Investigation of an Environmentally Friendly Incense Consisting of Soy-based Adhesive and Wood Powder

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This study investigated the feasibility of an environmentally friendly incense consisting of a soy-based adhesive and miscellaneous wood powder (MWP). Key properties, such as water absorption, burning speed, density, and tensile strength, were examined. The suitable adhesive usage amount for the preparation of incense was 31.8%. When the soy-based adhesive contained 3% polyvinyl alcohol (PVOH), the water absorption, burning speed, density, and tensile strength of the incense were 24.6%, 13.93%, 0.713 g/cm^3, and 1.01 MPa, respectively. Incense made of soy-based adhesive with PVOH displayed a higher tensile strength and decreased moisture resistance. The denser structure and even distribution of the MWP was observed *via* scanning electron microscopy of the incense with soy-based adhesive modified by 3% PVOH. When paraffin wax was added with the MWP, the incense had a higher moisture resistance, but the effects on the tensile strength were negligible. A combination of PVOH-modified soy-based adhesive, paraffin wax, and MWP was found to be suitable for preparing an environmentally friendly incense.

Keywords: Incense; Soy-based adhesive; Paraffin wax; Wood powder

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INTRODUCTION

Incense is widely used in various places as an air freshener, an insect repellent, a religious item, *etc.* (Chuang *et al*. 2013; Cohen *et al*. 2013). The global annual consumption of incense exceeds 200 million tons, to which Asian countries are the largest consumers (Lung *et al*. 2010). Incense smoke is considered to be an indoor pollution source that is comparable to or more serious than cigarette smoke (Jetter *et al*. 2002). A variety of substances, such as carcinogens (*e.g.*, polycyclic aromatic hydrocarbons, formaldehyde, *etc.*), suspected carcinogens (*e.g.*, acetaldehyde), irritants, and allergens harmful to the human body, have been detected in incense smoke (Lui *et al*. 2016; Kuo and Tsai 2017). Inhalation of these substances can cause asthma, rhinitis, and various respiratory diseases such as lung cancer or nasopharyngeal cancer (Bootdee *et al*. 2016; Chen *et al*. 2017a). Unfortunately, there are few substitutes for incense, especially when it is used for religious purposes. Therefore, methods to reduce the generation of harmful substances during the burning of incense has become an important research topic in the incense industry.

There are many incenses with different functions and appearances, which are dependent on the application and occasion. In general terms, all incense is comprised of the same raw materials: wood powder, spices, and adhesives (Višić *et al*. 2018). The adhesives are mainly derived from the petrochemical products (*e.g.*, acrylic amide, styrene, *etc.*), which are non-renewable and will be restricted by the shortage of petroleum resources (Lee *et al*. 2018). Furthermore, the petroleum-based adhesives contain an aromatic structure, which releases a large number of harmful substances, such as polycyclic aromatic hydrocarbons and formaldehyde, during the burning of incense. Therefore, it is necessary to investigate environmentally friendly adhesives from renewable materials for use in incense.

The preparation of environmentally friendly adhesives from biomass materials, such as vegetable protein (Chen *et al*. 2013), starch (Masina *et al*. 2017), and lignin (Navarrete *et al*. 2012), has attracted considerable attention in recent years because they are renewable, environmentally safe, and readily available. Vegetable protein is particularly desirable, as it contains many functional groups, including primary amines, carboxyl groups, and hydroxyl groups. Soy protein is one of the widely studied vegetable proteins for the preparation of soy-based adhesives that were used in the production of plywood in the early 20th century, but were replaced by urea-formaldehyde adhesives that had better water resistance (Chen *et al*. 2018). Through the persistent efforts of many researchers, the water resistance of soy-based adhesives has continuously improved, and great progress has been made in the bonding of wood (Chen *et al*. 2012). Previous research has found that alkali-modified soy protein isolate adhesives applied to bonded plywood displayed improved water resistance (Hettiarachchy *et al*. 1995). Better performances have been found in the plywood bonded with other soy-based adhesives, which were cross-linked by synthetic resins, including polyamidoamine-epichlorohydrin (Li *et al*. 2004), epoxy resin (Chen *et al*. 2017b), and polymeric methane diphenyl diisocyanate (Tenorio-Alfonso *et al*. 2017). In recent years, soy-based adhesives were also applied to bond particle board and fiber board. Prasittisopin and Li (2010) reported that a soy-based adhesive system consisting of soy flour and an aqueous curing agent can be used for the preparation of particle board. Zhang *et al*. (2018a) found that epoxidized oleic-modified soy protein adhesives improved the water resistance of straw fiberboard. The mechanical and water-resistant properties of the straw fiberboard met the requirements of the Chinese standard GB/T 11718 (2009) for medium-density fiberboard. Incense is a composite with similar constitutions as fiberboard. Therefore, soy-based adhesives may be suitable adhesives for the preparation of incense. However, little information is available about the incense bonded with bio-based adhesives such as soy-based adhesive. In this study, traditional petroleum-based adhesives were substituted for polyvinyl alcohol(PVOH)-modified soy-based adhesives to bond miscellaneous wood powder (MWP) for the development of environmentally friendly incense. The effect of paraffin wax on incense was also investigated. The properties of incense, such as the burning speed, density, and water absorption, were evaluated. The raw materials used in the soy-based adhesives were environmentally benign; thus, the developed incense can be regarded as environmentally friendly. The incense showed the excellent properties through a suitable combination of soy-based adhesive and wood powder. This study provides useful insights into the development of environmentally friendly incense derived completely from biomass materials.

EXPERIMENTAL

Materials

Miscellaneous wood powder with a moisture content of 5.12% was obtained from Quanzhou Yuetaixiang Industry Co. (Fujian, China). Defatted soy flour was ground from defatted soy meal and passed through a 100-mesh sieve with 99% acceptance. The soy flour had a protein content of 53.4%, a carbohydrate content of 36.3%, and a moisture content of 8.56% (Wonderful Industrial Group Co., Shangdong, China). Commercial paraffin wax and PVOH were purchased from Youxixianbaiyuan Wood Co. (Fujian, China). Analytical grade sodium hydroxide was supplied by Tianjin Fuchen Reagent Co. (Tianjing, China).

Methods

Wood powder treatment

The MWP was used for the pretreatment with paraffin wax. A total of 1000 g of MWP was placed into a circular box and stirred at approximately 250 rpm at room temperature. The melted paraffin wax was then sprayed into the box *via* a spray gun (W-71, Puyuan, Taiwan, China) for 30 s. The paraffin wax was dosed at 0%, 0.1%, 0.3%, 0.5%, 0.7%, or 0.9% of the MWP usage. Finally, the pretreated MWP was transferred into a plastic valve bag.

Soy-based adhesive preparation

The commercial PVOH particles were diluted with tap water and stirred at 85 °C for 60 min. The PVOH solutions were prepared at concentrations of 0%, 1.0%, 2.0%, 3.0%, 4.0%, and 5.0% and cooled to room temperature. Next, 160 g of the PVOH solution and 40 g of the defatted soy flour were added to a 500-mL three-necked flask and stirred for 40 min in a 35 °C water bath. Finally, the slurry was warmed to 40 °C, pH was adjusted to 11 with sodium hydroxide solution (30%), and mechanically stirred for 30 min to obtain the soy-based adhesive.

Incense preparation

The soy-based adhesive was blended with the paraffin wax-treated MWP. The mixture was blended for 10 min and then placed in an 240 mL iron-molded tube with an extrusion die head (I-240, Zhongya, Hebei, China) (3.0-mm internal diameter) for extrusion. The extruded mixture was oven-dried at 80 °C to obtain the incense and was stored in a desiccator for further characterization.

Incense characterization

For the moisture absorption characterization, 5 g of each incense sample was placed in a desiccator at room temperature for 24 h and weighed. The sample was then placed in a weighing bottle and kept in a temperature and humidity chamber (Edeson Instrument Co., Zhejiang, China) for treatment at 30 °C and 100% relative humidity. After treatment, the weighing bottle was covered with a lid and cooled to room temperature in a desiccator. After 24 h, the bottle was weighed using an analytical balance. The water absorption of the incense was calculated according to Eq. 1,

$$Water\ Absorption\ (\%) = \frac{m_3 - m_2 - m_1}{m_1} \times 100 \quad (1)$$

where m_1 is the mass of the sample after 24 h in the desiccator (g), m_2 is the mass of the sample after treatment in the temperature and humidity chamber (g), and m_3 is the mass of the sample after being cooled to room temperature in the desiccator (g). The results are presented as the average value of three replicates.

For the burning speed characterization, each incense sample was fixed on a metal shelf and placed in an uncovered square box (40 cm × 40 cm) to record the burning time. The burning speed was calculated according to Eq. 2,

$$Burning\ Speed = \frac{t}{L} \tag{2}$$

where L is the length of the incense sample (mm) and t is the burning time (s). The results are presented as the average value of three replicates.

For the density characterization, the length, diameter, and weight of the incense samples were measured with a Vernier caliper (111n-101b, Guanglu, Guilin, China), a micrometer scale (211-101F, Guanglu, Guilin, China) and an analytical balance (ME204E, Mettler Toledo, Shanghai, China), respectively. The density of the incense was calculated according to Eq. 3,

$$Density = \frac{4m}{3.14 \times d \times d \times L} \tag{3}$$

where L is the length (cm), d is the diameter (cm), and m is the mass (g). The results are presented as the average value of three replicates.

The tensile strength of the incense (Fig. 1) was performed using a tensile testing machine (MTS, Shenzhen, China) with a crosshead speed of 5 mm/min. The diameter and tensile force of the incense was recorded. The tensile strength of incense was calculated according to Eq. 4,

$$Tensile\ Strength = \frac{4F}{3.14 \times d \times d} \tag{4}$$

where d is the diameter (mm) and F is the tensile force (N). The results are presented as the average value of six replicates.

Fig. 1. The tensile strength testing mechanism

The incense samples were also characterized *via* scanning electron microscopy (SEM) analysis. The incense sample was placed in a vacuum spray machine (Laica ACE200, Wetzlar, Germany) to vacuum-spray gold for the samples. The microstructure of the fracture surface of the incense was investigated using SEM (SU8010; Hitachi, Tokyo, Japan) at an accelerating voltage of 1.0 kV.

RESULTS AND DISCUSSION

Both the soy-based adhesive and MWP are characterized by their low cost and low environmental impact. The incense prepared from these two components displayed similar characteristics as feedstock. The water absorption, tensile strength, burning speed, and density were tested to clarify the changes in the properties of incenses with different macro-level combinations of soy-based adhesive and MWP. The morphology features of the incenses at the micro-level were analyzed using SEM.

Effect of the Soy-based Adhesive Usage Amount

The adhesive dosage affected the operability and appearance of the incense. The appearance and properties of the incense samples with 44.4%, 31.8%, and 23.1% (dry basis) of soy-based adhesive (no PVOH) are displayed in Fig. 2 and Table 1, respectively. The data in Table 1 show that the water absorption and burning speed of the incense decreased with decreasing proportions of soy-based adhesives, whereas the density and tensile strength increased with decreasing proportions of soy-based adhesives. At a 44.4% soy-based adhesive dosage level, the incense had many flaws (*e.g.*, rough surface, loose texture, and many holes) after drying (Fig. 2i). This was also in agreement with the phenomenon found in the experiment, which showed that the incense had good fluidity and was easily extruded from the molded tube when the soy-based adhesive content was increased. Therefore, an increased adhesive content negatively affected the incense formation. When the soy-based adhesive amount was decreased to 31.8%, the incense had considerable tensile strength (0.73 MPa) and was not easy to break off, resulting in a continuous structure and smooth surface after drying. When the soy-based adhesive usage was 23.1%, the incense also displayed good appearance and a higher tensile strength (0.81 MPa) than the 31.8% soy-based adhesive dosage, but it was easier to break off in the preparation process. This could be ascribed to the increased density of the incense, because the density of wood composites has a positive correlation with their mechanical strength.

Fig. 2. Incense with different soy-based adhesive usage amounts (i) 44.4%, (ii) 31.8%, and (iii) 23.1%

Table 1. Properties of Incense with Different Soy-based Adhesives Usage

Soy-based Adhesive Content (%)	Water Absorption at 40 min (%)	Burning Speed (s/mm)	Density (g/cm^3)	Tensile Strength (MPa)
44.4	119.0 ± 8.6	17.76 ± 0.43	0.619 ± 0.057	0.62 ± 0.09
31.8	54.8 ± 5.4	13.24 ± 0.27	0.716 ± 0.024	0.73 ± 0.05
23.1	49.6 ± 6.7	12.55 ± 0.59	0.791 ± 0.039	0.81 ± 0.06

The Effect of PVOH Content in Soy-based Adhesives

Defatted soy flour is a complicated mixture consisting of approximately 50% soy protein and 40% carbohydrates. After alkali treatment, the globular structure of the soy protein unfolded and exposed the hydrophilic groups (*e.g.*, -OH, -COOH, and $-NH_2$) inside, leading to enhanced toughness. However, poor adhesion can hinder the process (Fig. 2 and Table 1) (Zhang *et al*. 2018b). Hence, a commercial PVOH was used for the improved stickiness of soy-based adhesives (Zheng *et al*. 2017). Incenses consisting of soy-based adhesives (31.8%) and MWP (68.2%) were prepared and then their moisture absorption, burning speed, density, and tensile strength were measured. The results are shown in Fig. 3.

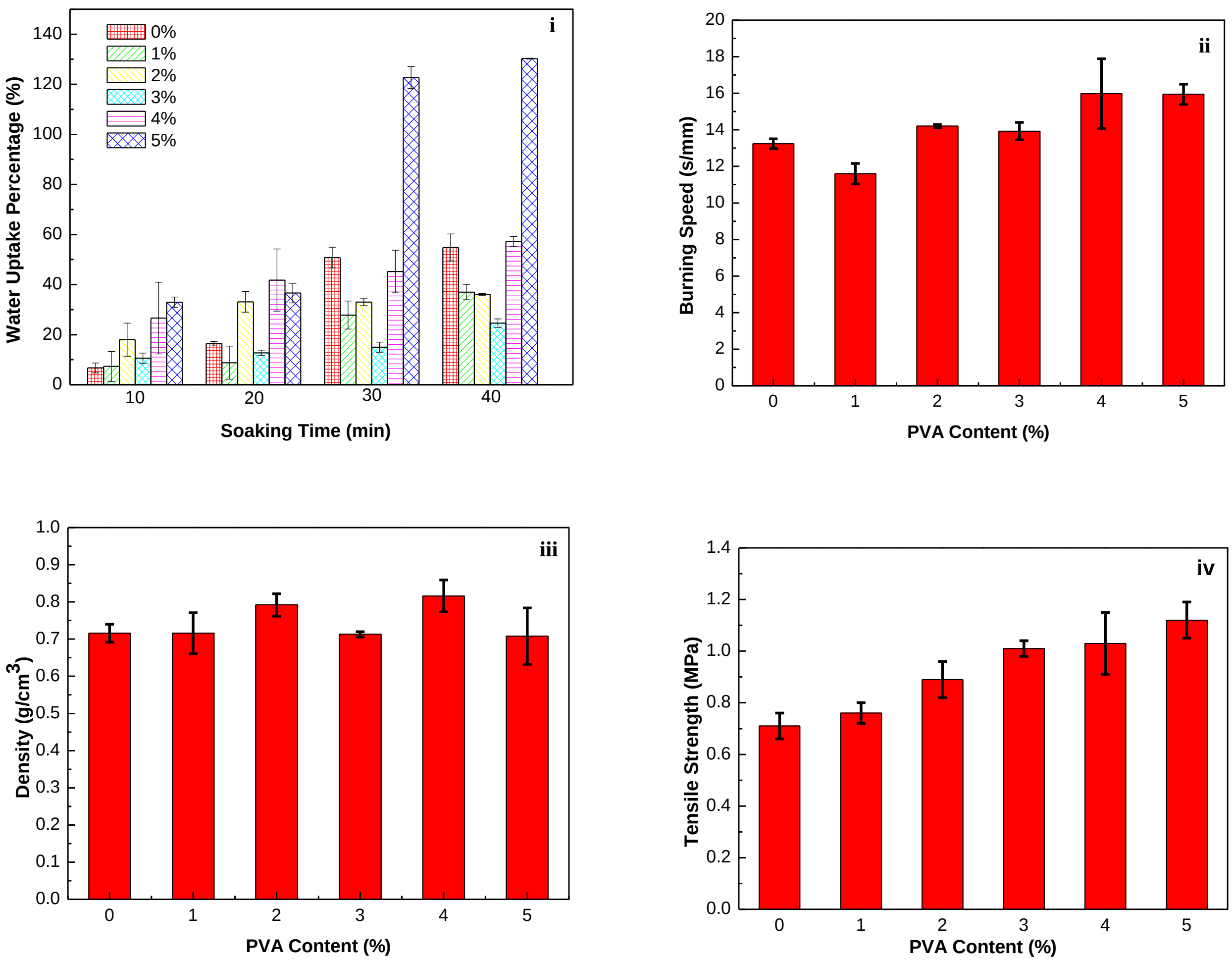

Fig. 3. The effect of PVOH content in soy-based adhesives on the properties of incense (i) water absorption, (ii) burning speed, (iii) density, and (iv) tensile strength

Figure 3i shows that the water absorption of the incense increased with increased soaking time, but the effect of PVOH usage on the water absorption of incense was not noticeable in the first 30 min. At a soaking time of 10 min, the incense bonded with the unmodified soy-based adhesive had the lowest water absorption. After using the PVOH in soy-based adhesives, all the incenses had increased water absorption. The largest water absorption was obtained with 5% PVOH usage. After 20 min, the water absorption of the 5% PVOH incense sample rapidly increased, while the 1% to 4% PVOH incense samples displayed a slow increase in water absorption. These changes might have been due to the formation of hydrogen bonds between the soy protein and PVOH. Because PVOH contains a large amount of hydroxyl groups, when the PVOH usage was 1% to 4%, the amount of hydroxyl groups in the PVOH were comparable with polar groups in the soy protein to form strong hydrogen bonds. When the PVOH usage was higher than 5%, there were more free hydroxyl groups in the incenses, which reacted quickly with water to increase the water absorption. Therefore, there was a suitable range for PVOH usage. When the water absorption time was 40 min, the water absorption of the incense gradually decreased for the samples with 0% to 3% PVOH concentration. Higher PVOH usage rapidly increased the water absorption of the incense. The results indicated that a soy-based adhesive with 3% PVOH was suitable for controlling the water absorption of incense.

Figure 3ii shows that the burning speed of the incense increased as the PVOH usage increased. This may have been because the incense structure was relatively loose and many holes were found in samples with less PVOH usage, which resulted in a faster burning speed. When the PVOH usage was further increased, the surface of the incense was covered with PVOH. The strong hydrogen bonds between the PVOH, MWP, and soy protein made the incense denser, leading to a slower burning speed. Generally speaking, a slower burning speed will reduce incense consumption and enable it to be readily extinguished in the burning process. A slower burning speed will be preferred by the customer, because of the relative decreased cost. Figure 3iii shows that the PVOH dosage did not affect the density or the burning speed of the incense. This was mainly because the low concentrations of PVOH had a negligible effect on the density of the soy-based adhesives. Further adhesive dosage had a negligible effect on the density of the incense. Figure 3iv shows that the tensile strength of the incenses increased as the additive amount of PVOH usage increased. This was because the PVOH contained a large number of hydroxide radicals, which can form a large number of hydrogen bonds with functional groups (*e.g.*, -OH) in soy protein and wood fiber. When the soy-based adhesive contained 3% of PVOH, the tensile strength of the incense increased to 1.01 MPa, which was 42.3% higher than the incense bonded using adhesive without PVOH. The result was comparable to the tensile strength (0.95 MPa) of commercial products.

The Effect of Paraffin Wax Content in MWP

Paraffin wax is composed of a variety of saturated hydrocarbons and has good waterproof properties. Paraffin wax has been widely used to improve moisture resistance in many products such as paper, particleboard, and fiberboard (Grigsby and Thumm 2012). Hence, the dissolved paraffin wax was sprayed on the surface of MWP to further improve the moisture resistance of the incense. During the drying process of the incense, the paraffin wax was evenly distributed, which protected the MWP from water droplets. To analyze the effect of the paraffin wax on the incense, MWP with different paraffin wax doses (0%, 0.1%, 0.3%, 0.5%, 0.7%, and 0.9%) was prepared and then bonded by soy-based adhesives with 3% PVOH usage. The results are shown in Fig. 4.

Figure 4i shows that the water absorption of the incense samples increased as the soaking time increased and decreased as the paraffin wax usage increased. The water absorption measurements of the incense samples with 0.1% paraffin wax added were 44.3%, 55.9%, 74.7%, 50.4%, 42.8%, 30.6%, and 22.1% of the samples without paraffin wax at the 10 min, 20 min, 30 min, 40 min, 50 min, 70 min, and 90 min soaking times, respectively. When the soaking time was 24 h, the incense samples without paraffin wax disintegrated, while the incense samples with 0.1% paraffin wax increased the water absorption to 253.1%. The tendency of increased water absorption was also found on the other incense samples with paraffin wax. These results indicated that the water resistance of the incenses were improved by the paraffin wax, because the paraffin wax blocked some of the water absorption means (*e.g.*, pit structure) in the wood cells (Widsten 2002).

Furthermore, there was no remarkable difference in the water absorption of the incense with paraffin wax when the soaking time was between 40 min and 90 min. However, a remarkable difference was observed at a soaking time of 24 h.

Figure 4ii shows that there was no noticeable change in the burning speed of the incense when the paraffin wax usage was increased. This indicated that the burning speed of incense was mainly related to the formula and the amount of adhesive used. The density of the incense decreased as the paraffin wax usage increased (Fig. 4iii). This was because the paraffin wax had low density, which resulted in the decreased weight of the incense at the same volume. A similar tendency was observed for the tensile strength of incense when paraffin wax usage was 0.5% and above (Fig. 4iv). Although paraffin wax is an excellent waterproofing agent, it had a negative effect on the mechanical strength of incense. Therefore, considering the price of paraffin wax and the properties of incense, the actual amount of paraffin wax used in the incense can be adjusted as needed.

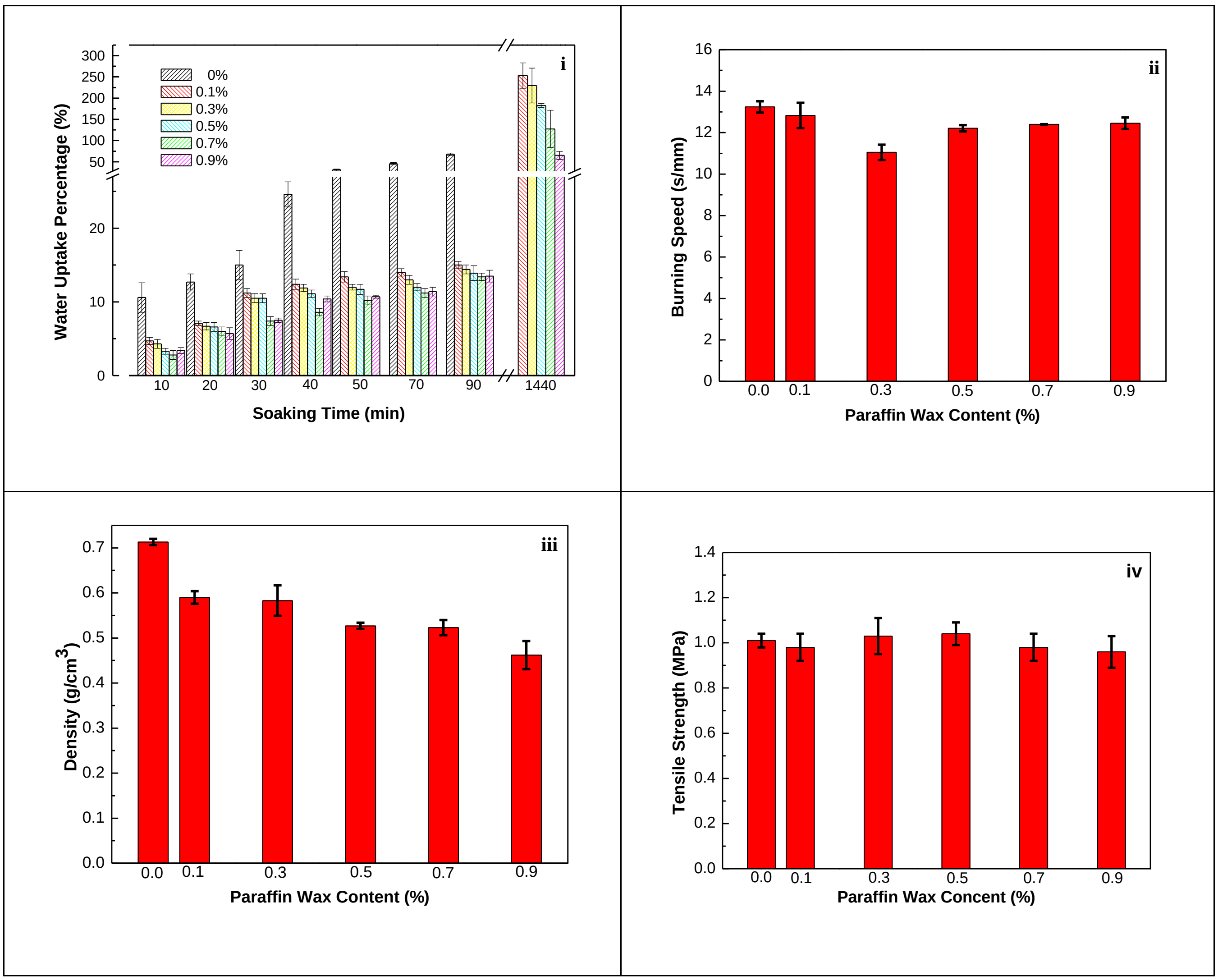

Fig. 4. The effect of paraffin wax content in MWP on the properties of incense (i) water absorption, (ii) burning speed, (iii) density, and (iv) tensile strength

Fracture Surface Analysis

To further investigate the microstructure of the incense, SEM was used to observe the fracture of the incense with 0% and 3% of PVOH usage (Fig. 5). Many large holes were found in the incense without PVOH, and the MWP was not well-distributed. After the 3% application of PVOH, the incense displayed a denser structure and an even distribution of MWP. This was in agreement with the other results regarding the effect of PVOH.

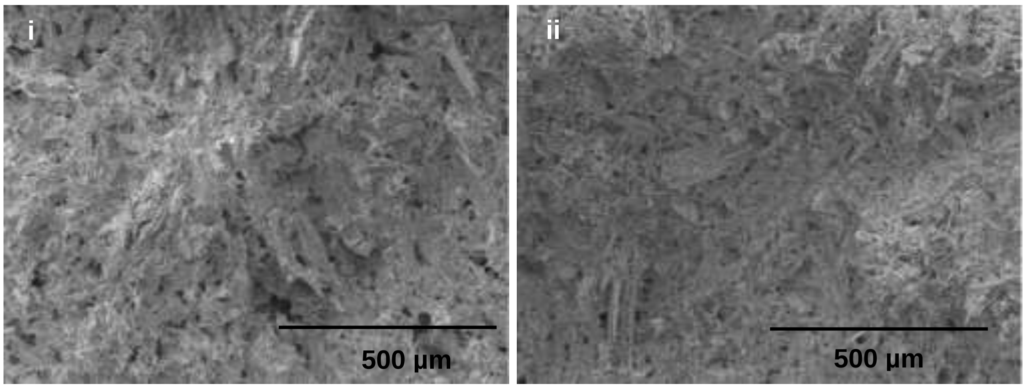

Fig. 5. The SEM images of the fractured surface of the incense with different PVOH contents in the soy-based adhesive: (i) 0% PVOH and (ii) 3% PVOH

CONCLUSIONS

1. The water absorption and burning speed of the incense samples decreased with decreasing proportions of soy-based adhesives, while the density and tensile strength increased with decreasing proportions of soy-based adhesives. The optimum soy-based adhesive dosage for the preparation of incense was 31.8%.
2. The weight of the incense samples increased with increased soaking time. The incense comprised of PVOH-modified soy-based adhesive had a denser structure, better distribution of miscellaneous wood powder (MWP), and a higher tensile strength. The addition of PVOH increased the water absorption and burning speed of the incense, and there was no remarkable correlation between the burning speed and the density of the incense. The soy-based adhesive with 3% PVOH content was best suited for the preparation of incense.
3. Paraffin wax improved the water resistance of the incense. The water absorption of incense samples with different paraffin wax doses increased with soaking time. When the paraffin wax usage was increased, the water absorption and density of the incense decreased. Paraffin wax usage had no apparent effect on the burning speed of the incense. Paraffin wax was suitable as a waterproofing agent for incense, but the optimum dosage was dependent upon the application conditions.

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