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Application of silk composite to decorative laminate

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Abstract—Recently, natural fiber reinforced composite is attracting attention and considered as an environmentally friendly material. Usually cellulosic fibers are used to reinforce the composites, but some protein fibers such as silk and wool serve the same purpose. In this paper, we proposed a method of producing artistic composite from artistic fabric by using silk fiber reinforced biodegradable plastic, which is designated as 'silk composite', for reinforcement. In order to expand applications of the silk composite, we performed the compression molding of decorative laminates with woody material, which was selected as a core material, and examined the properties of molded decorative laminates with various content of the silk composite. Since plywood and medium-density fiberboard (MDF) are widely used for decorative laminates, we selected them as core materials. As a result, flexible decorative laminates with high flexural strength were obtained by compounding the silk composite with wood materials.

Keywords: Decorative laminate; silk composite; flexural properties; impact resistance; composite compound ratio.

1. INTRODUCTION

Traditionally, glass fibers and carbon fibers have been used as reinforcement of composites. In recent years, instead of these traditional fibers, natural fibers are attracting more and more attention and they are considered as a type of environmentally friendly reinforcement. Most researches focused on the composites with cellulosic fibers such as kenaf, jute and ramie [1–3]. But a few researches used protein fibers such as silk and wool as reinforcement for the composite [4, 5]. Protein fibers are superior to cellulosic fibers in their properties of large breaking elongation and good heat resistance. In the previous papers [6, 7], researches on the composites using silk fibers and biodegradable plastics were introduced. In

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order to produce silk composite, silk fiber was directly used in the form of artistic fabric such as ‘NISHIJIN-ORI’ which is one of Kyoto’s traditional handicrafts, so that properties of silk fiber and artistic design of fabric could be effectively utilized for the composite [7]: namely, an artistic composite with high tensile and bending strength could be obtained. It is expected that more value-added composite materials can be created by compounding silk composites with other materials to expand the application of silk composite in large fields.

Under these circumstances, in this paper, a decorative laminate was proposed as one of the applications of the silk composite. The decorative laminate used artistic silk composite which was laminated on the surfaces of the woody board. The compression molding method with heating was utilized to mold the decorative laminate and the mechanical properties were investigated. Decorative board is an example of the board which demands artistry at the surface. An artistic pattern is generally printed on the surface of the decorative board. Here, the creation of the decorative board with high strength is expected by using the silk composite as a surface material.

2. MATERIALS AND MOLDING METHOD

2.1. Silk fabric

There are a lot of different woven structures in various fabrics. In this study, a plain weave fabric was used as a reinforcement of the silk composite. The fabric consisted of degummed silk yarns. This fabric is often used for ‘OBI’. Figure 1 illustrates the aspect of silk fabric used here. Construction parameters of the fabric are listed in Table 1.

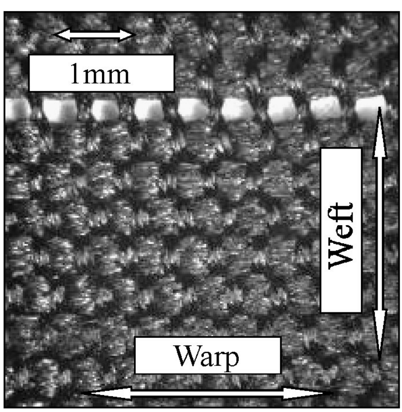

Figure 1. Aspect of silk fabric.

Table 1.
Construction parameter of silk fabric

	Density (yarns/cm)	Fineness (tex)	Weight (g/m^2)
Warp direction	32	7.35	108.3
Weft direction	18	42.2	

Figure 2. PBS (polybutylene succinate) film.

2.2. Biodegradable plastic

A biodegradable plastic was used as the matrix material of the silk composite. It is anticipated to expand its applications as a part of activities to reduce the environmental load. In this research, polybutylene succinate (PBS) with relatively low melting temperature was selected to lighten the heat deterioration of silk fiber during the molding process and to prevent the disfiguration of the surface of he decorative laminate. Film type PBS was prepared for the compression molding of decorative laminate. The thickness of the film is 30 μm and the melting point is 115°C. Figure 2 illustrates an aspect of the PBS film used here.

2.3. Core materials

Plywood and medium-density fiberboard (MDF) are usually used for wall materials and furniture in our daily lives. They were used as core materials of decorative laminate in this research. Some samples of core materials are illustrated in Fig. 3. Plywood is made up of three or more thin wood layers which are bonded together, and the grain of alternate layers is oriented at right angles, respectively. Lauan plywood graded class 1 referring to Japanese Agriculture Standards (JAS) [8] was selected in this work. The specific gravity of plywood is 0.51. On the other hand, MDF, i.e. engineering wood, is made from compressed and bonded wood fibers. The strength and dimensional change are homogeneous in every horizontal

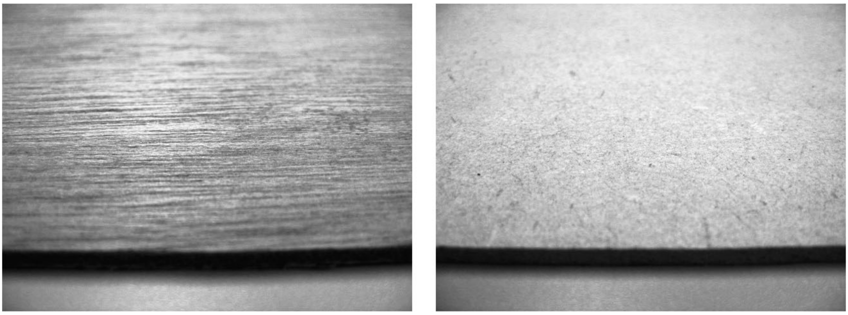

Figure 3. Core material (left: plywood, right: MDF).

Table 2.
Surface roughness of core material

	Plywood	MDF
Rz (μm)	81.4[1] 35.3[2]	31.3

[1]Orthogonal to grain direction.
[2]Parallel to grain direction.

direction, and the surface is fairly smooth, as shown later. The specific gravity of MDF is 0.78. This value is larger than that of plywood.

In the molding process of decorative laminate, the silk composites and the core materials were adhered respectively to the melted PBS film. The surface roughness of plywood and MDF should be checked as one of factors affecting mechanical adhesiveness between woody board and PBS resin. Table 2 illustrated the results of roughness measurements of woody materials. The value was independent of horizontal directions in MDF. The thickness of each core material was set to 4 mm during the experiments.

2.4. Fabrication of silk composite and decorative laminate

The compression molding method with heating was applied to the molding of boards. The laminating number of silk fabric and PBS film varied according to the pre-determined volume fraction of silk fabric. All materials used here were dried in a drying oven before molding. The silk fabrics and PBS films were laminated alternately, and the top and bottom layers of the laminates consisted of films. The laminates were put on both surfaces of the core material, as shown in Fig. 4.

In order to fully impregnate the melted PBS resin into the silk fabrics, the molding materials were covered tightly by Teflon sheet so that air trapped inside it could be removed by using the vacuum pump as illustrated in Fig. 5. Here, the porous non-woven fabric was set above the outlet of air to remove the air easily.

The heating temperature was set to 140°C for all composites and decorative laminates. The heating time was regulated depending on the amount of silk fabrics.

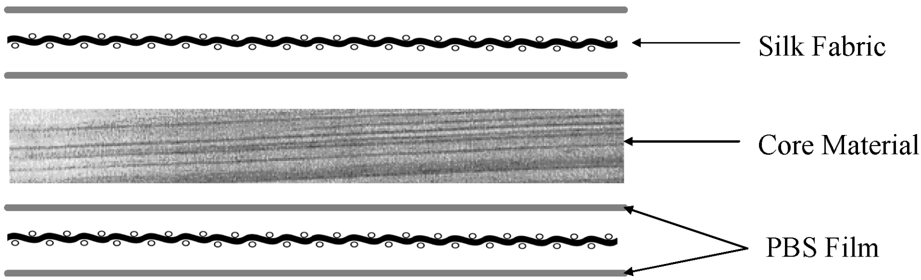

Figure 4. Preparation of molding compound.

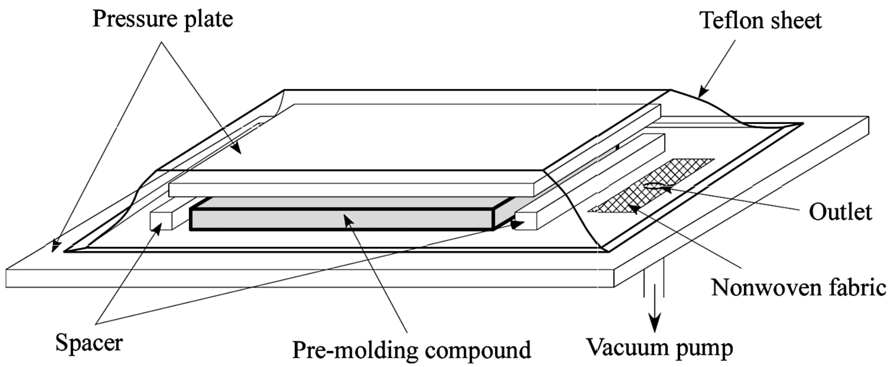

Figure 5. Compression molding of decorative laminate.

The time was set to 30 min for the silk composites and 5 min for the decorative laminates, respectively.

The volume fraction of silk fiber in the composites was 33% throughout the experiments. The thickness of decorative laminate depended on the compounding ratio of silk composites and core materials. The compounding ratio V_f was defined as a volume fraction of silk composite within the decorative laminate. Figure 6 illustrates an example of molded decorative laminate. We can see fabrics clearly through the surface resin layer.

If two or more layers of silk fabrics are used to fabricate the decorative board, there is the possibility of showing the second fabric layer through the first fabric layer. Therefore, it is desirable to use a plain fabric without a pattern for the second fabric layer. Moreover, it is very important to mend the distortion of the pattern of fabrics before compounding, and the compression molding should be carried out carefully. Otherwise, the straight pattern is sometimes curved after compounding, as shown in Fig. 6.

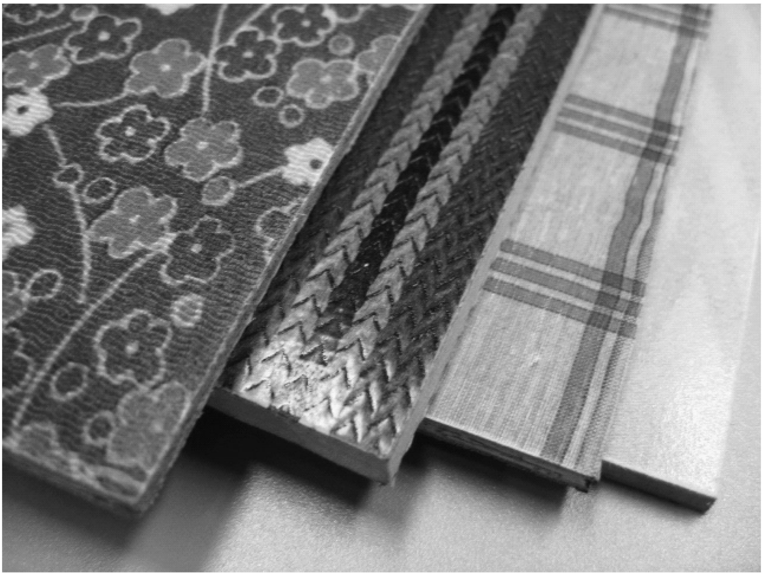

Figure 6. Artistic decorative laminate.

3. EXPERIMENTAL PROCEDURE

3.1. Flexural test

A three-point flexural test was conducted to investigate the mechanical properties of the silk composites, the decorative laminates and the core materials. The flexural strength and modulus were measured.

The flexural test for the silk composites was carried out according to JIS K7071 standard by using electric tensile Instron model 4206. The crosshead speed was 2 mm/min. The dimensions of the test piece were 80 × 15 × 4 mm. The span length for the flexural test was 64 mm. Meanwhile, the flexural tests for the core materials and the decorative laminates were carried out according to JIS A5905 standard. The crosshead speed was 10 mm/min. The dimensions (length × width) of test piece were 200 × 50 mm. The span length for the flexural test was 150 mm. Five specimens were used for each test.

3.2. Observation of destruction

A digital microscope was used to observe the specimen after flexural tests and the destruction modes. Photographs were taken at the edge side around the loading point.

3.3. Impact test

In order to estimate surface properties of the boards, the impact test was conducted by the DuPont method [ASTM-D27954]. Sheet impact tester (Toyoseiki H-100) was used for the test. Test pieces were sandwiched between a spherical punch and a stand, and the punch had a tip with radius of 6.3 mm. A weight (500 g) was dropped onto the punch from a specified height H. The appearance of the test piece after the test was observed visually and the depth of the resulting concave indentation h was measured by dial gauge. Five specimens were used for each test.

4. RESULTS AND DISCUSSION

4.1. Flexural property

Figure 7 illustrates the mean value of flexural strength of the decorative laminates using the plywood and MDF as core materials. There was a difference of data within ±5% of the mean value for five specimens. It can be noted from the figure that the flexural strength of silk composite ($V_f = 100\%$) is larger than that of both core materials ($V_f = 0\%$), and the flexural strength of decorative laminate increases along with the increasing compounding ratio of silk composite.

A stress–strain curve of each specimen is illustrated in Figs 8 and 9. The core material of plywood was shown in Fig. 8 and MDF in Fig. 9, respectively. The configuration of the stress–strain curve for the decorative laminate approached that of silk composite along with increasing compounding ratio of silk composite. That is to say, the maximum stress and breaking strain increase along with increasing compounding ratio.

Figure 10 illustrates the mean value of flexural modulus of decorative laminates using the plywood and MDF as core materials. There was a difference of data within ±5% of the mean value for five specimens. The flexural modulus of silk composite ($V_f = 100\%$) was smaller than those of core materials ($V_f = 0\%$). Therefore, the flexural modulus of decorative laminates decreased when the compound ratio V_f increased. It is inferred that decorative laminates using silk composite as surface material became more flexible than pure woody materials.

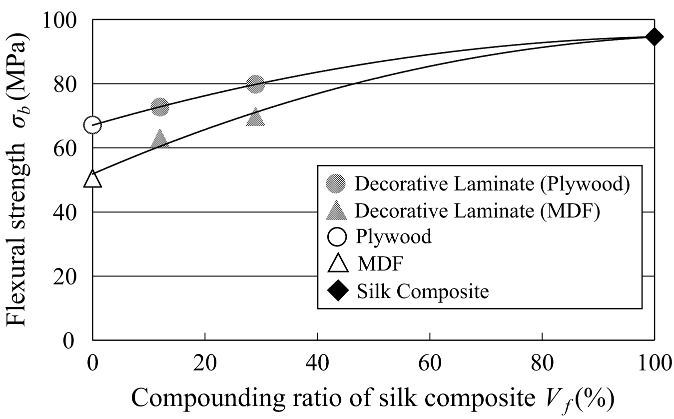

Figure 7. Relationship between flexural strength compounding ratio of silk composite.

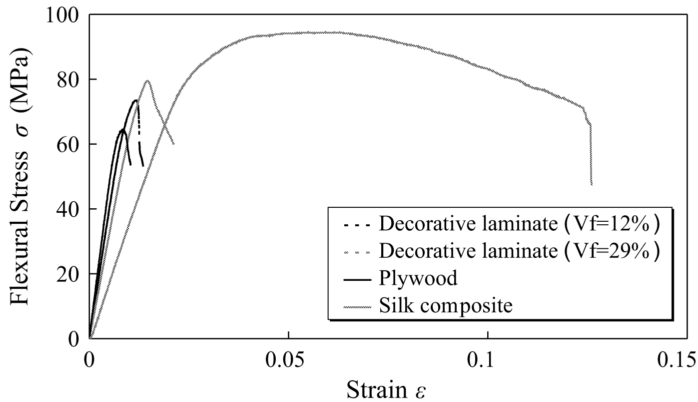

Figure 8. Stress–strain curve (core material: plywood).

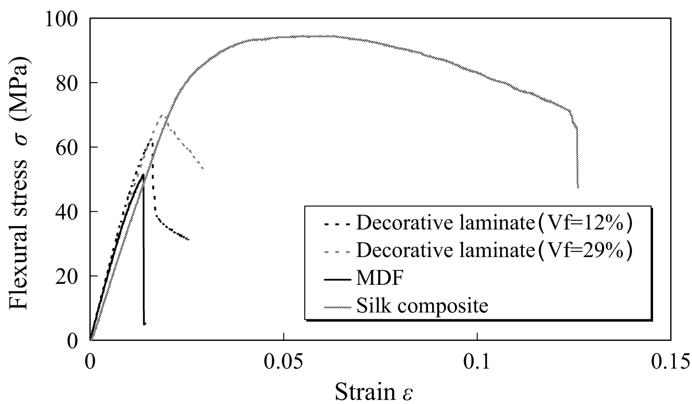

Figure 9. Stress–strain curve (core material: MDF).

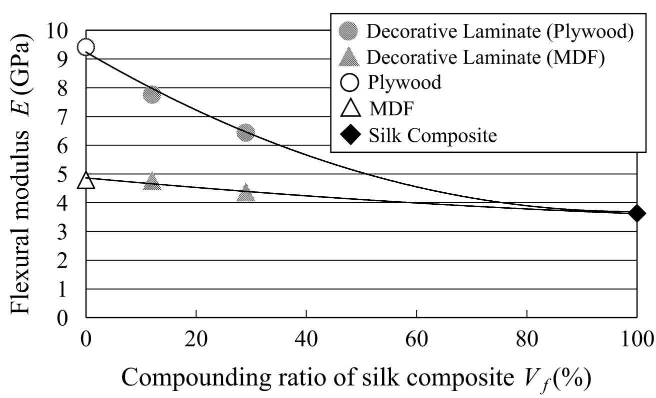

Figure 10. Relationship between flexural modulus and compounding ratio of silk composite.

Figure 11 illustrates the specific strength of each specimen with various compounding ratios of silk composite. The specific gravity of plywood was small and

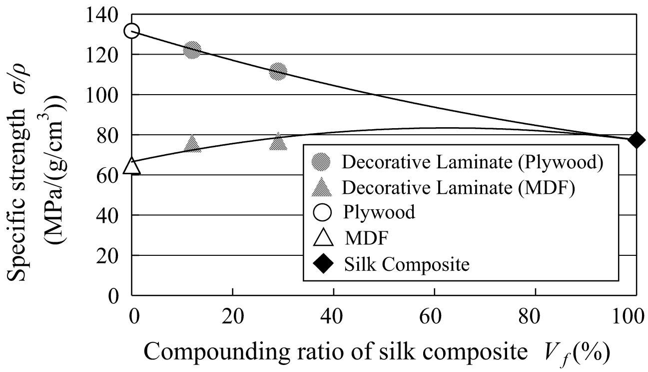

Figure 11. Relationship between specific strength and compounding ratio of silk composite.

that of MDF was larger than that of the plywood. Moreover, the strength of plywood was higher than that of MDF, so the specific strength of the decorative laminate using plywood decreased with increasing compounding ratio of silk composite. However, in the case of the decorative laminate using MDF, specific strength increases with increasing compounding ratio of silk composite.

4.2. Destruction mode of specimen

Figure 12 shows aspects of destruction of the specimen after flexural tests. The loading point is indicated by arrows. In the case of both core materials, the tension side was clearly fractured. It can be seen that the delamination occurred at the lower side (tensile side) of the plywood.

However, in the case of the decorative laminate using plywood (i.e. $V_f = 12\%$), the delamination can be seen mainly at the upper side (compression side). It suggested that the silk composite could prevent the tensile fracture of plywood. Meanwhile, in the case of the decorative laminate using MDF, the fracture can be seen at both tensile and compression sides. However, the fracture occurred only at the compression side for a larger compounding ratio of silk composite as shown in the case of $V_f = 29\%$. Moreover, the buckling of silk composite part could be clearly seen near the loading point. The surface roughness affects the adhesion area between core material and silk composite, and then the mechanical behavior: the buckling behavior particularly may be influenced by the roughness. A study of the effect of surface roughness on the mechanical behavior is our future research theme. It could be concluded that the increase of flexural strength of decorative laminates that was illustrated in Fig. 7 might be caused by the reinforcing effect of the silk composite on the tensile fracture of core materials. In order to improve the flexural strength of decorative laminates, it is expected that the reinforcing method which prevents the compression side from the fracture of core material and the buckling of silk composite will be developed as soon as possible.

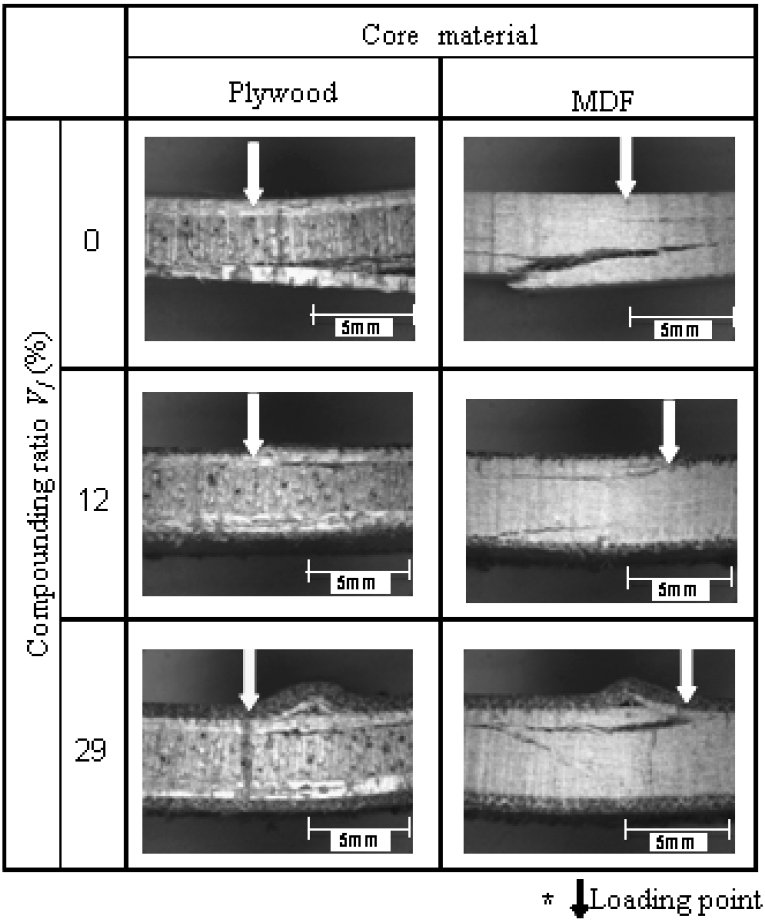

Figure 12. Destruction behavior of specimen.

4.3. Impact resistance

Figure 13 illustrates the aspects of the surface of specimens after impact test. The fall level of weight H was 1000 mm in this case. It could clearly be seen that the pure wood materials (i.e. $V_f = 0\%$) were damaged heavily and the cracks spread around the impact point. However, the damage was lightened for the decorative laminate. Especially, the fracture area became very much smaller with increasing V_f and the cracks could not be seen in $V_f = 29\%$. As discussed in the previous paper [6], the energy absorption against the impact load is somewhat larger for the silk composite. Therefore, it seems that good absorption of the impact energy caused by the falling weight can be obtained for the decorative board with silk composite at the surface. This leads to less damage of the decorative board.

Figure 14 illustrates the relationship between the value of H and the mean value of depth of the concave indentation h. There was a difference of data within $\pm 7\%$ of the mean value for five specimens. It implied that there was no significant difference

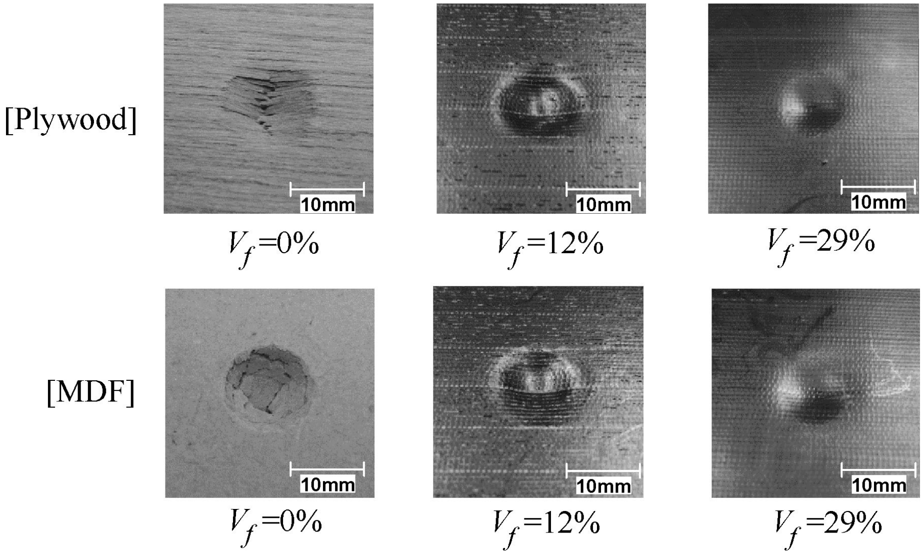

Figure 13. Aspect of surface ($H = 1000$ mm).

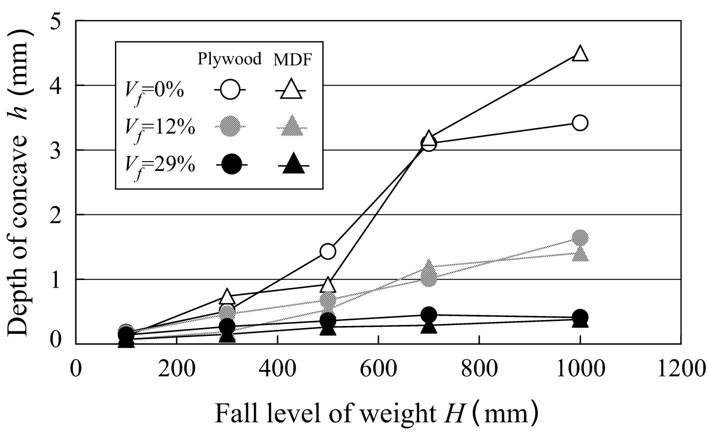

Figure 14. Relationship between fall level of weight and depth of concave.

in H between the results of plywood and MDF. The value of h increased largely with increasing value of H for plywood and MDF. However, a fairly small increase of h could be found in the case of the decorative laminates. It could be noted that the value of h for decorative laminates was somewhat smaller than that of plywood or MDF. It could therefore be concluded that the decorative laminate that used silk composite as surface material had an excellent impact resistance.

5. CONCLUSIONS

In this paper, decorative laminates that used artistic silk composites as their surface materials were molded and their properties were discussed. Some conclusions were drawn as follows:

(1) Plywood and MDF can be reinforced by silk composites, and flexural strengths of decorative laminates increase along with growth of compounding ratio of silk composite.

(2) Flexural modulus of decorative laminate decrease with increasing compounding ratio of silk composite. And decorative laminates that used silk composite as surface material become more flexible than pure woody material.

(3) When plywood is used as a core material, specific strengths of decorative laminate decrease with increasing compounding ratio of silk composite. However, when using MDF as a core material, specific strengths increase with increasing compounding ratio of silk composite.

(4) Destructions of pure plywood and MDF occur at the tension side. However, destructions of decorative laminate mainly occur at the compression side.

(5) Decorative laminates that use silk composites as surface materials have an excellent impact resistance.

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