV, and this could be seen by the many small fragments of the epoxy in Figures 3(B) and 4(B). Otherwise, the tightness level of the junction between the epoxy adhesive and the PVC-based WPC materials were close after the damp cycle and UV accelerated aging.

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