Chapter

Wood Adhesive Fillers Used during the Manufacture of Wood Panel Products

Long Cao, Xiaojian Zhou and Guanben Du

Abstract

During the manufacture of wood panel products, fillers are commonly added to wood adhesives to lower costs and give body to liquid adhesives and also reduce undesired flow or overpenetration into wood. The fillers used in wood adhesives are often neutral or weakly alkaline compounds that typically require no chemical reaction with curing agent, or other components. Fillers are mixed with other components prior to the application of resin on the surface of wood, wood veneer, or wood flakes. Fillers can be either organic (e.g., rye, wheat, walnut shell, and wood flours), or inorganic (e.g., calcium carbonate, calcium sulfate, aluminum oxide, or bentonites). Overall, fillers are low-cost materials for improving the properties of wood or even give it new functions.

Keywords: fillers, wood adhesives, performances, advantages, applications

1. Introduction

Fillers are solid additives that are primarily used to lower the cost and give body to liquid adhesives or reduce undesired flow or overpenetration into wood. This leads to an improvement in properties of the adhesives and gives rise to new functions [1]. Fillers usually increase the rigidity of cured adhesives. They may also modify the coefficient of thermal expansion of a film to approximately that of the adjacent adherends. This can reduce thermal stresses in the joint generated during cooling following heat-curing conditions or when thermally cycled during service. Fillers, normally, are neutral or weakly alkaline compounds and do not chemically react with adhesives, curing agents, or other components in wood adhesive system.

2. Filler species

There are many kinds of adhesives for manufacturing of wood panel products, and the type and the amount of filler greatly affect its performance [2]. The choice of filler depends on the materials and application, making fillers one of the most important components of adhesives during the production of wood-based boards. Adding an appropriate filler to an adhesive can reduce the amount and cost of glue and also improve the performance of the adhesive. Commonly used adhesive fillers are organic, such as flour, soybean powder, wood powder, and bark powder or other agroindustrial wastes (**Table 1**), such as palm kernel and starch material, etc. In addition, inorganic materials such as metal powders, metal oxides, and minerals, have also been used as adhesive fillers, typically to improve compression strength and dimensional stability.

Types	Amounts (%)	Function	Main application in wood adhesive	Application fields
Flour, wood powder, soybean powder, bark powder	10–30	Decrease cost, increase ductile behavior, avoid overpenetration and heterogeneous spread	Urea-formaldehyde, phenol-formaldehyde, melamine-formaldehyde resin, polyvinyl acetate resin	Wood-based panels, wood-glued products
Copper oxide, magnesium oxide, magnesium hydrate, iron sesquioxide, titanium dioxide, chromium hemitrioxide, zinc oxide, copper powder, silver powder, magnesium carbonate, iron powder	25–100	Improve compression, hardness, thermal conductivity, electrical conductivity, and processability	Epoxy, rubber, polyurethane glue, phenol-formaldehyde resin, polyvinyl acetate resin	Wood structure products
Calcium carbonate, cement, clay, talcum powder	25–100	Reduce cost and curing shrinkage and increase compression and hardness	Polyurethane, epoxy, urea-formaldehyde, phenol-formaldehyde, polyvinyl acetate resin	Wood structure products
Carborundum, mica powder	<100	Reduce cost and increase physical properties	Epoxy, phenol-formaldehyde resin	Wood structure products
Synthetic cement, Ganister sand	10–20	Improve the fluid flow performance	Polyurethane, epoxy resin	Wood structure products
White carbon black	20–100	Improve the mechanical properties	Rubber, epoxy resin	Musical device
Land plaster	10–100	Reduce cost and increase viscosity	Epoxy resin	Wood bonding and coating
Kaolin	<10	Improve thixotropy and fluid flow performance	Epoxy resin, urea-formaldehyde resin, polyvinyl acetate resin	Wood-based panels
Graphite	<50	Increase thermal performance, lubricity, and wear resistance	Epoxy, rubber resin, polyvinyl acetate resin	Musical device
Asbestos powder, glass fiber, talcum powder	20–50	Improve impact strength and heat resistance	Rubber, epoxy, urea-formaldehyde resin, polyvinyl acetate resin	Musical device and coating

Table 1.
The types, amount, and function of fillers in wood adhesives.

According to their color, fillers can be divided into white fillers and color fillers. They can also be divided according to their preparation method into natural fillers and synthetic fillers. They can be divided according to their function into temperature-resistant fillers, conductive fillers, and anti-sink fillers. According to their particle sizes, they can be divided into natural fillers, ultra-fine fillers, and nanoscale fillers. According to their composition, they can be divided into compound fillers and mixture fillers.

3. The advantages of fillers for wood adhesives

The adhesive composition mainly includes a matrix material, curing agent, toughening agent, diluent, filler, and modifier. However, fillers are solid materials that do not chemically react with the adhesive component but can change its performance [3, 4]. The main functions are summarized in **Table 1** and further discussed in this section.

3.1 Increase the mechanical properties of the adhesive

Many polymers have weak intermolecular interactions and low cohesive energies, so their mechanical properties are inferior to other materials. Fillers with an appropriate particle size can enhance the adhesive strength, and the active surface of filler particles can be used to cross-link several large molecular chains to form a network structure. When one molecular chain is stressed, the stress can be dispersed and transferred to other molecules through cross-linking. Even if one chain fractures, the other chains remain intact, and it is unlikely that the entire structure will immediately fracture, leading to a substantial improvement in the mechanical properties of adhesives. Commonly used fillers, such as flour, metal powders, and metal oxides, can improve the compression strength of adhesives and their dimensional stability. Adding carbon black, silica, or calcium carbonate into silicone and rubber glue can improve the tensile strength, hardness, and wear resistance, etc.

3.2 Give new functions of adhesives

Conductive and magnetic adhesives are obtained by the addition of silver powder and carbon-based iron powder into adhesives, respectively. The thermal conductivity of adhesives can be improved using copper powder, aluminum powder, alumina, and magnesium oxide as fillers. The thermal conductivity adhesives can be widely used in microelectronic assembly and bonding electronic products instead of spot welding. The magnetic adhesives can be improved production efficiency because of simple operation process in electrical machinery bonding field. In epoxy resins, zinc chromate and $Zr(SiO_3)_2$ can help retain strength and reduce water absorption. Flame retardant powders such as aluminum hydroxide can improve the flame retardancy of an adhesive. Some fillers can also improve the resistance of adhesive joints to moisture and heat aging and salt spray.

3.3 Reduce joint stress

Fillers can prevent local overheating near the bonding interface because the curing reaction is exothermic. In most cases, the curing shrinkage of wood adhesives often occurs during the glue bonding process, but filler can be used to adjust the shrinkage rate. The addition of wheat flour can reduce cracking, which is caused by curing shrinkage of urea-formaldehyde resins. The proper selection of filler can reduce the difference between the thermal expansion coefficient and the expansion rate between adhesives and bonded materials. Additionally, it can reduce the internal stress of joints, the thermal expansion coefficient, and curing shrinkage ratio of adhesives.

Colloids form during the curing process due to chemical reactions and cause volume shrinkage. Thermal shrinkage will also occur due to the different thermal expansion coefficient of the adhesive. These two types of shrinkage will produce internal stresses in the rubber layer, resulting in stress concentration, cracking, or joint damage of the rubber layer, which directly affects the service life of rubber joints. Filler can be used to adjust shrinkage during curing, reduce the difference of thermal expansion coefficients between the wood adhesive and the object being glued, and can also prevent cracks from extending. Thus, fillers can significantly improve the bonding strength, especially the shear strength at high temperatures.

3.4 Improve operation process

Fillers in adhesives can adjust the curing speed, prolong the pot life, and facilitate manufacturing. During plywood manufacturing, wheat flour added into urea-formaldehyde resin can increase the viscosity of an adhesive to prevent it from excessively penetrating into wood pores. Fillers can also improve the thixotropy of liquid glues to control their fluidity, adjust the curing speed, extend the service life, and facilitate operation and construction.

Normally, adhesive bonding strength, adhesion, and heat resistance significantly increase when a certain amount of filler is added, especially polar fillers, such as metal powders, metal oxides, and minerals. This reduces adhesive curing shrinkage and coefficients of thermal expansion.

The addition of asbestos wool and glass fiber has been shown to improve the impact strength. Quartz, porcelain, and iron powders can increase the hardness and compression resistance of adhesives, while graphite and talcum powders can improve wear resistance. Alumina and titanium dioxide can increase the bonding strength. Flour is the most widely used filler in wood adhesives in the wood panel industry and is used to improve the mechanical properties, shrinkage, expansion behaviors, and other physical performances at the glue-wood interface. Most importantly, the use of flour reduces the cost.

An appropriate proportion of filler should be used to provide the desired function and to ensure the overall superior performance of an adhesive. A high proportion of filler will increase the viscosity of the adhesive, making it difficult to control and stir, leading to inferior wettability and a low bonding strength. It may also reduce the de-lamination strength and increase wood failure. Overall, the purpose of fillers is to enhance the physical and mechanical properties of wood-based panels.

Filler selection should meet the following requirements:

1. Non-toxic

2. Unreactive toward other components in the wood adhesive system

3. In a specific physical state, such as uniform particle size

4. Low-cost, a wide range of sources, and convenient processing

5. Should not contain moisture, grease, or harmful gases; moisture absorption is not easily changed

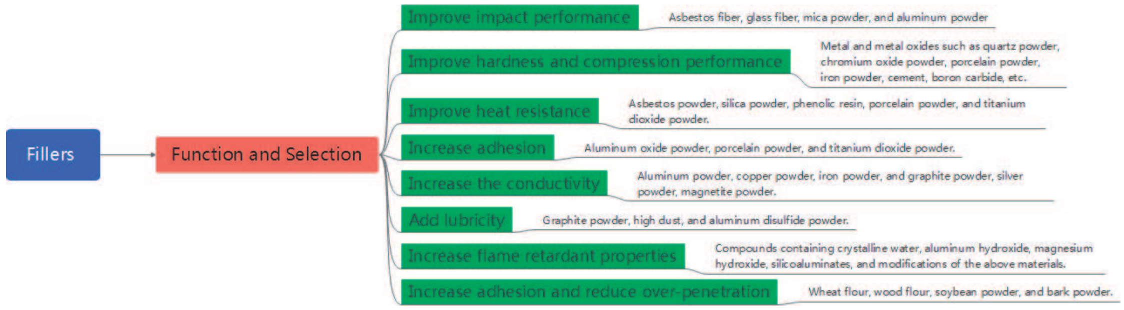

Figure 1.
The function and selection of fillers.

6. Easily dispersed and has good lubrication with adhesive

7. Should meet the specific requirements of the adhesive, such as electrical conductivity, heat resistance, etc.

The selection of appropriate fillers in wood adhesive systems is important because different fillers have different effects, as show in **Table 1** and **Figure 1**.

4. Applications of fillers

There are many different types of fillers, which have different applications. The most widely used fillers include natural calcium carbonate, barite powder, quartz powder, talc powder, kaolin, mica powder, attapulgite (aluminum-silicon-magnesite containing water), and flours of different renewable biomaterials.

Nanomaterials have quantum size effects, small size effects, surface effects, and macroscopic quantum effects. The addition of small amounts of nanoscale powders into an adhesive can significantly increase its viscosity, improve the bonding strength, and prevent caking. For example, it was found that nanoscale calcium carbonate prolonged the curing time of resin and the content of free formaldehyde decreased as the amount of calcium carbonate increased. Nanoscale montmorillonite was also shown to increase mechanical properties and reduce formaldehyde emission [5–7].

4.1 Calcium carbonate

Calcium carbonate ($CaCO_3$) is an odorless white powder and is one of the most widely used fillers [8]. Lightweight precipitated calcium carbonate can be synthesized by a chemical method with a whiteness of 90% and a relative density of 2.6 g/cm^3. Heavy calcium carbonate is composed of natural calcite, limestone, chalk, and shells, which are ground to certain fineness by a mechanical method.

In the adhesives industry, calcium carbonate is widely used as a filler because of its low price, non-toxicity, white color, abundant resources, easy mixing in formulas, and stable performance. The addition of nanoscale calcium carbonate to an adhesive can enhance the mechanical strength and increase the transparency, thixotropy, and spreading smoothness. Additionally, the adhesive easily provides a shielding effect, leading to an anti-UV aging effect, as well as an improvement in its mechanical strength.

4.2 Kaolin

Kaolin, usually called clay or china clay, has a main mineral component of kaolinite, which is a variety of crystal rock with the molecular formula

$Al_2O_3 \cdot SiO_2 \cdot nH_2O$. Kaolinite has a flake structure and can be divided into calcined kaolin and washed kaolin. Calcined kaolin generally has a higher oil absorption, opacity, porosity, hardness, and whiteness than washed kaolin.

Kaolin normally forms an unstable structure in water because of its charge distribution, with positively charged sheet edges and a negatively charged surface. If the kaolin dosage is high, it will form a gel, preventing an adhesive from flowing [9]. Clay is sometimes added to epoxy resins to thicken or modify coefficients of thermal expansion.

4.3 Renewable bio-based materials

Flour and other renewable bio-based materials include wood powder, starch, protein, and lignocellulose as well as the agroindustrial wastes. Adding a small amount of starch into wood adhesives can significantly increase the viscosity and effectively improve the solid content and initial viscosity of the adhesive [10–12]. Oxidized starch and palm kernel can also neutralize excess acidic substances in the rubber layer, prevent excessive decomposition of the cured rubber layer, and improve the aging resistance of urea-formaldehyde and melamine-urea-formaldehyde resin adhesives [13, 14]. It was also concluded that the stability and initial viscosity of a resin, its pre-compression behavior, and the bonding strength of adhesive products were improved. Walnut shell flour is a filler that is incorporated in urea or resorcinol adhesives to improve spreading or reduce penetration into open wood pores [15–17]. In addition, sorghum flour, protein, bark, and lignin, these kinds of agricultural, forestry, and industrial wastes as fillers have been used in plywood adhesives system [18–21].

In general, different fillers have different advantages. Although kaolin has better properties than flour and calcium carbonate, flour is renewable and sustainable. Most importantly, it is much cheaper, resulting in broader applications in the wood panel industry.

5. Conclusions

Fillers are low-cost additives for wood adhesives during the manufacture of wood composites. They undergo no chemical reactions with the components of wood adhesive systems and can improve some properties or even provide new functions. In the wood panel industry, almost all factories use kaolin clay or flour blended with other components in wood adhesive systems to reduce undesired flow and overpenetration into wood pores in the glue interphase. With the development of society, low-carbon economy, energy conservation, and environmental issues will drive future adhesive developments. Thus, we can predict that future fillers will be functional, differentiated, refined, nanosized, dust-free, and environmentally benign.

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Conflict of interest

There is no conflict of interest in this field.

Author details

Long Cao†, Xiaojian Zhou*† and Guanben Du*
Yunnan Provincial Key Laboratory of Wood Adhesives and Glued Products, Southwest Forestry University, Kunming, China

*Address all correspondence to: xiaojianzhou@hotmail.com and gongben9@hotmail.com

† These authors are contributed equally to this work.

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