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STEAM-PRESSING MECHANISM OF LOW DENSITY MAGNESIA-BONDED WOOD-WOOL PANEL

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ABSTRACT

In this paper, wood-wool panel was prepared by steam pressing as opposed to the traditional cold-pressing and hot-pressing methods in order to eliminate the shortcomings of both methods. Cold pressed wood panels have low strength. The overall performance of heat pressed wood panel was poor. The water absorption of these two panels was too large. The steam pressing mechanism was studied by the means of X-ray diffraction and scanning electron microscope. The surface structure, moisture absorption and mechanical properties of wood-wool panel were investigated by experimental testing and numerical analysis. The surface structure of the wood-wool panel became stable, the moisture absorption was reduced, and the mechanical properties of the wood-wool panel were enhanced. The static bending strength of autoclaved wood-wool panel was 4% higher than that of cold-pressed wood-wool panel, and 7.4% higher than that of hot-pressed wood-wool panel. And the sound absorption coefficient increased by 6.3% and 5% respectively. The thermal conductivity was 2.4% lower than that of cold-pressed wood-wool panel.

KEYWORDS: Magnesite, wood-wool panel, X-ray diffraction, scanning electron microscope, steam-pressing mechanism.

INTRODUCTION

Since living standards are higher, environmentalists prefer new building materials that integrate environmental, heat insulation, sound absorption and decoration (China Building Material Academy 2003, Jiang et al. 2003, Xiong et al. 2020, Song et al. 2018, Hu 2017), and the low density magnesia-bonded wood-wool panel is such a building material, which is often used as sound absorption, noise reduction and thermal insulation material in industrial and civil buildings (Zhang et al. 2002, Yang 1999). In recent years, China has imported low density wood-wool panel as decorative sound-absorbing material in some public buildings (Gong 2006, Tu 2007).

Because of its excellent physical and mechanical properties and fashionable decorative appearance, this new material was generally accepted and widely used by people. However, due to moisture absorption, not only the appearance quality of the wood-wool panel was coloured, but also its application range was limited. There were free magnesium chloride or sodium chloride in wood-wool panel, and their moisture absorption and deliquescence result in efflorescence, which was the underlying cause of hygroscopicity in wood-wool panel (Cao 2008, Ma 1997). Therefore, it is of great significance to solve the problem of hygroscopicity, which is of positive significance to the development of the wood veneer industry in China, the sustainable and efficient development of the fast-growing poplar industry and the development of high value-added products.

Low density magnesia-bonded wood-wool panel was a new building material with sound absorption, heat preservation, decoration and other functions, which taken magnesite as adhesive and wood-wool as reinforcing agent, and was mixed and stirred with magnesium chloride solution, and then added with additives. The traditional technologies of their manufacturing were cold-pressing and hot- pressing (Soroushian et al. 2003, Li et al. 2012, Yan et al. 2005, Jiang et al. 2002, Sun 2002, Chen et al. 1992, Lu et al. 1991). However, the panel made by cold pressing method has good mechanical properties, but its strength was poor. The wood-wool panel made by hot pressing had good thermal conductivity, but other properties were average, and its strength decreased greatly. Those two kinds of wood-wool panel had poor hygroskopicity (Aiken et al. 2020, Nguyen et al. 2020, Gul et al. 2017).

In this paper, wood-wool panel was prepared by steam pressing (Song et al. 2018, Kitchens et al. 2016, Euring et al. 2016), and the steam pressing mechanism was studied by the means of X-ray diffraction and scanning electron microscope (Akinyemi et al. 2019).

MATERIAL AND METHODS

Experimental design

Those process parameters (Na et al. 2008, 2018, 2020) were used for experimental design: panel density of 0.45 $g^{\cdot}cm^3$, panel width of 350 × 350 mm, maximum internal vapor pressure 0.27 MPa, and magnesium chloride solution relative density of 1.26 $g^{\cdot}cm^{-3}$ (Na et al. 2014). Temperature of 140°C, time of 30 min, $MgO/MgCl_2$ molar ratio 6, gray-wood ratio 2, compound additives (talcum powder + aluminum powder + jarosite + $NH_4H_2PO_4$), and additive amount was 1% of the quality of magnesia-bonded. After the maintenance of wood-wool panel, the powder samples were cut parallel to the surface of the wood-wool for X-ray diffraction and scanning electron microscope tests, and samples were cut for performance tests.

Experimental materials

The magnesia-bonded was purchased from Shandong Laizhou Hongda Building Materials Factory (MgO of 60%). The magnesium chloride solution with relative density of 1.26 $g^{\cdot}cm^{-3}$ and magnesium chloride content of 27.77% was prepared by densimeter. Chopped veneer of fast-growing poplar in noodle machine with a thickness of 1-2 mm was cut into wood-wool with a length of 200 mm and a width of 2 mm, and the moisture content was about 12%. The compound additive is talcum powder + aluminum powder + jarosite + $NH_4H_2PO_4$. The amount of each material was calculated by the Eqs. 1 and 2:

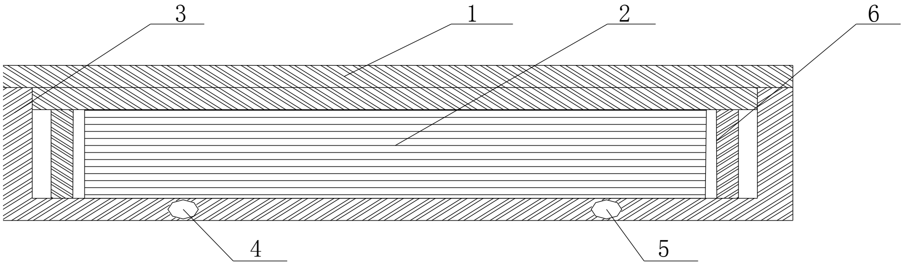
$$G = \frac{DV}{1 + 1/B + A + 0.2 + 0.3/B}\delta \tag{1}$$

$$P = \frac{DV}{B + 1 + BA + 0.2B + 0.3} \tag{2}$$

where: G - gray content (g), P - wood-wool amount (g), D - absolute dry density of panel ($g \cdot cm^3$), V - panel volume (cm^3), A - weight ratio of $MgCl_2$ and MgO, B = 0.2 - gray-wood ratio (when magnesium oxychloride cement was hydrated, the ratio of crystal water to cement was generally 0.2), δ = 1.05-1.10 - loss coefficient (Gong 2006).

Equipment

The transformation of the closed steaming machine, specifically introduced in the utility model patent - manufacturing light bittern wood-wool panel steaming equipment (ZL 200620073700.4). The steam generator is DZFZ-3 type, its maximum steam pressure is 0.4 MPa, the highest temperature is 140°C. The noodle machine is MT-60, 2 mm wide cutting tool. Scanning electron microscope (SEM) is S-3400N II, scanning electron microscope laboratory of Nanjing Forestry University. X-ray diffraction analyzer (XRD) is X′TRA type, Modern Analysis Center of Nanjing University. The blast drying oven is DHG-9030A and the maximum temperature is 250°C. The constant temperature and humidity box is SPX-150C, temperature range 5-50°C, humidity range 60-90%. The electronic balance is JY series, with precision of 100 mg.



1- frame cover, 2- steam-pressing products, 3- frame body, 4- outlet/exhaust steam channel, 5- inlet steam channel, 6- thickness gauge.

Fig. 1: The sketch map of steam-pressing machine.

Preparation

According to the experimental requirements, the materials were mixed first. The prepared $MgCl_2$ solution was put into the spray barrel, the surface of the wood-wool was evenly sprayed, and the magnesia-bonded or the magnesia-bonded with additives were evenly sprayed and exposed highly on the surface of the wood-wool. After that, the wood-wools were randomly and evenly spread across the forming frame, and a template was used to pre-stress the wood-wools to form the wood-wools. Then the formed panel was put into the press frame, the press was closed, (the steam valve was closed) for steam-pressing. After being pressed for the given time, it was steam-pressed and maintained for 5 min and then taken out, and then maintained for 28 days and then cut into sample for testing performance.

RESULTS AND DISCUSSION

Steam pressing mechanism analysis

According to investigation (Xu 2006) when wood was heat-treated at a temperature above 130°C, the moisture absorption of wood was obviously reduced. In definite steam-pressing conditions, the strength will not be affected by short-time heat treatment. Because the polysaccharides of wood began to be decomposed at 120°C, hemicellulose and cellulose could be decomposed obviously at a high temperature of 180°C, and the decomposition of lignin was slower than both. That is to say, polysaccharide substances with strong hygroscopicity were reduced at high temperature above 130°C, while the relative content of lignin with weak hygroscopicity was increased. So the overall hygroscopicity of wood was obviously reduced. The plastic shrinkage of wood part will also be caused by high temperature treatment. Moreover, under the high-temperature steam conditions, the magnesium chloride solution generated precipitate $Mg(OH)Cl$. The capillary was blocked, and the water was prevented, so the moisture absorption capacity of the wood-wool panel was reduced. Therefore, it was more rational for the steam-pressing method to be used.

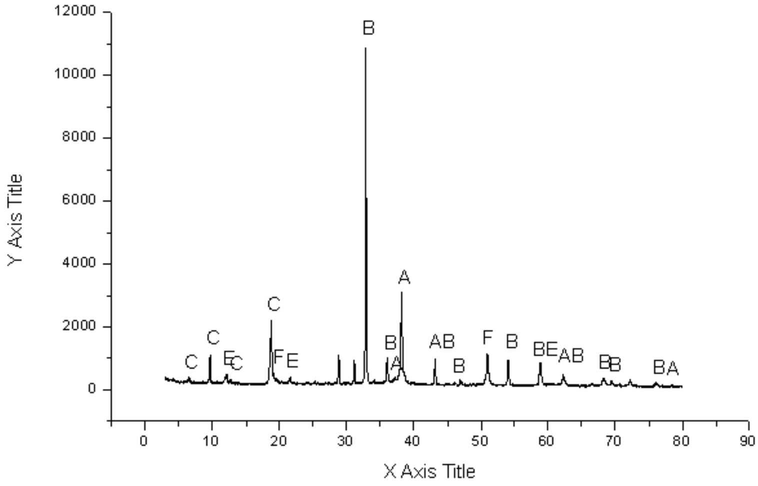
The mechanism of steam-pressing was also obviously affected by process factors. According to the hydration mechanism research conducted by the author in the early stage, the five-phase products produced by the hydration reaction of magnesia-bonded and magnesium chloride by steam-pressing was more than that under cold or hot pressure, and the reaction time was shorter. The production of 5 phases of hydration products in steam-pressing reaction was also affected by the change of molar ratio and gray-wood ratio. More stable hydration products with 5-phase crystal form could be produced with proper molar ratio and ash-wood ratio by steam-pressing, so that the wood-wool can be firmly combined together and the mechanical properties of the wood-wool panel could be greatly improved to meet the needs. Additives were used to improve the poor water resistance of the wood-wool panel itself, and water-resistant substances were generated on the surface of the wood-wool panel to prevent absorbing moisture, so that the phenomenon of moisture absorption and efflorescence of the wood-wool panel was minimized.

In the following, the microscopic analysis of the surface structure of the wood-wool panel was conducted with XRD and SEM testing methods, and the steam-pressing mechanism of the low density magnesia-bonded wood-wool panel was discussed.

XRD analysis of surface structure of wood-wool panel

It can be seen from Fig. 2 that the main components of XRD were $MgCO_3$ (magnesite), MgO (periclase), $Mg_3Si_4O_{10}(OH)_2$ (talc), E-5 phase and $Mg(OH)_2$. This showed, under the condition of steam-pressing the hydration reaction can be promoted , so that 5-phase hydration products can be easily generated.

While part of $MgCO_3$ (magnesite) in hydration products may already exist in magnesia-bonded, and the other part may be$MgCO_3$ produced by reaction between MgO and CO_2 in air under steam-pressing conditions. The mechanical properties of hydration products and wood-wool panel were improved due to the residual $Mg_3Si_4O_{10}(OH)_2$ (talc) and excessive MgO (periclase) in the hydration products. The $Mg(OH)_2$ in the hydration product may be generated by the excess $MgCl_2$ solution under the action of additives. It was shown by XRD that the characteristic peaks of each product were not much different except $MgCO_3$ (magnesite), but $MgCO_3$ (magnesite) was unstable and decomposed at high temperature, and was stable under general conditions, thus the hydration products on the surface of the wood-wool panel were relatively stable, resulting in relatively stable performance of the wood-wool panel.



A-MgO B-$MgCO_3$ C-$Mg_3Si_4O_{10}(OH)_2$ E-5-phase F—$Mg(OH)_2$

Fig. 2: XRD spectrum of the surface of wood-wool panel.

SEM analysis of surface structure of wood-wool panel

Fig. 3 displayed SEM patterns of the surface structure of the wood-wool at four different power of 300, 800, 1200 and 4000.

From the pattern under 300 power, it can be seen that the surface structure of the wood-wool panel was relatively dense on the whole, the wood-wool and the hydration product were well bonded. Although there were a few cracks, the surface structure was fine. At 800 and 1200 power, it can be further seen that the hydration products were basically gel-like, which indicated that there were more gel-like 5 phases. The hydration products were relatively stable, and the surface structure of the wood-wool panel was also stable. The picture under 4000 power clearly showed that the gel-like hydration products were cemented together like a network, and the cemented materials were short and close-boarded, the stability of the hydration products was obviously increased and was glued firmly with the wood-wool, and the surface structure of the wood-wool panel was made a firmer bond, so it was not easy to absorb moisture and break. In this manner, the moisture absorption performance of the wood-wool panel was also improved.

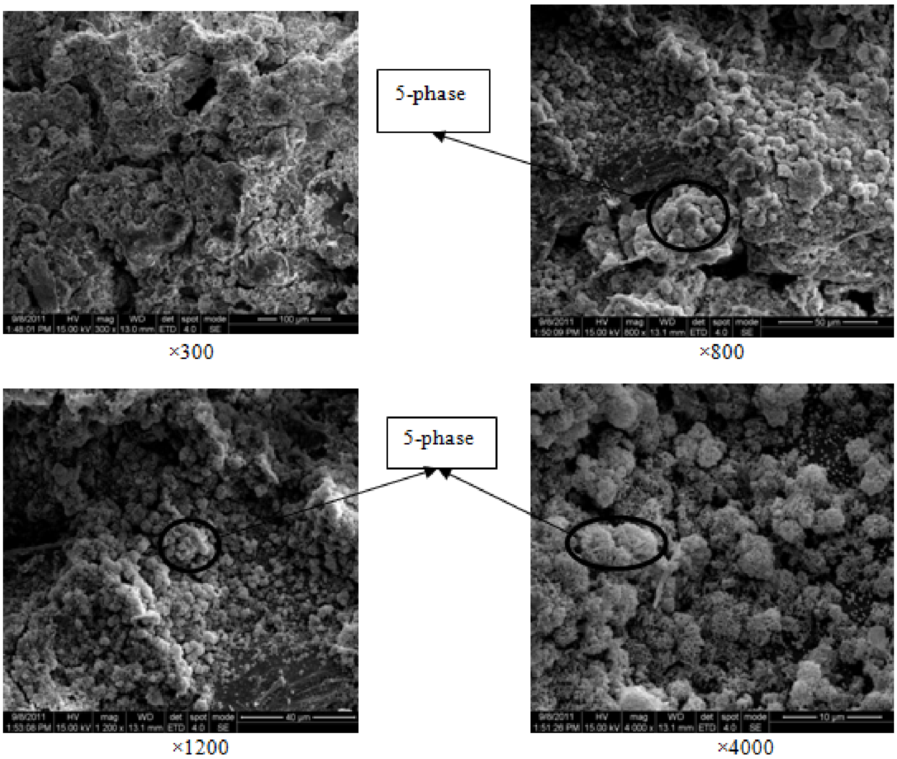


Fig. 3: SEM micrograph of the surface of wood-wool panel.

Physical and mechanical properties of wood-wool panel

The physical properties of three low density magnesia-bonded wood-wool panels after maintenance treatment were tested, and the results were shown in Tab. 1.

Tab. 1: The physical property data of magnesia-bonded wood-wool panel.

SN	Density (g·cm^{-3})		Modulus of rupture (MPa)		Absorption coefficient		Thermal conductivity (W·m^{-1}·K^{-1})	
	Single value	Mean value	Single value	Mean value	Single value	Mean value	Single value	Mean value
1	0.446	0.448	1.76	1.76	0.38	0.40	0.081	0.08
2	0.448		1.78		0.42		0.082	
3	0.450		1.74		0.40		0.077	

The performance indicators for the likewise products of wood-wool panel at home and abroad were as follows (Zhong 2005) (Tab. 2).

Tab. 2: The domestic technique data of magnesia-bonded wood-wool panel (Zhong 2005).

Name	Unit	Tolerance
Volume density	kg·m^{-3}	350-500
Modulus of rupture	MPa	$\geq 5.9\times10^{2}$
Thermal conductivity	W·m^{-1}·K^{-1}	≤ 0.23
Absorption coefficient	%	> 20

In Tab. 1 was given the physical and mechanical properties of the wood-wool panel prepared by steam-pressing. Tabs. 2 and 3 given the technique data of magnesia-bonded wood-wool panel at home and abroad.

Tab. 3: The foreign technique data of magnesia-bonded wood-wool panel (Zhong 2005).

Thickness and areal density	25 mm, 12 - 14 $kg\cdot m^{-2}$
	35 mm, 16 - 18 $kg\cdot m^{-2}$
	50 mm, 24 - 28 $kg\cdot m^{-2}$
Noise reduction coefficient	NRC = 0.5-0.7
Thermal conductivity	$\lambda = 0.09\ W\cdot m^{-1}\cdot K^{-1}$
Modulus of rupture	$\sigma_b = 1.62$ MPa

By comparing the results of Tab. 1 with those of Tabs. 2 and 3, it can be seen that the physical and mechanical properties of the wood-wool panel prepared by steam pressure meet the technical indexes at home and abroad. The static bending strength of autoclaved wood-wool panel was 4% higher than that of cold-pressed wood-wool panel, and 7.4% higher than that of hot-pressed wood-wool panel, and the static bending strength was significantly improved. The sound absorption coefficient increased by 6.3% and 5% respectively. The thermal conductivity was 2.4% lower than that of cold-pressed wood-wool panel, and had no significant change compared with that of hot-pressed wood-wool panel. (Li et al. 1991, 2012, Zhou et al. 2006). The results showed that the surface of the wood-wool panel prepared by steam-pressing was fully reacted with a solution of magnesia-bonded and magnesium chloride so that the bond between the wood-wools was firm enough to meet the requirements of building materials. Besides, due to the space between the wood-wool panel, the wood-wool panel had better sound absorption and heat preservation performance.

CONCLUSIONS

The research on the steam-pressing mechanism, XRD, SEM micro-analysis and physical and mechanical properties of the wood-wool panel indicated that under the steam-pressing condition, more stable hydration products with 5-phase crystal state can be produced with right molar ratio, gray-wood ratio and additives, so that the wood filaments can be firmly combined together, and the moisture absorption of the wood-wool panel was reduced (Chen et al. 1996, Feng et al. 2002), the mechanical properties of the wood-wool panel were improved. Besides, the sound absorption and heat insulation properties of the wood-wool panel were also improved, and the functional properties of the wood-wool panel were superb. In conclusion, the surface structure of the wood-wool panel prepared by steam pressing method was stable, the hygroscopicity was improved and the physical properties were fine. The facts had proved that this steam-pressing method was workable.

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