COMPRESSION MOLDING OF SANDWICH BOARD BY REGULATING TEMPERATURE DISTRIBUTION IN HEATING PROCESS

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Abstract

The heat insulating board is widely used for our daily lives and industrial fields, and it is generally expected the excellent mechanical properties such as bending strength and low density which is brought high insulating property. The canapé or sandwich structure is one of the solution methods for these expectations. For example, almost all of the existent sandwich boards have an interface between strong surface layer and core layer with low density. And this interface sometimes becomes a weak point of the board.

In this study, as a pre-molding material, a non-woven fabric which was mixed both wool as a matrix and PLA fiber as a binder material was used, and we conducted a compression molding of canapé and sandwich boards without interface between surface and core layers by regulating the continuous temperature distribution during the molding process.

1 Introduction

In the usual compression molding with heating, an uneven temperature distribution is avoided because of calling for a uniform product. But, in this study, an uneven temperature distribution was given to the upper and lower specimen. This heating method is named temperature graded heating here. The non-woven fabric which was uniformly mixed matrix fiber and binder fiber was used as a pre-molding material, and the canapé (two layers) and sandwich (three layers) boards which had both the fibrous layer and the hardened layer were molded by temperature graded heating. The fibrous layer leaves the non-woven fabric without the melting of the binder fiber, and the hardened layer is consisted of the structure in which the matrix fiber is bound by the binder fiber. The fibrous layer has many voids, and the hardened layer has few voids, therefore, high insulating and high strength board is expected.

Then, the composite structure which was composed of some layers is usually made by the process in which each layer is made individually and pasted each other[1)]. But, in the molding method by using the temperature graded heating proposed in this paper, the composite structure is molded by regulating the temperature distribution without the pasting process. This method can avoid the existence of clear interface, because a continuous temperature distribution forms a composite structure. Therefore, the interfacial peeling is expected to escape.

In this study, the composite board without the interface was molded by using temperature graded heating, and the mechanical and thermal properties were discussed.

2 Materials

2.1 Matrix and Binder Fiber

Wool and PLA fibers were applied to matrix and binder materials of insulating board, respectively. Wool is a natural fiber which has high heat insulating property[2)] and also no flammability[3)]. PLA is a typical thermoplastics fiber made from plants. The properties of Wool/PLA fiber are 64mm/65mm in fiber length, 24.5μm/23μm in fiber diameter and both 1.3g/cm^3 in density. The melting point and melting flow rate of PLA are 165℃ and 22.5g/10min. at 175℃, respectively.

2.2 Pre-molding Material

The non-woven pre-sheet was made by mixing the wool fiber with PLA fiber by using the carding machine, and then the pre-sheets were laid together and the non-woven fabric with about 40mm thick and 4.1kg/m^2 density was molded by using a needle punching machine. This non-woven fabric was used as a pre-molding material in this study. Two cases of weight fraction of PLA in the cloth such as 70% and 50% were prepared.

3 Molding Method

3.1 Molding Machine

In this molding, a hot press machine (TESTER SANGYO SA-303) was used. This machine has 2.1kw in heater capacities for upper and lower plates, respectively, and a couple of compression plates are heated individually. The raising temperature rate can be changed by regulating PID values. The size of compression plates is 250mm×250mm. Here, in order to grasp the changes of temperature in the specimen during the molding, 10 thermocouples were installed inside the fabrics at five sections from the upper side to the lower side. The room temperature is kept 25℃ during the molding process.

3.2 Canapé Structure

Canapé structure named in this paper means the two layers structure which had both the fibrous upper layer and the hardened lower layer. This composite structure doesn't form a clear interface. In order to get the structure like this, the pre-molding material was given a graded temperature in which the upper side was lower temperature and the lower side was higher temperature. Here, the weight fractions of wool in the pre-molding material were fixed at 30% and 70%. The thicknesses of all composites were adjusted 10mm by using the 10mm-thick spacer. Then, the average theoretical density and void ratio of all composites were 0.41 g/cm^3 and 68% respectively.

Next, the concrete heating method during the molding process is explained. Firstly, the temperature of the specimen in the condition of the room temperature was pre-heated until 60 ℃ . Secondary, the temperature graded heating was started. The setting temperatures in the upper/lower side of the hot press machine were 140/175, 155/175 and, 175/175℃ as shown in Table 1, and P, I, and D values were 10, 750, and 190 respectively. Finally, when the temperatures at the upper and lower surface of specimens were arrived at the setting temperatures respectively, the upper and lower heaters of the hot press machine were turned off, and specimens were cooled down by air fans immediately until 60℃ by keeping the pressure. Here, the heating time from 60℃ to each setting temperature took about 40 minutes, and the cooling time was about 120 minutes. The symbols shown in Table 1 are applied to distinguish the various composites from now.

Table 1 Definition of specimens

Temperature \ Material	Wool 30% /PLA 70%	Wool 50% /PLA 50%
Upper140℃ /Lower175℃	A30	A50
Upper155℃ /Lower175℃	B30	B50
Upper175℃ /Lower175℃	C30	C50

3.3 Sandwich Structure

Sandwich structure in this paper means the three layers structure in which the fibrous core layer sandwiched between two hardened layers without the clear interfaces. To get the structure like this, the specimen was given a graded temperature in which the surface layers were higher temperature and the core layer was lower temperature. Here, the weight fractions of wool in the specimens were 30% and 50%, and the thicknesses of all composites were fixed at 10mm.

Next, the detail of the molding process is mentioned. Fig.2 shows the flow of the molding process. Firstly, the pre-molding material was put between two steel plates, and pressed until 10mm thickness by using a hot press machine, and bolted two plates were bolted together. The purpose of these operations is to realize the rapid cooling in the cooling process. This rapid cooling was realized by the idea to cool down the specimen out of the hot press machine This method enabled a temperature graded heating which the surface layers were higher temperature and the core layer was lower temperature because the thermal conduction from surface layer to core layer was escaped. After setting the specimen into the hot press machine, the specimen was pre-heated until 60℃, and then the temperature was raised up until the setting temperature in the core part of the specimen. Here, all PID values were 0, and the setting temperatures were 140, 150, and 160℃ respectively. Thereafter, the specimens were cooled down out of the hot press machine until 60℃ as mentioned above. Here, the heating time from 60℃ to each setting temperature was about 15 minutes, and the cooling time was about 13 minutes. The symbols shown in Table 2 are applied to distinguish the various composites from now.

Table2 Definition of specimens

Material / Max. Core Temp.	Wool 30% /PLA 70%	Wool 50% /PLA 50%
140℃	SA30	SA50
150℃	SB30	SB50
160℃	SC30	SC50

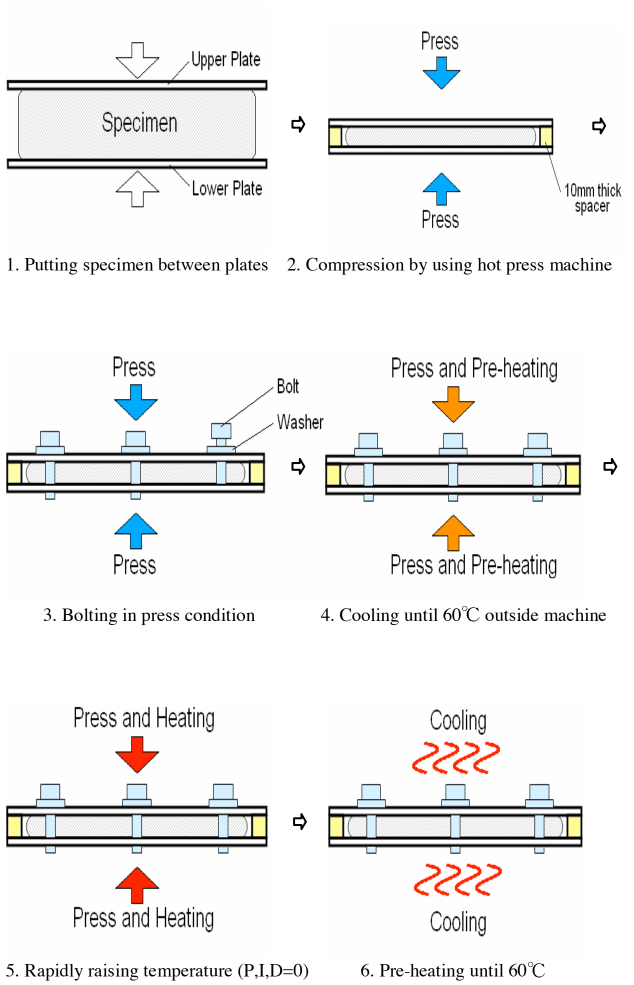


Fig.2 Molding process for sandwich board

4 Evaluating Method for Composites

4.1 Thermal Conductivity Test

In order to evaluate the insulating property of the composites, thermal conductivity was measured by using a measuring system (Eiko Seiki HC-074). The thermal conductivity was measured by using the heat flux sensors under the condition in which a specimen was given different temperatures in the upper side (20℃) and the lower side (40℃). The size of the specimen is 200×200×10mm.

4.2 Bending Test

As an evaluation of the mechanical property of the composites, bending strength and bending modulus were measured by three-point bending test. The dimensions of the test piece are 200mm in length, 15mm in breadth, and 10mm in thickness. The cross head speed is 5mm/min, and room temperature is 25℃.

4.3 SEM Observation of Cross-section

In order to grasp the internal conditions of the composites, the cross-sections of the composites were observed by SEM (Scanning Electron Microscope). The cross-sections were cut out by using a razor blade. Samples were coated with gold material and were observed in the condition of 15 kV accelerating voltage.

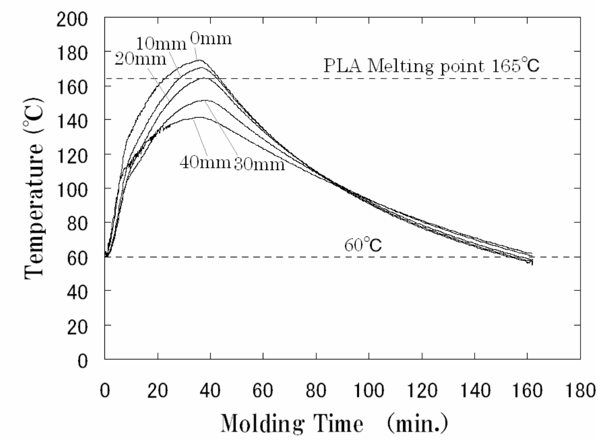
5 Results and Discussion

5.1 Canapé Board

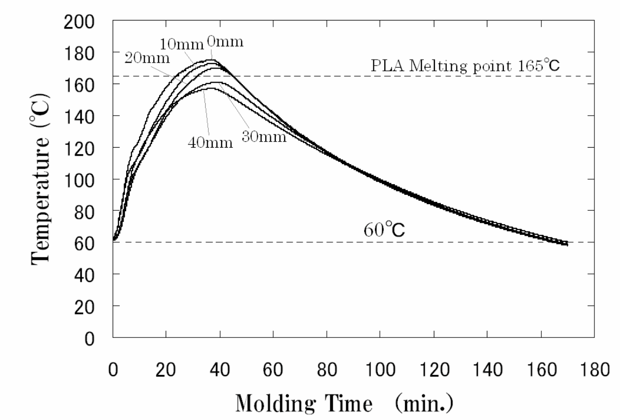
5.1.1 Temperature History of Specimens during Molding Process

The relationships between temperature and time during the molding process of A30, B30, and C30 are shown in Fig.3. Although there are no illustrations, the results of A50, B50 and C50 are similar to those of A30, B30, and C30, respectively. It is noted here that, when both upper and lower surfaces of samples arrived at the set temperatures, the temperatures in A30 and B30 fall down monotonously from the position of upper to lower surfaces, on the other hand, the temperature in C30 is almost same in the every positions.

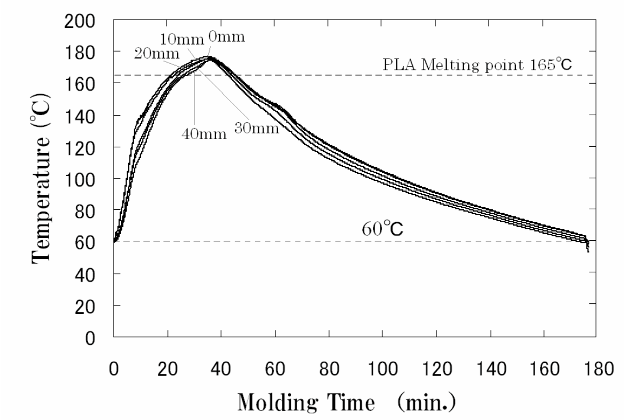
After the molding process, the positions of thermocouples in composites were measured by cutting the composites. The photograph of the cross-section of B30 is shown in Fig.4. In this figure, the circle marks indicate the position of thermocouples. The distance of neighboring thermocouples near heating plate of 175°C is small. Here, the maximum temperature distributions in A30, B30 and C30 were plotted in Fig.5 by referring to the positions of thermocouples after the molding process. It is cleared here that the temperature distribution is almost liner in the cross-section. The temperature distributions were stepped over the PLA melting point in A30 and B30, meanwhile, the temperatures at all positions of C30 exceeded PLA melting point.



(a) A30



B30



(b) C30

Fig.3 Temperature-time relation during molding process

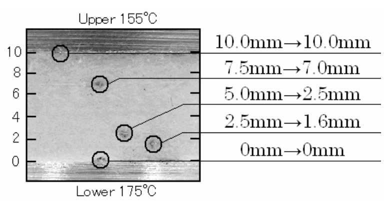


Fig.4 Position of thermocouples in B30

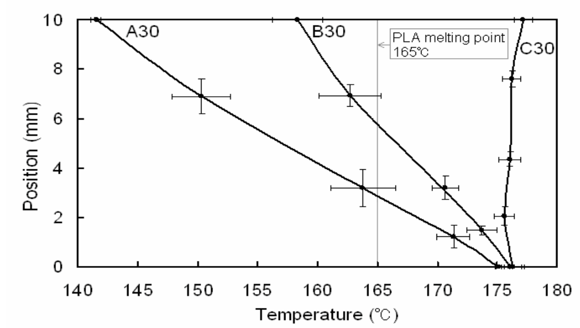
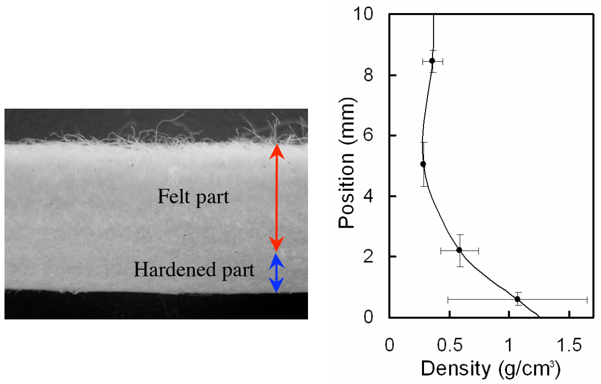


Fig.5 Temperature distribution of canapé board

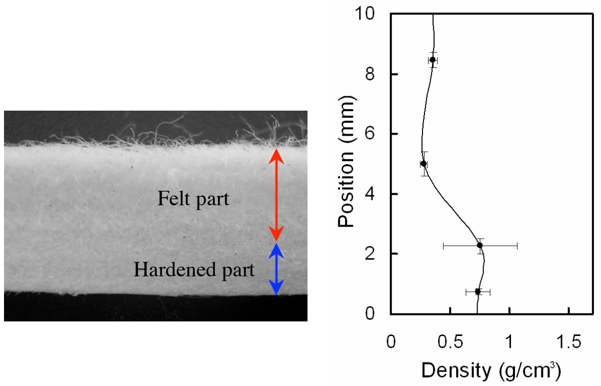
5.1.2 Observations of Cross-sections

Aspects of the cross-sections of composites for A30, B30 and C30, and their density distributions in the thickness direction are shown in Fig.6. The density distribution was evaluated on the basis of average density (0.41g/cm^3) of composite and the estimated distance between neighboring thermocouples before and after the molding process. In Fig.6, A30 and B30 have kept the state of non-woven fabric in the upper side, and PLA fiber was melted and hardened in the lower side. Namely the unsymmetrical cross-section for upper and lower side was observed. On the other hand, the structure in which PLA fiber was melted and hardened at all places can be seen in C30. Here, the densities in the lower sides of A30 and B30 are high, and those of A30 and B30 are about 3 and 2 times higher than those in the upper sides of A30 and B30, respectively. The density of C30 is constant for all positions.

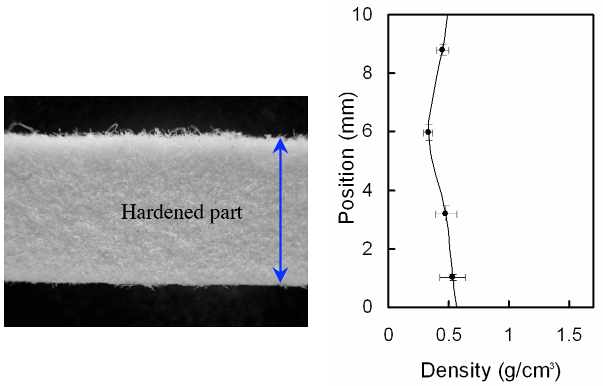
Fig.7 shows the cross-section observed by SEM at positions of near 0, 3.2, and 5mm from lower surface in B30. Here, in B30, the set temperatures were 155°C on upper surface and 175°C on lower surface, respectively, and PLA melting point was 165°C. Therefore, the melted and hardened fibrous PLA can be seen at the position of near 0mm, and only fibrous PLA exists at the position of near 5mm. Namely, the composites which were molded by regulating temperature distribution in heating process had both the areas with melted PLA and non-melted PLA in the internal cross-section. The interface position between these areas was searched by SEM observations. As a result, it was found at around 3.2mm from the lower surface. Fig.7-(b) shows SEM photograph at 3.2mm. It was shown that the boundary can not be seen clearly, but many fibrous PLA existed in the upper side of this figure, and melted PLA can be seen clearly in the lower side of this figure. The transitional region from melted to no melted area is estimated about 500μm thickness.



(a) A30



(b) B30



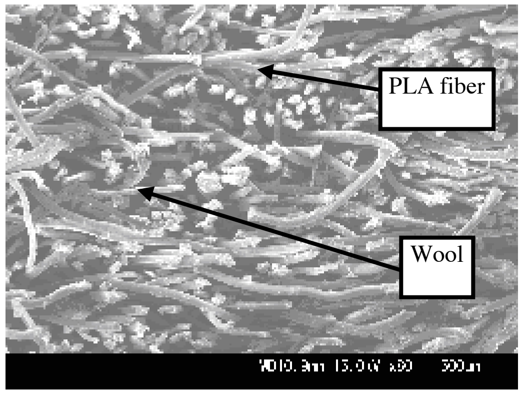
(c) C30

Fig.6 Aspect of cross-sections and Density distribution of composites

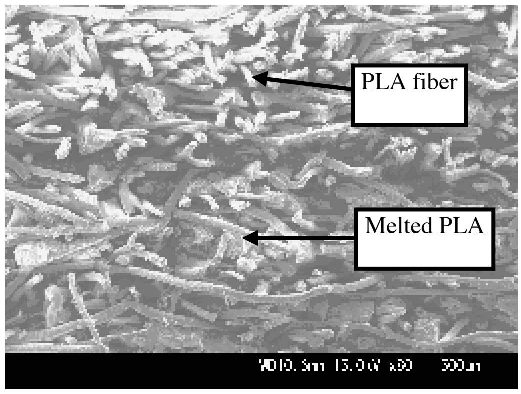
5.1.3 Thermal Conductivity

The unsymmetrical density distribution is characterized for the canapé structure, therefore two types of measuring methods were carried out. Namely, the higher density part was faced to the lower plate of the equipment in Type I , and faced to the upper plate in Type II .

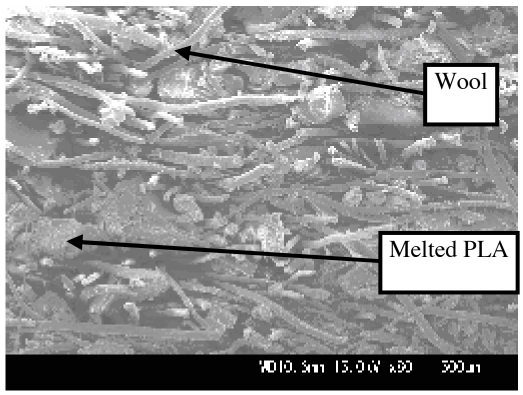
The measured thermal conductivity was shown in Fig.8. It was cleared that few difference of results existed between Type I and Type II . The lower thermal conductivity can be seen for the canapé boards (A30, B30, A50 and B50) in comparison with that for uniform density boards (C30 and C50). For example, the thermal conductivity of A30 is 15% lower than that of C30 though the average density of boards is constant for all specimens such as 0.41 g/cm^3. It seems that the non-melted fiber layer of canapé board contribute to reduce the thermal conductivity.



(a) B30 in 5.0mm



(b) B30 in 3.2mm



(c) B30 in 0.0mm

Fig.7 Observation of cross-section by SEM

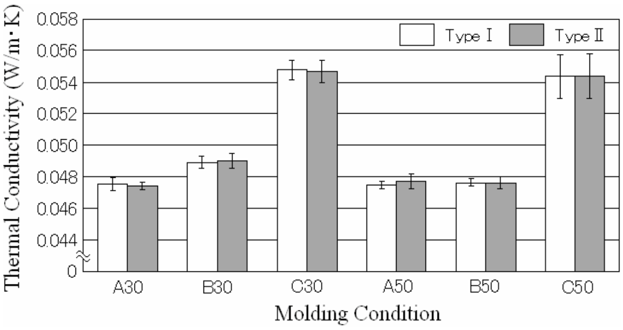


Fig.8 Thermal conductivity of composites

5.1.4 Bending Properties

The bending strength and modulus are shown in Figs.9 and 10, respectively. Here, the compression stress appeared at the higher density part for Type Ⅰ. On the other hand, the tensile stress appeared at higher density part for Type Ⅱ. It is clearly seen that the bending strength and modulus of Type Ⅰ is higher than those of Type Ⅱ. It is also noted here that the bending strength and modulus for canapé boards are fairly smaller than those of uniform density boards.

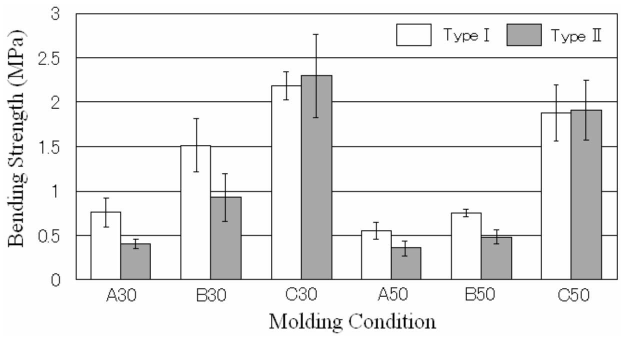


Fig.9 Bending strength of composites

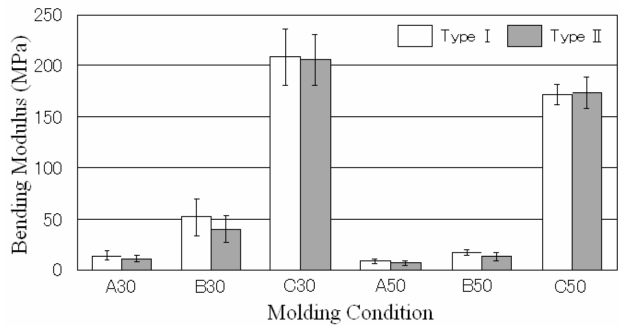
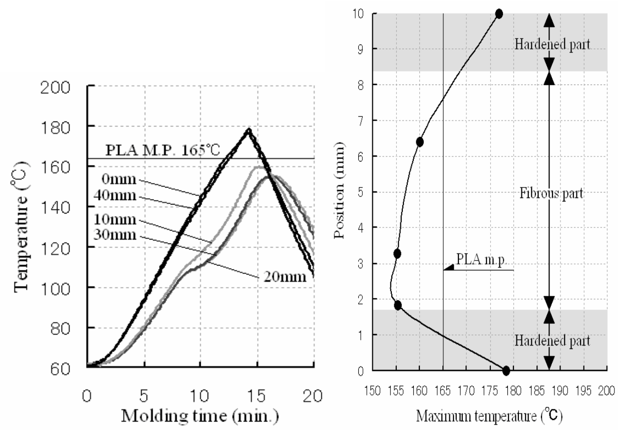


Fig.10 Bending modulus of composites

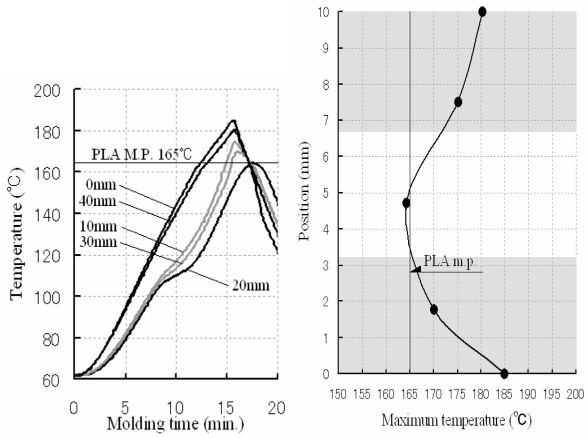
5.2 Sandwich Board

5.2.1 Temperature History of Specimens during Molding Process

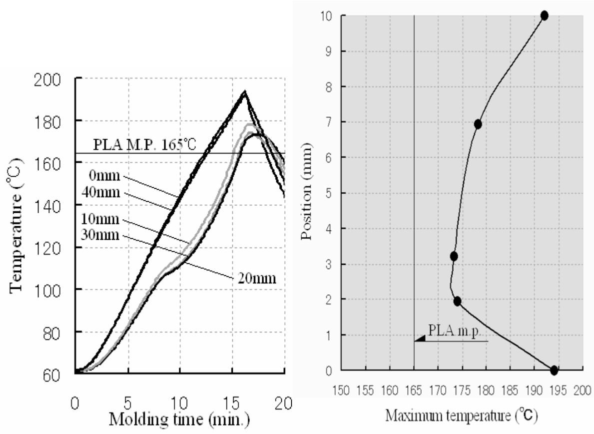
The temperature histories during the molding process and the maximum temperature distributions for SA30, SB30 and SC30 are shown in Figs.11 (a), (b) and (c), respectively. It is cleared that the temperature in the surface part is about 20℃ higher than that in the core part. Here, the temperature in the core part raised about 15℃ during the cooling process because of the retained heat, though the cooling was carried out rapidly. As a results, in the case of SA30, the temperature in the core part was lower than melting point of PLA. In the case of SB30. the temperature in the core part was nearly equal to the melting point of PLA. In the case of SC30, the temperatures at all measured points were higher than the melting point of PLA.



(a) SA30



(c) SB30



(c) SC30

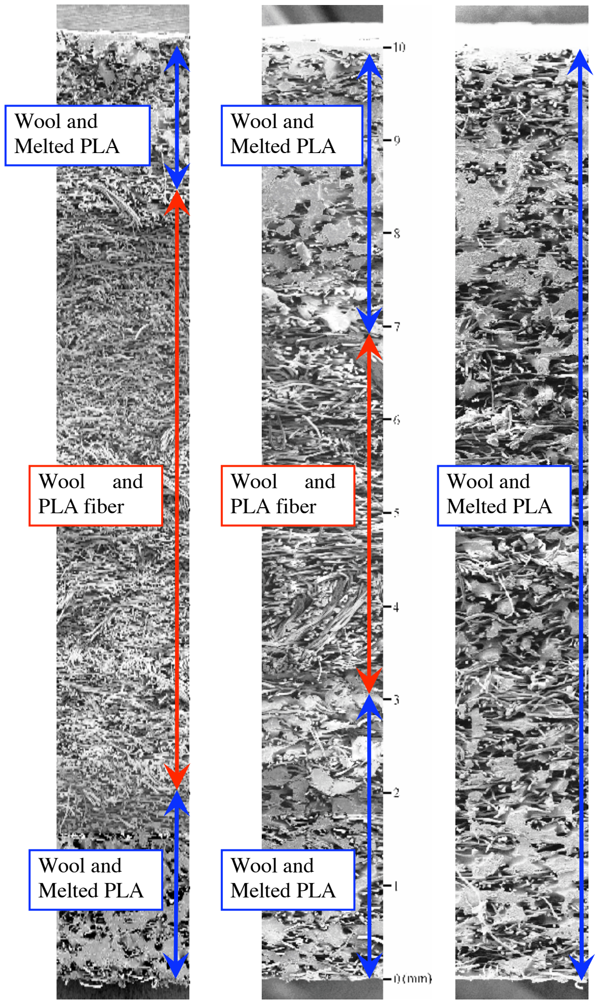
Fig.11 Temperature-time relations during the molding process, and Maximum temperature distributions in SA30, SB30 and SC30

5.2.2 Observations of Cross-sections

Figs.12 (a), (b) and (c) show the aspect of cross-section of SA30, SB30 and SC30, respectively. The melted and hardened PLA portion can be seen at the surface layer of SA30 and SB30, and the non-melted PLA fiber can be seen in core layer. The surface layer with melted PLA was thicker for SB30 in comparison with that for SA30. However, the clear interface between surface and core layers can not be seen here. Now, all composites in this paper have the same average density, therefore the density of surface layer becomes higher than that of core layer. The thickness of the hardened part made by melted PLA is estimated about 3, 7 and 10mm for SA30, SB30 and SC30, respectively, and was shown in Fig.11 by the gray color. All of the PLA fiber was melted uniformly in the case of SC30.

5.1.3 Thermal Conductivity

The measured results of the thermal conductivity of sandwich boards are shown in Fig.13. It should be noted here that the thermal conductivities of SB and SC series were nearly same values, but those of SA series were lower values than those of SB and SC series. This fact means that the contribution of fibrous core layer to reduce the thermal conductivity is larger than that of hardened surface layer to enlarge the thermal conductivity. It is concluded here that the sandwich structure is advantageous to reduce the thermal conductivity under the condition of fixed average density of composite.



(a) SA30 (b) SB30 (c) SC30

Fig.12 Cross-sections of sandwich boards

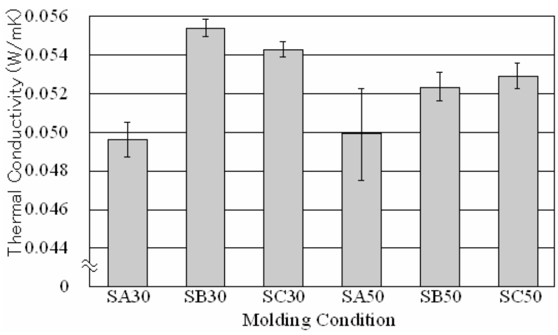


Fig. 13 Thermal conductivity of composites

5.1.4 Bending Properties

Bending strength and modulus of composites are shown in Fig.14 and Fig.15 respectively. It is noted here that the composites with thicker surface layers had the higher bending strength and modulus. And the bending strength and modulus are higher for the composites with higher content of PLA.

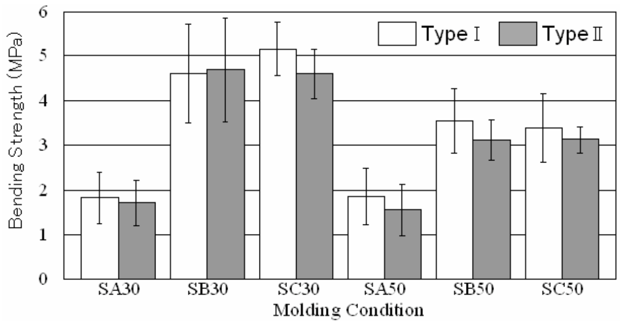


Fig.14 Bending strength of composites

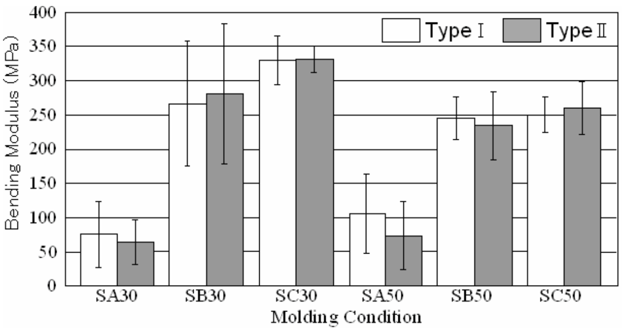


Fig.15 Bending modulus of composites

6 Conclusions

In this paper, the canapé and the sandwich boards were molded by regulating the temperature distribution in the heating process. As a pre-molding material, the wool/PLA non-woven fabric was used. An uneven temperature was given to the upper and lower surfaces and core of specimen to obtain the graded temperature distribution. This heating method was named “temperature graded heating” here.

The canapé board could be molded by setting the temperature at higher value for lower surface and at lower value for upper surface. On the other hand, the sandwich board could be obtained by cooling the specimen rapidly after heating process.

Even though the average density of composite is constant, the thermal conductivity takes a small value for canapé and sandwich structures in comparison with that of specimen with homogeneous density. The bending strength and modulus were disadvantageous for canapé and sandwich structures.

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