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Molding of wood powder with a natural binder

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Abstract

This paper describes the molding of wood powder using sucrose as a natural binder, as a means of fabricating products based on natural resources. The conditions, such as the temperature and binder content of the wood powder, were optimized in order to produce compacts successfully in the molding process. In experiments, the plasticization temperature of sucrose was initially investigated by thermogravimetric/differential thermal analysis for the prediction of the thermal flow temperature of the wood powder combined with sucrose. In addition, flow behavior of the mixture was evaluated for the temperature and the binder content by capillary flow tests. Based on these data, molding test of wood powder with sucrose was conducted to evaluate the injection moldabilty. As a result, the plasticization point of sucrose was found to be approximately 176 ºC, with a mass reduction onset at 200 ºC due to decomposition to volatile products. Wood powder mixed with sucrose flowed at temperatures above 180 ºC, although flow was restricted above 220 ºC due to the effect of gases evolved from the sucrose. The minimum sucrose content required for flow was 30 wt% within the temperature range of 180 to 200 ºC. The mixture was found to fill a mold under optimized conditions, forming compacts with good surface texture at a sucrose content of 30 wt% and 200 ºC. This method allows the fabrication of products from naturally occurring materials with minimal environmental impact.

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Keywords: wood powder; sucrose; fluidity; injection molding

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1. Introduction

Biomass materials such as wood represent environmentally-friendly alternatives to fossil resources. As an example, wood is typically non-toxic, and the combustion of wood is carbon neutral because the wood absorbs and stores carbon dioxide in the atmosphere during growing up. Furthermore, wood can be produced in a sustainable manner by the appropriate planting and trimming of trees. Therefore, the use of wood resources as industrial materials is an important aspect of ensuring a sustainable society. Incorporating wood into industrial applications requires effective processing methods. Wood products are generally shaped by cutting processes, because the deformability of wood is inferior to that of metals and plastics. Therefore, much of the original material is turned into waste chips during the cutting process. In addition, it is difficult to use wood with inconvenient shapes, such as branches. Wood-based materials that can use chips, such as wood-plastic composites (WPC), are an effective use of these resources. The WPC consist of wood powder in conjunction with a thermoplastic binder [1]. The WPC having various shapes can be obtained by several techniques, including extrusion, press molding and injection molding, because the thermoplastic between the wood particles can become fluid upon heating. In particular, injection molding is a high productivity technique, because products are continuously obtained. Therefore, the WPC have been used to produce automotive components, architectural materials and household electronics [2].

Unfortunately, the WPC may generate environmental contaminants during their use or disposal as a result of the synthetic resins used as binders. In a previous study, a new technology was developed for fabricating products composed solely of wood powder by press molding, extrusion and injection molding as a means of addressing this issue [3]. In these processes, wood powder combined with water was found to exhibit fluidity under high temperatures and pressures, and subsequently bond into a compact when cooled. The thermal fluidity of a material is important for injection molding various shapes, because the material will not flow smoothly into a mold if it has low fluidity [4]. Because thermal fluidity of wood powder was lower compared to that of the WPC, molding defects were easy to appear.

On the other hand, the thermal flow and self-adhesion of wood powder exhibited during this process is considered to result from the naturally occurring saccharides that wood originally has [5]. Fig. 1 shows a schematic drawing of the thermal flow of the wood powder. In the case of only wood powder, saccharides and decomposed matters of saccharides function as a binder. The binder plasticizes upon heating, and the material, which is composed of the particles and the binder, flows due to the deformation of the binder and the slip of the particles. The binder solidifies between the particles upon cooling, and then the material is bonded. It is therefore possible that the fluidity and adhesiveness of wood powder can be improved by adding saccharides such as sucrose, which works as the binder. In view of the molding, the temperature is an important factor because the plasticity of the sucrose changes drastically with temperature.

On the above basis, the present work investigated the molding of wood powder using sucrose as a natural binder. The objective of our study was to clarify the effects of added sucrose on the moldability of wood powder, as well as to optimize the molding conditions, such as the temperature and binder content of the wood powder. In present work, thermal analyses of sucrose were conducted in order to estimate the thermal flow temperature of the mixture of the wood powder and the sucrose. Based on the results of these thermal assessments, flow tests were performed using a capillary die in order to investigate the effect of temperature and the binder content on the fluidity of the mixture prior to molding trials. Finally, a molding test was conducted to evaluate the injection moldability under the condition that the mixture flowed in the flow test, and the moldability of the mixture was evaluated by observing the compacts.

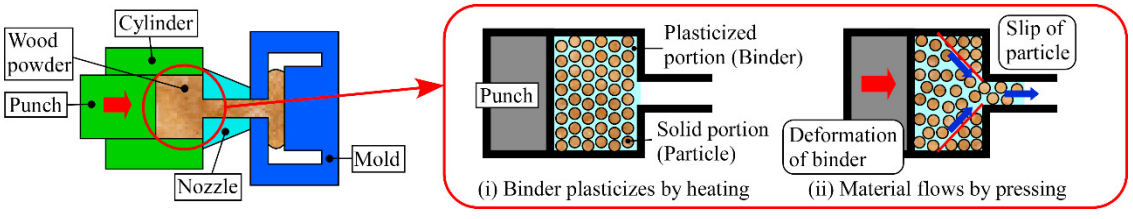

Fig. 1 Schematic drawing of thermal flow of wood powder.

2. Materials and Methods

2.1. Wood powder and natural binder

Wood powder was obtained by milling the chips of Japanese cedar, and the powder that passed through a 500 μm screen was used in this paper. Prior to use, the wood powder was dehydrated in a drying oven at 80 °C for 12 h. Sucrose was used as a natural binder and the wood powder was combined with sucrose in distilled water, followed by evaporation of the mixture in a drying oven at 80 °C for 36 h. The dried mixtures were employed for subsequent flow trials and molding test.

2.2. Thermal analysis

The fluidity of a wood powder/binder combination is greatly affected by physical and chemical changes in the binder, such as plasticization and decomposition. Therefore, thermal analysis of the sucrose was conducted using a thermogravimetric/differential thermal analyzer (TG/DTA, TG8120, Rigaku), employing alumina powder as the reference material. During these measurements, sucrose and alumina were placed in separate aluminum pans and nitrogen gas was purged at 300 ml/min. Endothermic and exothermic reactions and mass changes were assessed as the temperature was increased from ambient to 300 °C at a constant rate of 5 °C/min.

2.3. Flow tests

Fig. 2 shows a schematic drawing of the flow test apparatus. A die containing a capillary was set at the bottom of the container. The container and the under plate were heated using band heaters, and the temperature of the device was maintained at a constant value using thermocouples and temperature controllers. A 30 g quantity of the dried mixture was placed into the container, which was heated to the desired test temperature, T. The mixture was pre-heated in the container for 5 min in order to soften the mixture, after which the punch was moved downward at a constant velocity of 0.1 mm/sec using a servomotor. The mixture was compressed by the punch and the mixture flowed into and out the bottom of the capillary. The punch press was stopped if the punch surface pressure, P, reached 200 MPa. The applied force was recorded during the punch pressing, and the punch position was defined by the distance between the punch and the capillary die. In these trials, the effects of T and binder content, BC, on the flow behavior of the mixture were investigated.

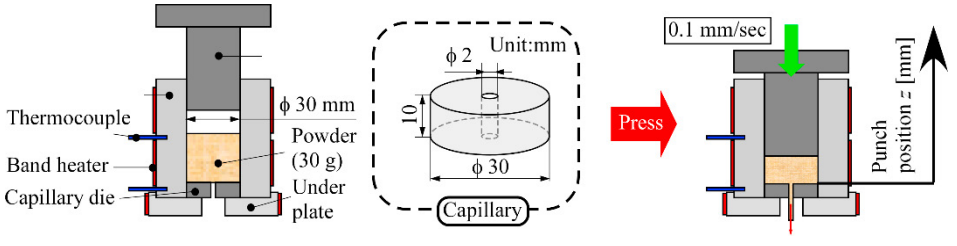

Fig. 2. Schematic drawing of the capillary flow test apparatus.

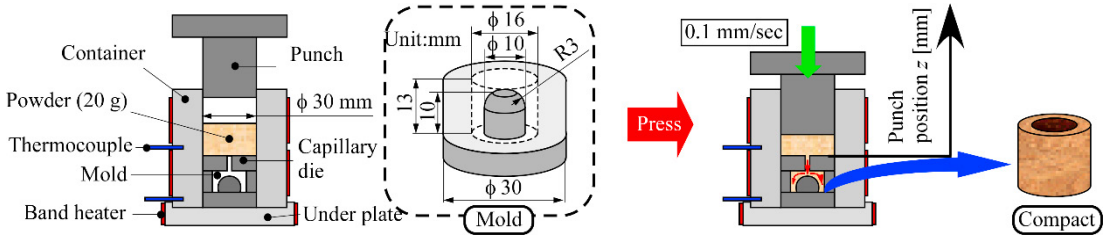

Fig. 3. Schematic drawing of the molding apparatus.

2.4. Molding test

Fig. 3 shows a schematic drawing of the molding unit. The punch, container and capillary die in this apparatus were the same as those in the flow tests, but a mold was placed under the capillary die. The experimental procedure was also the same as in the flow tests. A 20g quantity of the mixture was placed into the container and then flowed out from the capillary into the mold during the punch pressing. Successful filling of the mold produced cup-shaped compacts with outer and inner diameters of 16 and 10 mm and a length of 13 mm. The moldability was evaluated as an appearance and surface of the compact. The binder content, *BC*, ranged from 30 to 50%, and the temperature, *T*, values of 180 to 200 °C were applied, based on the results of the flow tests.

3. Results and Discussion

3.1. Thermal analysis of sucrose

Fig. 4 shows the TG/DTA data obtained for sucrose. Endothermic peaks are seen at 176, 215 and 270−280 °C, while a mass loss occurs beginning at 200 °C, due to the decomposition of the sucrose. The first endothermic peak, not associated with a mass loss, is attributed to plasticization [6]. The second and third endothermic peaks in conjunction with mass reduction are ascribed to thermal decomposition of the sucrose. Plasticization of the sucrose is important in order to allow the wood powder to flow, while volatilization of the sucrose during the molding process can cause voids in the compacts, which degrades the mechanical properties. Therefore, it was determined that the appropriate molding temperature range was from 176 to 200 °C.

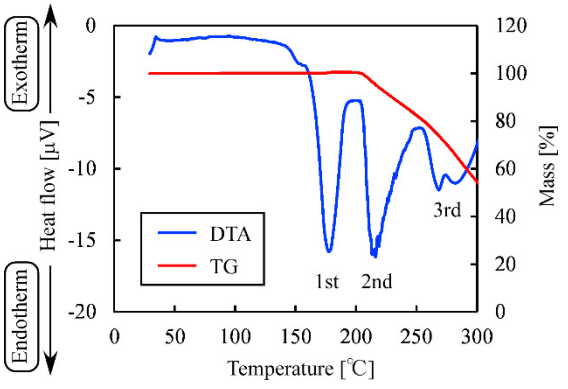

Fig. 4. Thermogravimetric (TG)/differential thermal analysis (DTA) data for sucrose.

3.2. Punch surface pressure variations during flow tests

Based on the results of the thermal analysis, the temperature, *T*, values over 160 °C were used during the flow tests. Fig. 5 plots variations in the punch surface pressure, *P*, throughout the flow tests of wood powder with sucrose. Fig. 5(a) shows the effects of *T* at the binder content, *BC*, value of 50 wt%. Here it is evident that the mixture did not flow out from the capillary at 160 °C, but was instead merely compressed between the punch and the capillary die. As a result, *P* increased with compression of the mixture, up to the test maximum of 200 MPa. The mixture did flow at 180 and 200 °C. In these cases, *P* initially increased along with the compression of the mixture prior to flow, and then decreased as flow began, remaining approximately constant during the mixture flow. As the punch approached

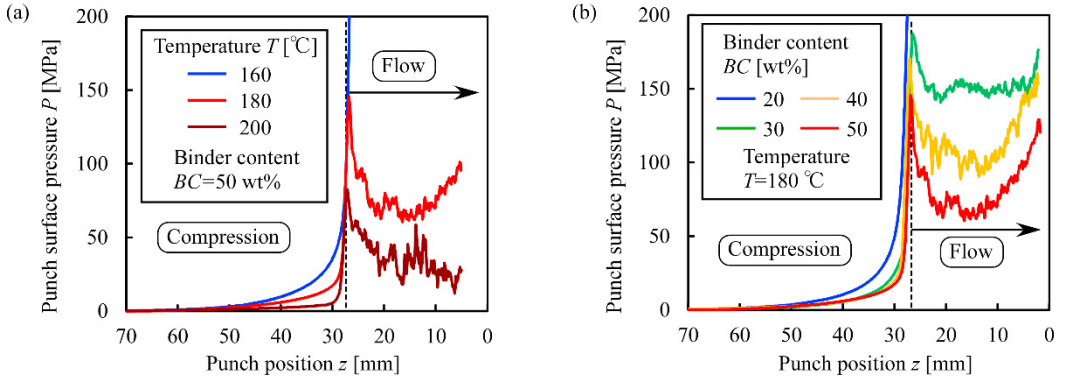

Fig. 5. Punch surface pressure variations during pressing, showing the effects of (a) temperature, *T*, and (b) binder content, *BC*.

Table 1. Mixture flow pressures, P_f, at various binder contents, *BC*, and temperatures, *T*.

		Binder content *BC* [%]			
		20	30	40	50
Temperature *T* [°C]	160	×	×	×	×
	180	×	187 MPa	170 MPa	145 MPa
	200	×	128 MPa	114 MPa	82 MPa

×: The mixture did not flow.

the capillary die, *P* increased again because the punch met the dead zone, in which the mixture does not flow, against the capillary die. The mixture flowed when it was above the plasticization temperature of the sucrose, which was 176 °C (Fig. 4), so it appears that the mixture flow is dependent on the fluidity of the sucrose. Interestingly, *P* at *T*=200 °C was lower than at *T*=180 °C. This result indicates that a greater degree of fluidity was obtained at 200 °C. Trials at 220 °C generated too much gas within the molding apparatus to conduct the flow test, as the result of the volatilization of the sucrose. Therefore, it was concluded that the most appropriate temperature range for the mixture flow was between 180 and 200 °C.

Fig. 5(b) summarizes the effects of *BC* at a *T* value of 180 °C. The mixture was found to flow at *BC* values above 30 wt%, and *P* decreased with increases in *BC*. The fluidity of the mixture increased at higher *BC* values because the plasticized portion, which was sucrose, represented a greater fraction of the solid portion, which was wood powder in this work. The pressure values required for mixture flow, P_f, are shown in Table 1. P_f is the peak *P* value obtained during mixture flow, as shown in Fig. 5. P_f was evidently lower at 200 °C and decreased with increases in *BC*.

3.3. Moldability of wood powder with sucrose

Molding tests were conducted under the conditions that were found to allow mixture flow during the preceding flow tests. Table 2 shows the effects of the temperature, *T*, and the binder content, *BC*, on the moldability during Molding of the wood powder with the sucrose. It can be seen that the mold was filled successfully upon increasing both *T* and *BC*. Fig. 6 presents images of the compacts obtained at a *BC* of 40 wt%. The mold was not filled completely along the side walls at 180 °C (Fig. 6(a)), so the sides of the compact appear different from the bottom. The mold was almost completely filled at 190 °C (Fig. 6(b)), although the color of the compact is uneven because of partially unfilled regions on the surface. The compact having an even appearance was obtained at

Table 2. The effects of temperature, *T*, and binder content, *BC*, on the transfer moldability of wood powder with sucrose.

		Binder content *BC* [%]		
		30	40	50
Temperature *T* [°C]	180	×	△	○
	190	△	○	○
	200	○	○	○

× Not filled mold
△ Partly filled mold
○ Completely filled mold

Fig. 6. Appearance of compacts obtained at a binder content, *BC*, of 40 wt% and a temperature, *T*, of (a) 180, (b) 190, and (c) 200 °C.

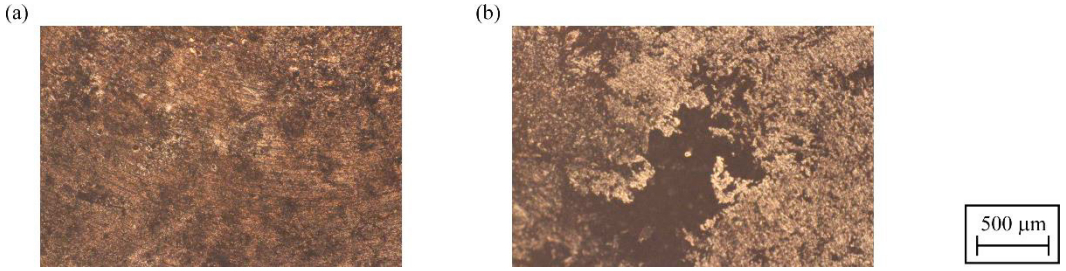

Fig. 7. Images of compacts obtained at 200 °C and a binder content, *BC*, of (a) 30, and (b) 50 wt%.

T=200 °C, as shown in Fig. 6(c).

Fig. 7 presents microscopy images of the bottom surfaces of compacts made at 200 °C using two different *BC* values. Large voids are evident on the surface made using a *BC* of 50 wt% (Fig. 7(b)). These voids are attributed to the volatilization of the sucrose during molding, so it was possible to suppress the voids by decreasing *BC* as shown in Fig. 7(a).

4. Conclusions

This work demonstrated the molding of wood powder using sucrose as a natural binder, and appropriate molding conditions which was temperature and binder content were clarified. Firstly, the thermal property of sucrose was investigated in order to estimate the thermal flow temperature of the wood powder with sucrose. From the results of the thermal analysis, it was estimated that the appropriate molding temperature range was from 176 to 200 °C, because the sucrose plasticized while the volatilization of the sucrose was not active in this temperature range. The thermal fluidity of wood powder with sucrose was investigated by capillary flow test. Mixtures in which the binder content was 30 to 50 wt% flowed at 180 to 200 °C, and the fluidity increased with increases in the temperature and the binder content. Based on the results of these flow tests, molding test was conducted to evaluate the injection moldability. The mixture successfully filled the mold at 200 °C at all binder levels assessed, and compacts were obtained. The best compact which the surface was smooth were obtained at a sucrose content of 30 wt% and a temperature of 200 °C, because large voids resulting from the volatilization of the sucrose were apparent on the surfaces of the compacts with a high binder content. This method appears to represent a potential means of producing environmentally friendly materials using naturally derived substances.

Acknowledgements

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