For. Stud. China, 2010, 12(4): 218–222
DOI 10.1007/s11632-010-0401-y

RESEARCH ARTICLE

Research on utilizing recycled plastic to make environment-friendly plywood

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Abstract In our study, we replaced traditional adhesives with compounds made with recycled plastic shopping bags in order to make hot-melt plywood using various amounts of plastic film, different hot-pressing temperatures and hot-pressing times. All three variables have an effect on the intensity and water-resistance of plywood. The results show that the bonding strength of plywood does not increase with increasing amounts of plastic film. When the hot-pressing temperature is increased to 150°C, the bonding strength does not necessarily increase any further. At a hot-pressing time of 6 min, the bonding strength reaches a maximum, after which it will decrease. The optimum hot-pressing parameters are as follows: 100 g·m^{-2} of recycled plastic, a hot-pressing temperature of 150°C and a hot-pressing time of 6 min. This study puts forward a new idea of making use of plastic waste, which, ultimately, may solve the problem of formaldehyde emission without damaging the environment. It has enormous potential market applications.

Key words recycled plastic shopping bags, hot-melt plywood, hot-pressing parameters, comprehensive performance

1 Introduction

Wood is the only renewable resource in the world among four major types of raw material, the others being steel, cement and plastics, and as well, wood is an ecological material in the development of many economies and societies. Wood-based forest products have played an indispensable role in our entire national economy (Cheng and Song, 2006). Man-made boards are among the most efficient uses of wood. In 2007, the total output of man-made boards has reached 88.39 million m^3 in China, which is 4.41 times larger than that in 2000 (State Administration of Forestry, 2008). At the end of 2005, China had become the largest man-made board producing country in the world. Plywood has been our leading product. Its production reached 35.62 million m^3 in 2007 (State Administration of Forestry, 2008). Plywood is mainly used for decoration, furniture manufacturing, packaging and construction. The products are primarily three-layer or five-layer urea-formaldehyde-resin bonded or phenolic-resin bonded plywood (Qian, 2006).

At present, urea-formaldehyde and phenolic resins are the adhesives used mainly in plywood production and account for 87.1% and 9.6% of all adhesives used in plywood manufacture, respectively, in 2004 (Qian, 2006). Urea-formaldehyde resin is non-flammable, has good adhesive strength, is resistant to changes in high temperature, light and corrosion, and has a short curing time, simple production technology and low production costs. But it also has a number of disadvantages, such as a high curing shrinkage ratio, a brittle colloidal property, weak water resistance and formaldehyde emission (Ye and Xiong, 2006). Phenolic resins are able to enhance bonding strength and water resistance (Sun, 2002), but they require a long curing time, high curing temperatures (Shi, 2004), and have high production costs and emit formaldehyde and phenol (Zhao et al., 2000). Formaldehyde released by urea-formaldehyde resin adhesives is recognized as a potential carcinogen. It irritates the eyes and respiratory tract mucous membranes, which eventually leads to immune dysfunction, liver and lung damage, affects the central nervous system and may even result in fetal malformation (Shi and Han, 2006).

Plastics, steel, wood and cement are known as the four basic materials of modern industry (Li and Wang, 2004). Plastic has high plasticity, mechanical strength, electrical insulation, low thermal conductivity, good chemical stability, easy coloring and is easy to process. It is widely used in all walks of life, especially in the form of disposable products, such as plastic bags, agricultural plastic film, greenhouse film (Su et al., 1995). In 2008, plastic production in China amounted to more than 37 million tons. With the production expansion and application improvement of plastics, large amounts of plastic waste have been generated. These waste products mainly come from packaging materials and agricultural mulch film (Zhang et al., 2000), which mainly consists of polyethylene (PE),

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polypropylene (PP), polystyrene (PS) (Sun, 2000) and polyvinyl chloride (PVC) (Dang, 1999).

Plastic films are difficult to degrade, entering the environment in various forms and resulting in yield reduction of crops (Zhao, 2005). According to some investigations, about 3.9 kg of residual plastic products from 666.67 m^2 land resulted in yield reduction of maize by 11–13%, wheat by 9–10%, rice by 8–14%, soybean by 5.05–9% and vegetables by 14.5–59.02% (Wang, 1999). As well, these plastic waste products have an extremely bad effect on rivers, transportation and tourist attractions (Wagner et al., 1991) and are referred to as “white pollution”.

These days, the amounts of plastic waste are large, while the rate of utilization of recycled plastics is very low (Karasak et al., 1983; Zhang et al., 2005). The total amount of recycled plastics was more than 16 million tons in 2008, while the utilization rate was less than 20% (Hua, 2010). Plastic is derived from fossil fuels, a limited resource; hence, the reuse of waste plastic films not only saves a mass of energy, but also protects the environment and realizes sustainable development. The processing of plastic waste occurs mainly in three ways around the world, i.e., by way of landfill, incineration and recycling (Collegman et al., 1988). Since plastic film is light and bulky, it is very difficult to be degraded by microorganisms. Hence, landfill is a waste of resources. Even worse, the residual plastic in the soil contaminates groundwater and destroys soil structures. Burning is more frequently used in developed countries. It will cause secondary pollution, although it will generate heat. So, this is not a good approach either (Collegman et al., 1988; William and Carroll, 1988; Chen et al., 2001; Yuan et al., 2004; Chen and Li, 2006). Recycling of plastic waste is the best approach which not only helps in solving the problem of environmental pollution caused by plastic film, but also realizes the reuse of a resource.

The recycling of plastic waste can be divided into three categories. One way is to treat and mold it directly after it has been collected, classified, cleared, smashed and prilled. A second way is to utilize it in new forms through physical modification and chemical treatment (Dang, 1999; Guo, 2005). For instance, recycled plastics may be made into polyvinyl chloride textiles after a series of processes, such as collecting, classifying, heating, melting, purifying, reeling and spinning (Dang, 1999). Hydrosoluble high polymers, such as sodium polystyrene sulfonates (NaPPS) are helpful in their intense coagulation properties in treating polystyrene plastic waste (Chen and Liu, 2006). The third way is for recycled plastics to be processed and made into various building materials, such as waterproof plastic oleamen, waterproof and low temperature resistant asphalt felts, waterproof rolls, assembled floors, man-made boards, plastic tiles, pallets, sound insulation material, rail fences, pressure-sensitive adhesives and material for wells (Chen et al., 2001; Zhu and Xu, 2003; Guo, 2005; Chen and Liu, 2006).

The objective of this study is to describe the manufacture of non-formaldehyde plywood from recycled plastics and to find suitable processing parameters for plywood production. We propose a new way and new idea to recycle plastic waste and provide a solution for formaldehyde emission in plywood.

2 Materials and methods

2.1 Materials

Recycled, 500 g plastic bags, mainly composed of polyethylene, polypropylene, polyvinyl chloride and polystyrene and poplar veneer (350 mm × 350 mm× 1.5 mm) with a moisture content of about 10% were used as study material.

2.2 Methods

2.2.1 Preparation of plywood

Recycled plastic bags were cleaned, processed with a chemical reagent, dried and shredded. After that we weighed an amount of recycled plastic bags and spread it between aspen veneers; then the plywood was hot-pressed according to the parameters, presented in Table 1.

2.2.2 Measurement of bonding strength

We tested the bonding strength of the plywood following the standards prescribed in GB/T 9846.7-2004

Table 1 Experimental parameters of hot-pressing

Treatment	Amount of plastics ($g \cdot m^{-2}$)	Hot-pressing Temperature (°C)	Hot-pressing time (min)
1	60	130	3
2	60	140	4
3	60	150	5
4	60	160	6
5	80	130	4
6	80	140	3
7	80	150	6
8	80	160	5
9	100	130	5
10	100	140	6
11	100	150	3
12	100	160	4
13	120	130	6
14	120	140	5
15	120	150	4
16	120	160	3

(Plywood of National Standard of the People's Republic of China, Part VII). The specimens were put on the testing machine in a straight line with both ends fixed in a movable holding fixture, with the specimen center at the center axis of the testing machine fixture.

2.2.3 Measurement of formaldehyde emission

The specimens used for the measurement of formaldehyde emission were made according to GB/T 9846.7-2004. The specimens were placed in wide -mouth bottles (500 mL) at a temperature of 20°C and kept for 24 h. The amount of emission of formaldehyde was measured with a formaldehyde determinator.

3 Results and discussion

3.1 Effect of the amount of recycled plastics on plywood performance

As can be seen from Fig. 1, the dry bonding strength of plywood, made with plastic film instead of an adhesive, is shown a reducing-increasing-reducing dynamic process with an increased use of plastics, while the opposite trend is apparent in wet bonding strength of the plywood. From Fig. 1, we can conclude that the bonding strength of the plywood decreased markedly in response to the increase in dosage of plastics when boiled in water at either a temperature of 60°C or 100°C, while in 60°C or 100°C water, the bonding strength of plywood with the most plastic reached their minimum. It is suggested that with less plastic a growing number of effective glue nails could be formed and the dry bonding strength could be enhanced by increasing the amount of plastic waste. However, when the dosage of plastic films continued to be increased beyond a certain range, the strength reduced, because of its poor tensile capacity and the growing thickness of the plastic layer in the plywood. Simultaneously, during the process of plywood hot-pressing, the stress generated in the plastic layer undermines the bonding strength. Take the macromolecules as an example, these produce stress which may reduce the bonding strength in its process of conversion from a state of free flow to a relatively stable solid state. When there is more plastic film used, the stress increases correspondingly, which explains the reason why the bonding strength of plywood would be reduced when continuously increasing the thickness of veneers after it has reached a certain level under these conditions of being heated in water with either a temperature of 60°C or 100°C. In addition, as the moisture in the layer evaporates, new stresses would appear. Furthermore, as the plastic film becomes thicker, the moisture increases, which causes stress enhancement and reduction in the bonding strength of plywood.

When the amount of waste plastic is 60 g·m^{-2}, the bonding strength reached its maximum and met the national standard under the conditions of water temperatures of 60°C and 100°C. However, only when the amount of waste plastics was 100 g·m^{-2} did the dry bonding strength of plywood reach its maximum. Meanwhile the bonding strength under the conditions of boiling water reduced slightly. Hence, the amount of 100 g·m^{-2} should be selected as a suitable parameter for plywood manufacture (Fig. 1).

3.2 Effect of hot-pressing temperature on plywood performance

As Fig. 2 shows, with an increase in hot-pressing temperature, the bonding strength of plywood indicates a clear upward trend and then declined. Under poaching condition of 60°C, the bonding strength of the plywood pressed at a temperature of 150°C reached its maximum, while under conditions of 100°C boiling water and a hot-pressing temperature of 160°C, the bonding strength of the plywood reached its maximum. This suggests that the bonding strength of plywood increases with an increase in hot-pressing temperature since these higher temperatures contributed to the melting of the plastic to provide better liquidity, permitting the plastic to disperse more evenly. Thus it created a good bonding environment and promoted the formation of effective bonding nails, all of which enhances the corresponding bonding strength. However, if the hot-pressing temperature continued to rise, the linear polymer plastic was subject to decomposition and fracturing, so that the rate of increase of the bonding strength declined.

Under the condition of boiling water, i.e., a temperature of 100°C, the bonding strength of plywood differed little between hot-pressing temperatures of

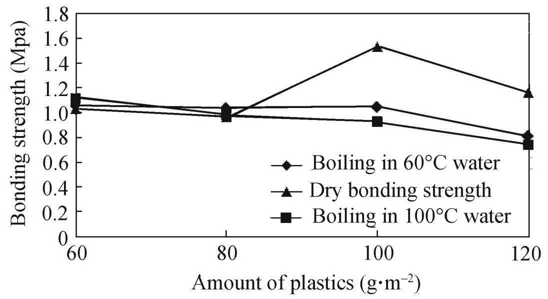

Fig. 1 Effect of amount of plastics on bonding strength

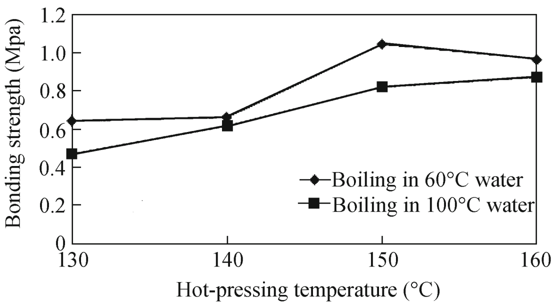

Fig. 2 Effect of hot-pressing temperatures on bonding strength

150°C and 160°C. At both temperatures, the national standard was reached. Taking into account the energy consumed, the hot-pressing temperature of 150°C was more economic.

3.3 Effect of hot-pressing time on plywood performance

From Fig. 3, we know that the hot-pressing time had considerable effect on the bonding strength of plywood. By increasing pressing time, there is sufficient time for melting and dispersion of plastics, allowing the bonding strength of plywood to increase gradually. With water temperatures of 60°C and 100°C and hot-pressing time ranging from 1 to 7 min, the bonding strength of plywood increased gradually and reached a maximum with a hot-pressing time of 6 min, after which it decreased instead of continuing to increase. This can be explained by the fact that after hot-pressing at 150°C for 6 min, the waste plastic had been melted fully and the thickness of plastics would be less if the pressing time were longer than 6 min, because some of the plastic had melted and flowed out of the plywood, resulting in the phenomenon of a lack of rubber and finally reducing the bonding strength of plywood. In addition, with the long hot-pressing time the melted plastic infiltrated the wood and hence caused a decrease in the plywood bonding strength. Therefore, a hot-pressing time of 6 min in actual production is more suitable.

3.4 Amount of formaldehyde emission

Table 2 shows that the formaldehyde emission of the plywood made by recycled plastics is very low, compared with that of ordinary plywood made with urea-formaldehyde resin: the amount of emission is almost zero. Furthermore, the release of formaldehyde is a reaction caused by the chemical composition of wood itself. As well, there is a small amount of formaldehyde in the air, so plywood can be considered a real "zero-emission formaldehyde" product. The process is a fundamental solution to the problem of formaldehyde release in plywood production.

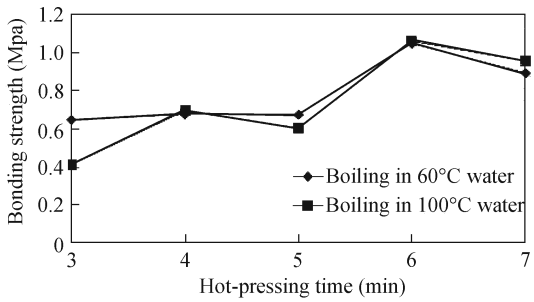

Fig. 3 Effect of hot-pressing time on bonding strength

Table 2 Amounts of formaldehyde emission from plywood

	Amount of plastics (g·m^{-2})				Hot-pressing temperature (°C)				Hot-pressing time (min)			
	60	80	100	120	130	140	150	160	3	4	5	6
PPM	0.055 (0.007)	0.070 (0.014)	0.055 (0.007)	0.055 (0.007)	0.045 (0.007)	0.040 (0.014)	0.050 (0)	0.040 (0)	0.050 (0.014)	0.050 (0.014)	0.050 (0)	0.060 (0)

Values in parentheses represent standard deviations.

4 Conclusions

The bonding strength of plywood made with recycled plastic material can meet national standard, while formaldehyde emission is nearly zero. Technological factors, such as the amount of plastic used, hot-pressing time and hot-pressing temperatures had various levels of effect on the bonding strength of plywood. From our study, we conclude that the optimal parameters were a plastic use of 100 g·m^{-2}, a hot-pressing temperature of 150°C and a hot-pressing time of 6 min.

Acknowledgements

This study was financially supported by the National Natural Science Foundation of China (Grant No. 31070501), Beijing Scientific Research and Base Construction Project in 2010 and the College Student Research Training Plan in Beijing Forestry University (No. 200705005). The technical help from H J Wang of Beijing Institute of Technology is gratefully acknowledged. We thank Dr. J Z Li of Beijing Forestry University and Dr. W Gao of Southwest Forestry University for their comments on the manuscript.

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(Received June 1, 2010 Accepted September 14, 2010)