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Studies on Wood Gluing
XIII: Gluability and Scanning Electron Microscopic Study of Wood-Polypropylene Bonding *

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Summary. The purpose of this paper was to clarify the gluability and adhesion mechanism of polypropylene as a hot melt wood adhesive for plywood bonding. The gluability of plywood glued with nonpolar and modified polypropylene satisfied approximately the specification of the Japan Agricultural Standard, Designation Types 1 and 2. The moisture content (8 to 25 %) of the core veneer had no recognizable effect on gluability. The durability of polypropylene and that of modified polypropylene were the same as that of melamine-formaldehyde resin. Molten polypropylene made good contact with veneer surface, and penetrated into the lumina of wood cells and other spaces. In the separated glue lines, casts of glue which had penetrated into the vessels had many mushroom-like projections which had filled the bordered pit cavities. It was indicated that the anchoring effect of polypropylene which had penetrated into various wood elements and spaces in the veneer contributed dominantly to the gluability.

Introduction

At present, thermosetting resin adhesives, such as phenol-formaldehyde resin and urea-formaldehyde resin, are the main adhesives used in the wood industry and their properties have been extensively studied. Thermoplastic emulsion resins or hot melt type adhesives have attracted some attention in recent years but information on their wood-bonding capabilities is limited. A primary concern is whether olefin resins, with their high melting points, can provide equal gluability and durability compared to conventional wood adhesives.

The objectives of this work can be summarized as follows:

1) The determination of the gluability of plywood bonded with polypropylene by means of either platen or roller press, and the durability of this plywood under several exposure conditions.

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2) Topographic studies of the glue lines which appear on transverse sections and stripped faces, and of chemically separated glue lines by a scanning electron microscope.

3) The determination of the relative contribution of mechanical and specific adhesion on the basis of the gluability of chemically modified wood glued with nonpolar polypropylene, (to be reported in a further paper).

Experimental

Wood bonding

Materials

Wood: Red seraya (*Shorea* sp.) veneer from Sabah was used. The veneer thickness was 0.75 mm for face and back, and 1.70 mm for the core. Veneer moisture content was 8 percent or less. Adhesives: Commercial polypropylene and modified polypropylene, phenol-formaldehyde resin, and melamine-formaldehyde resin were used.

Gluing and Test Methods

Three-ply plywood panels (30 cm x 30 cm) were prepared by either platen or roller press. The gluing conditions were as follows:
The platen press:
Polypropylene and modified polypropylene film, 60 μm thick
Hot press: 200 °C, 10 kg/cm^2, 2 minutes
Phenol-formaldehyde resin (resol) adhesive
Glue spread: 330 g/m^2; Hot press: 135 °C, 10 kg/cm^2, 2 minutes
Melamine-formaldehyde resin adhesive
Glue spread: 330 g/m^2; Hot press: 120 °C, 10 kg/cm^2, 1 minute
The roller press:
Polypropylene and modified polypropylene
Molten temperature: 290 °C, Glue line thickness: 60 μm

In order to study the effect of moisture content in the core veneers, another experiment was performed where the veneer was conditioned to moisture content ranges of under 8, 10–12, 14–16 and 20–25 percent. Plywood was prepared under the same gluing conditions as described above by the roller press using the conditioned core veneer while the face and back veneer was kept to less than 8 percent moisture content.

For test fence evaluation, two plywood panels (30 cm x 30 cm) for each condition were positioned 45° from the vertical, facing south for a period of one year. The bond quality of the plywood was evaluated according to the Japan Agricultural Standard (JAS). In this standard the specimens were subjected to one cycle of boil-dry-boil (designation Type 1) and hot-cold (designation Type 2) and tested while still wet at room temperature. Some plywood shear specimens were also tested wet after immersion in boiling water for up to five days and then cooled.

Scanning Electron Microscope (SEM) Study

Plywood glue lines prepared as described in the above experiment were observed in the following three modes: (1) glue lines which appear on the transverse sections of plywood cut at a right angle to the grain of the face veneer or the core veneer; (2) glue lines which appear on stripped faces prepared as follows: small pieces of plywood were soaked in water, and then the face veneer was stripped off using tweezers; and (3) glue lines separated from plywood by perchloric acid followed by sulfuric acid (72%) treatment. The glue lines samples were coated with gold of about 300 Å thick in a vacuum evaporator or ion-sputtering instrument.

Results and Discussion

Bond Quality and Durability

The glue-joint strength of plywood bonded with nonpolar polypropylene and that of modified polypropylene were slightly lower than that of phenol- and melamine-formaldehyde resin adhesives (Table 1). The gluability of all panels, however, approximately satisfied the specification of JAS, designation Types 1 and 2.

The glue-joint strength of modified polypropylene was equal or slightly higher than that of polypropylene (Table 1).

Table 1. Strength of plywood glued with various adhesives

		Glue-joint strength (kg/cm^2)		
Adhesive	Press method	Dry test	Wet test [a]	Wet test [b]
Polypropylene	Platen	11.4(54)	8.3(6)	9.2(13)
	Roller	10.5(19)	7.6(9)	9.4(17)
Modified polypropylene	Platen	15.1(72)	10.2(19)	12.0(8)
	Roller	11.7(60)	8.7(10)	9.8(37)
Phenol-formaldehyde	Platen	11.4(54)	14.5(53)	18.9(38)
Melamine-formaldehyde	Platen	15.2(94)	13.2(31)	18.6(74)

( ) Wood failure, %

[a] Boil-dry-boil test (JAS Designation Type 1)

[b] Hot-cold test (JAS Designation Type 2)

Table 2. Effect of core veneer moisture content on gluability

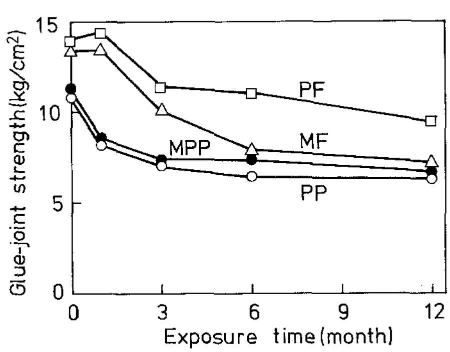
Adhesive	Moisture content %	Glue-joint strength kg/cm^2	
		Wet test [a]	Wet test [b]
Polypropylene	-8	13.1(42)	14.0(29)
	10–12	13.3(21)	14.4(23)
	14–16	12.0(18)	13.6(18)
	20–25	11.6(23)	13.0(17)
Modified polypropylene	-8	14.2(39)	14.9(33)
	10–12	12.2(18)	13.8(23)
	14–16	13.4(38)	14.4(42)
	20–25	14.0(53)	14.6(27)

( ) Wood failure, %
[a] Boil-dry-boil test (JAS Designation Type 1)
[b] Hot-cold test (JAS Designation Type 2)

The roller press tended to result in relatively low glue-joint strength because resin penetration into wood cavities was altered by the difference in pressing period (Table 1).

The gluability of plywood prepared by the roller press was not affected by the moisture content of the core veneer (Table 2).

The glue-joint strength decreased with increasing exposure to weathering, but the rate of decrease after three months was slight (Fig. 1). The durability of polypropylene and modified polypropylene joints was the same as that of melamine-formaldehyde resin adhesive.



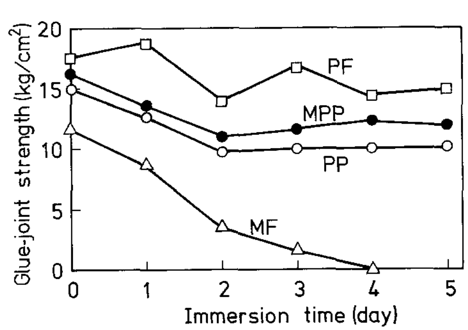


Fig. 1. Relation between glue-joint strength of plywood glued with polypropylene (PP), modified polypropylene (MPP), phenol-formaldehyde resin (PF) and melamine-formaldehyde resin (MF) and weathering exposure time

Fig. 2. Relation between glue-joint strength of plywood glued with polypropylene (PP), modified polypropylene (MPP), phenol-formaldehyde resin (PF) and melamine-formaldehyde resin (MF) and boiling water immersion time

Glue-joints using polypropylene and modified polypropylene retained 0.69 and 0.73 of their orginal strengths respectively, after continuous immersion for 5 days in boiling water (Fig. 2).

Thus, the results indicate that polypropylene and modified polypropylene may be used as hot melt type adhesives in wood gluing.

SEM Observations

The polypropylene melted during hot pressing and made good contact with veneer surfaces penetrating into lumina of wood cells, lathe checks and other spaces open on the veneer surface. The separated glue lines, therefore, gave good replicas of the wood structure of the veneer surfaces (Figs. 3 and 4), and topographic studies of glue lines could be easily done using a scanning electron microscope as previously reported for phenol-formaldehyde glue lines (Saiki, Goto, Sakuno 1975).

Penetration of Polypropylene into Cell Lumina

The Red seraya veneer had large vessels open on the surface which were filled with polypropylene, although hollows due to air bubbles were often observed in the glue

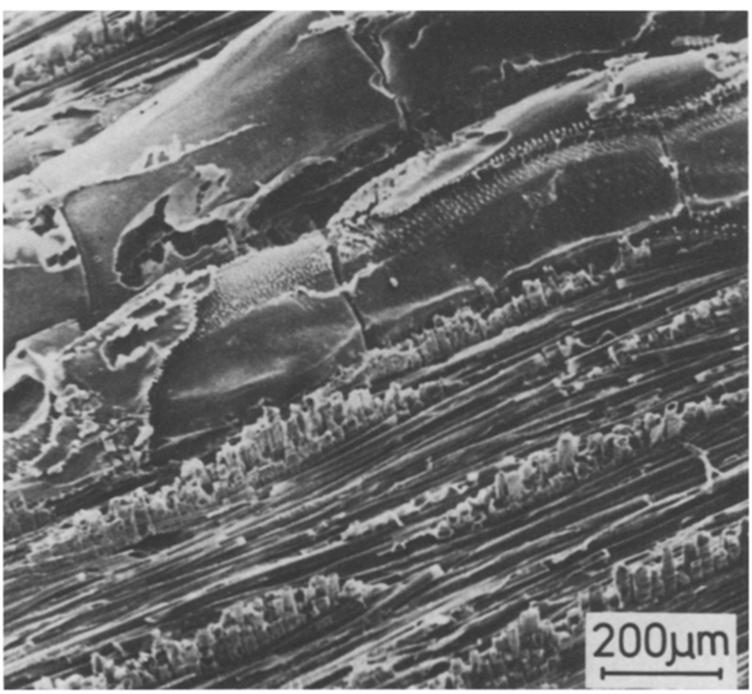


Fig. 3. Polypropylene glue line separated chemically from plywood

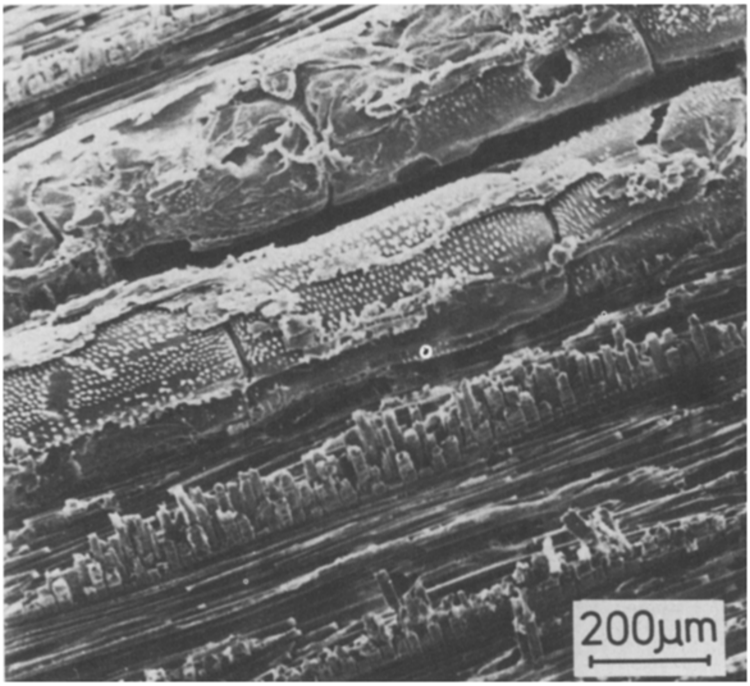


Fig. 4. Modified polypropylene glue line separated chemically from plywood

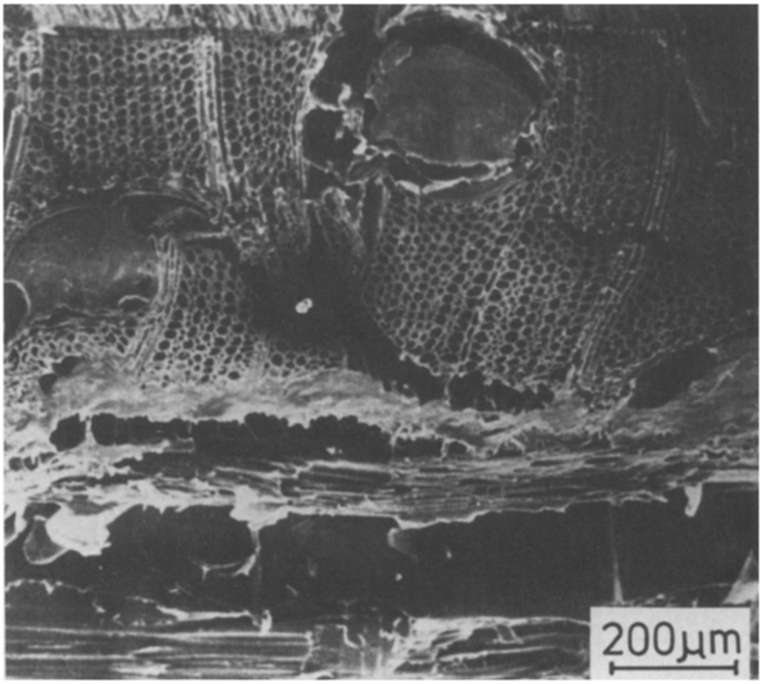


Fig. 5. Cross section of polypropylene glue line

lines. The vessel casts (polypropylene which had filled vessel lumina) were conspicuous in the separated glue lines, and formed a latticework in them.

On the transverse section of plywood it was often observed that polypropylene penetrated into vessels far from the glued face of the veneer (Fig. 5). Those vessels ran diagonally within the veneer with the open end of the lumen somewhere along the glue line, and from there molten polypropylene was able to penetrate. Polypropylene penetration into such diagonal vessels was quite deep and frequently reached the outer face of 0.75 mm thick veneer. Polypropylene exposed on the outer face could be observed on the weathered plywood because degraded surface cells had been eroded from the surface.

Molten polypropylene also penetrated deeply into wood fibers (Figs. 6 and 7), ray parenchyma cells (Figs. 8 and 9) and intercellular canals.

Polypropylene penetrated not only into cell lumina but also into pit cavities. In separated glue lines, vessel casts had many mushroom-like projections which had filled the bordered pit cavities (Fig. 10). On SEM observation of a cured water-reducible alkyd resin which had filled the voids in a piece of basswood, same mushroom-like projections and the cast of intervessel bordered pit pairs were illustrated (Côté, 1981). Small projections which had filled the simple pits were observed on the casts of parenchyma cells (Fig. 9). In the present study, however, it could not be ascertained

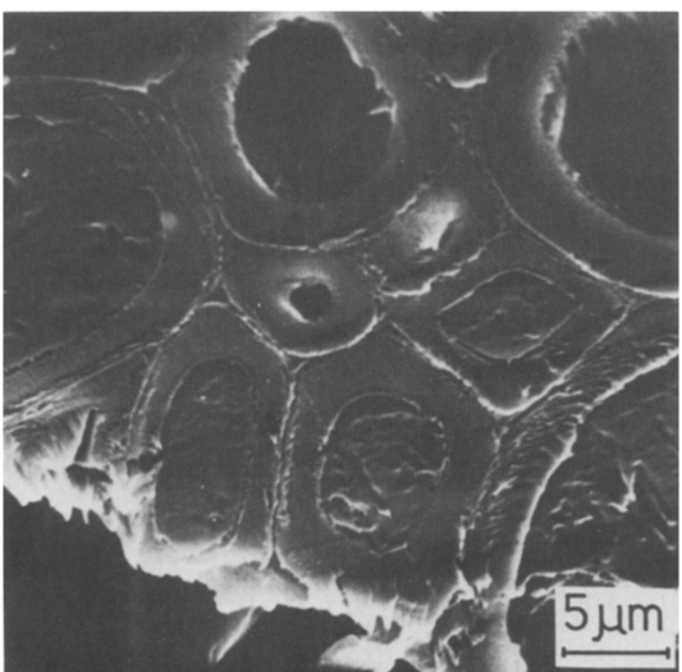


Fig. 6. Cross section of modified polypropylene glue line of plywood exposed to weathering

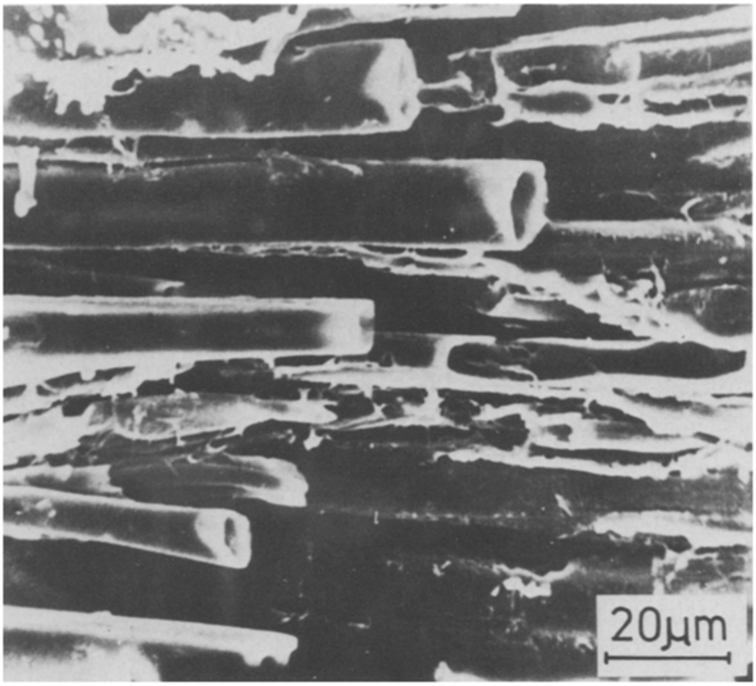


Fig. 7. Fiber glue cast of modified polypropylene glue line separated chemically from plywood

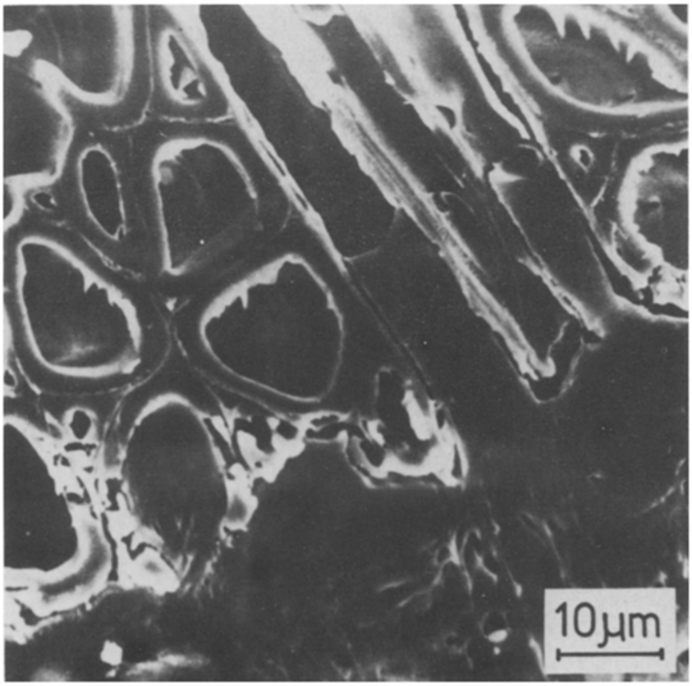


Fig. 8. Cross section of modified polypropylene glue line

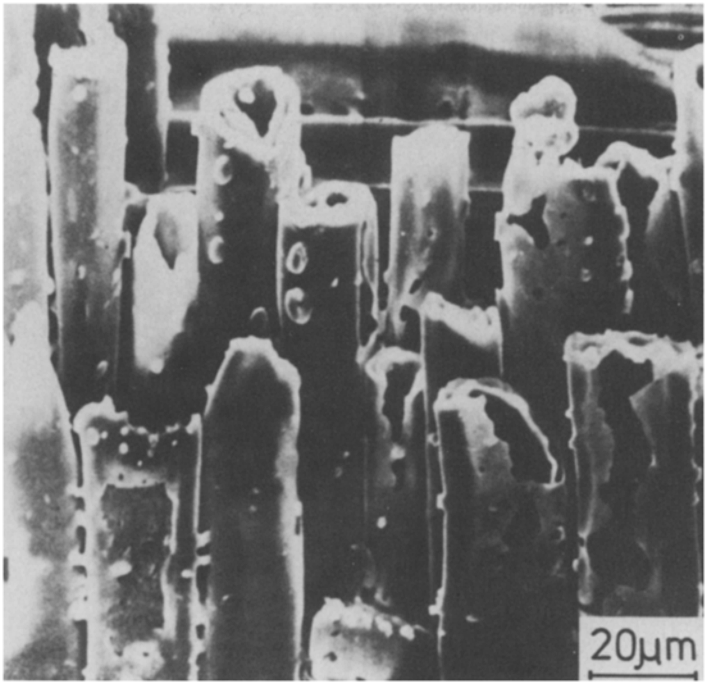


Fig. 9. Ray glue cast of modified polypropylene glue line separated chemically from plywood

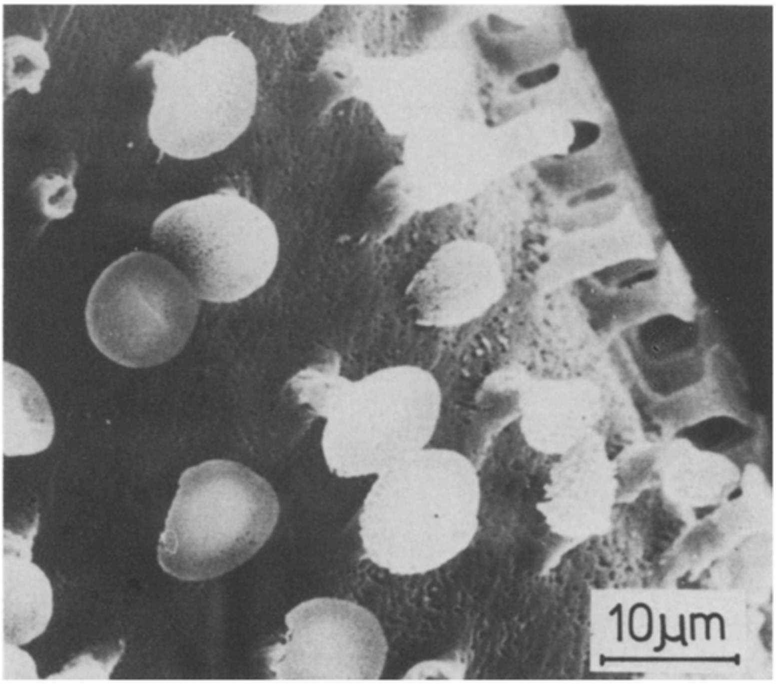


Fig. 10. Mushroom-like projection on vessel glue cast separated chemically from plywood

whether molten polypropylene penetrated through the pit membrane into adjacent cell lumina.

Penetration into lathe checks seemed to be minor and far less than into vessels (Fig. 5).

Contact Between Polypropylene and Cell Wall

The observations on the separated glue lines suggest that polypropylene made good contact with the lumen surface and exposed cell wall surface. Replicas of the warty structure could be observed on the surface of vessel casts. Glue lines in contact with wall surfaces exposed by rotary-cutting replicated the fibrillar structure of the wall layers.

The separated glue lines from weathered samples showed almost the same surface structure as that from unweathered ones.

Gluability of Polypropylene

The surface of polypropylene glue lines, separated chemically or mechanically from wood, finely replicated the surface structure of cell lumina and the exposed cell wall

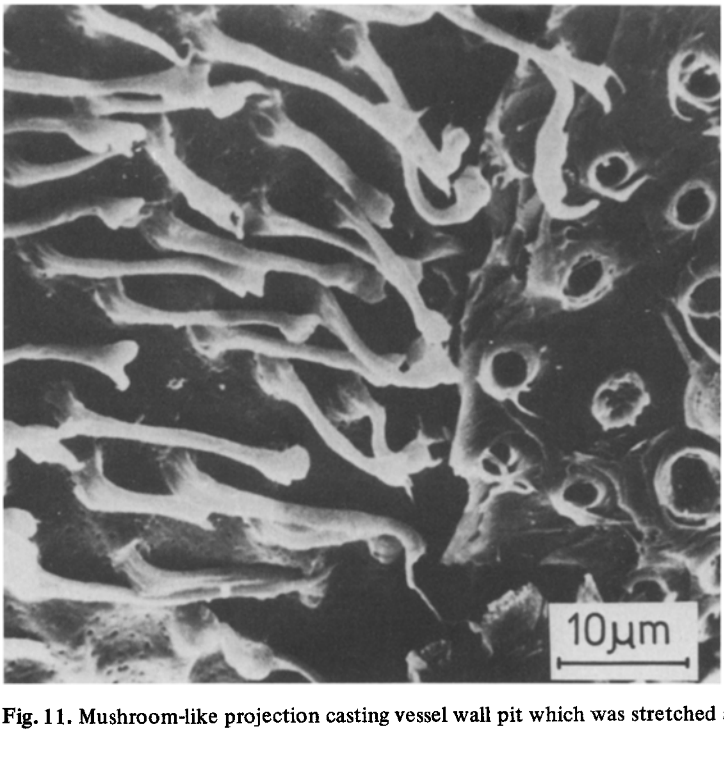


Fig. 11. Mushroom-like projection casting vessel wall pit which was stretched and torn

surface. These clear replications, however, do not indicate the existance of chemical bonds between polypropylene and wood substance because the wood elements could be easily separated from the glue lines after a short immersion in water. Glue-joint strength obtained in shear tests (Table 1), therefore, indicates an anchoring mechanism of polypropylene which penetrates into various wood elements and spaces in the veneer. Among the casts of polypropylene penetrated into the lumina of various types of cells, vessel casts are considered most effective in providing shear resistance of the Red seraya plywood tested because they formed a latticework in the glue lines and diagonally ran through almost the whole thickness of the face veneers.

The mushroom-like projections into vessel wall pit were stretched and torn when viewed on the stripped specimens (Fig. 11). These projections are also considered to contribute to the anchoring mechanism of vessel casts.

The authors consider that apparent glue-joint strength in the shear test strongly depends on the penetration of molten polypropylene into wood cells. Factors which affect the gluing are proportion of vessels included in the veneer, vessel diameter, vessel blockades, grain inclination of veneer, veneer thickness and so on. Peeling tests of polypropylene joints, if tested wet, would give additional indication of the true quality of the joint. The gluability of polypropylene should therefore be evaluated on the basis of various joint testing methods and tests should be extended to other hardwood species.

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