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Development and application of electro-conductive adhisive for wood

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This paper examined stirring condition, bonding strength, electrical properties and heating phenomenon of electro-conductive adhesive for wood.

1. INTRODUCTION

Much research has been conducted on developing a conductive adhesive [1) 2) 3)] and some results have found practical application. Platinum, palladium and gold have often been used for fillers to make adhesives conductive, and the volume resistivity (hereafter called 'resistance') after curing has usually been of the order of 10^{-2} to 10^{-4} Ω·cm. In these studies, suppression of the production of heat was needed because adhesives were developed to be used for electric current applications, as shown by the resistance range. We investigated the resistivity characteristics of an adhesive produced by mixing a commercial adhesive with an electro-conductive filler in an agitator, the mechanical strength characteristics of the conductive adhesive, and applications of the heat generated in the glue layer.

2. TEST METHOD

2.1. Adhesive stirring and resistance

We used modified phenolic resin adhesive(PH) (viscosity: 400 to 600 cps/25° C; solids content: 25%), and carbon black (CB); mean particle diameter: 38 μ ; specific surface: 37m ^{2} /g; oil adsorption: 447cc/100g) as filler. A Brookfield viscometer conforming to JIS K 6838 was used to directly measure the viscosity during stirring by stopping the motor of the agitator at 30, 60, 90, 120, 180, 240, and 360 minutes after the start of stirring. PH was stirred in 2000g units. The ratios of CB to PH were 20:100, 25:100, and 30:100 by weight. The temperature during stirring was set to 25 to 30° C. Resistance was also measured at 30 to 360 minutes after the start of stirring. The agitator was stopped at these times, and 15g of the adhesive was taken. An applicator was used to make a film-shaped specimen from the 15g of adhesive for the resistance measurement and tensile strength measurement. The measurement conformed to Japan Rubber Association Standard SRIS 2301. An ohmmeter with the four probe method was used to measure the surface resistance. The film specimens were cured by placing them in a 130° C environment for 30 minutes.

2.2. Bonding strength

The bonding strength of the conductive adhesive was obtained by measuring the tensile shear strength conforming to JIS K 6851. The tensile strength of the film specimens was measured conforming to ASTM L-type. Birch wood with mean moisture content of 10.0% and mean specific gravity of 0.68 was used as adherent. The bonding conditions were as follows: spread: 122g/m ^{2} ; heating temp.: 130

° C; heating time: 90min; pressure: 1.0 to 1.5 MPa. The specimens were placed for seven days at room temperature of 20 to 25° C after the bonding was completed.

2.3. Application of adhesive

2.3.1. Low-voltage bonding

The low-voltage bonding described in this paper is a method where a film-shaped adhesive(FA), which is electro conductive, is used, a voltage is applied during bonding, and the Joule heat generated is used to accelerate the curing. FA was produced by impregnating polyester non woven fabric(23g/m ^{2}) with adhesive that was made conductive (ratio of CB to PH: 30:100). The weight of the finished FA adhesive was 185g/m ^{2}, the surface resistance was 120 Ω/□, and the thickness was 0.25 to 0.3mm. A copper sheet of thickness 0.01mm was inserted between the adherents as an electrode. Figure 1 shows the shape and dimensions of the specimen and the electrodes. The bonding conditions were: pressing pressure: 2 MPa; voltage: 70 to 100 V; and applied voltage time: max. 240 sec. A thermocouple (0.05mm) was inserted between adherents to measure the increase in glue layer temperature during bonding.

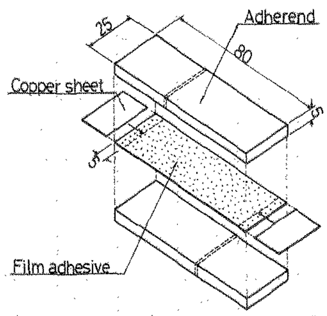

Fig.1 Forms and dimention of specimen

2.3.2. Panel heat development test

FA was used in this test. A panel specimen was produced by bonding lauan plywood of 12 mm thickness and lauan plywood of 3mm thickness with FA. The length was 1800mm and three widths were used to produce three types of specimens: type S-1 of 300mm, type S-2 of 600mm, and type S-3 of 900mm. Copper leaf of width 10 mm and thickness 0.01 mm was bonded to the panel specimen in the longitudinal direction as an electrode. The resistance between the copper electrodes o the panel specimen types S-1, S-2 and S- were 40 Ω , 83 Ω , and 110 Ω respectively.

The relationship between current and powe was obtained for each panel type with a applied voltage of up to 200V. An infrare radiation thermometer was also used t simultaneously measure the temperatur distribution on the surfaces of the pane specimens.

3. RESULTS AND DISCUSSION

3.1. Stirring and resistance

The viscosity of a mixture of PH and CI decreased rapidly during 100 minutes afte starting stirring, then decreased gradually. Th rate of decrease suddenly slowed and becam constant approximately 180 minutes after th start of stirring. The relationship betwee viscosity and stirring time was given by th following expression:

$$Y = A + \log B x \quad (r = 0.94 \text{ to } 0.98) \qquad (1)$$

where,

Y:viscosity, x:stirring time, A and B:constant.

The adhesives containing 25% and 30% CB had similar constant B values of -4.2 and -4.3, and showed the same pattern of decreasing viscosity. It was observed visually that the secondary aggregate of CB was dispersed 10 minutes after the start of stirring as shown in

Fig.2 Dispersion of carbon black

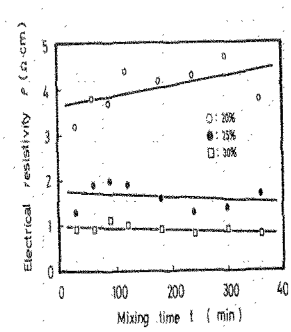

Fig.3 Relation between mixin time and electrical resistivit

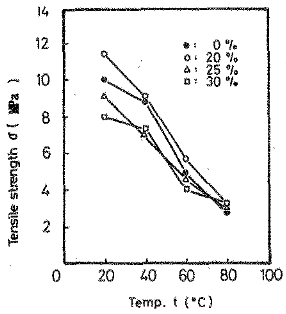

Fig.4 Relation between tensile strength and temperature

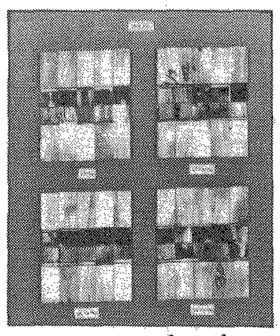

Fig.5 Failure surface of shearing test(20 °C)

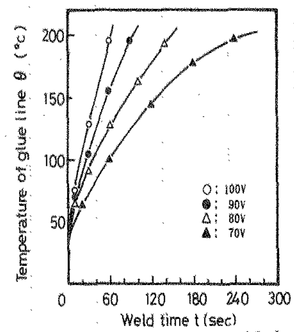

Fig.6 Relation between weld time and temperature of glue line

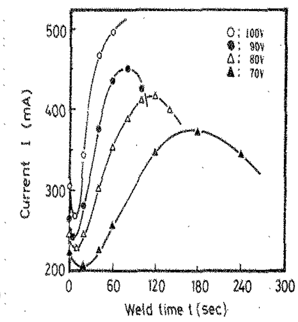

Fig.7 Relation between weld time and current

Fig. 2 (x 5000). However, the dispersion was uneven and some aggregates remained. The dispersion had progressed by 60 minutes after the start of stirring. The dispersion condition after stirring for 360 minutes was almost the same as that after 60 minutes.

Figure 3 shows the relationship between stirring time and resistance. The resistance of the adhesive containing 20% CB increases gradually while stirring for 360 minutes, but the resistance of adhesives containing 25% and 30% CB was not affected by the stirring time. We conjecture that this is because the carbon secondary aggregate disperses quickly as is clearly shown in Fig. 2, and that the dispersed secondary aggregates contact one another without shear fracture caused by stirring.

3.2. Bonding strength

Figure 4 shows how the tensile shear strength depends on the environmental temperature. The results for adhesive without carbon are plotted using ● marks. The tensile shear strength at 20° C increased by approximately 15% when 20% CB was contained, and decreased by 10% and 20% when 25% and 30% CB were contained, respectively. Similar results were obtained for the film adhesive. The strength of the adhesive without CB decreased by approximately 10% at 40° C, by 50% at 60° C, and by 70% at 80° C when compared to that at 20° C. That of other adhesives decreased almost linearly as the temperature increased and became approximately 3 MPa at 80° C.

We observed the failure surfaces visually. Figure 5 shows the failure surfaces at 20° C. Wood fracture is observed in specimens with adhesives containing 0% and 20% CB. The failure in the specimens with adhesives containing 25% and 30% CB is mainly interfacial failure, with only a partial wood fraction. A similar failure pattern was observed for 40° C but only interfacial failure occurs at and above 60° C.

3.3. Applications of adhesive

3.3.1 Low−voltage bonding

Figure 6 shows the increase in glue layer temperature with a voltage of 70 to 100V applied between specimen electrodes in Fig. 1. The adhesive cure temperature was 130° C. Figure 6 shows that the temperature of the adhesives in the specimens reaches 130° C within 30 to 100 seconds. This means that electro−conductive adhesive can be cured quickly with Joule heat generated by applying a voltage.

Figure 7 shows how the current varies as the glue layer temperature increases. The current slightly decreases temporarily after the voltage is applied, then increases as heat is generated, reaching a peak value, except for the voltage of 100 V. We conjecture that the reason for the behavior, excluding the decrease immediately after the voltage is applied, is that the fillers become closer to one another under the influence of the generated heat and pressure in the early stage of curing, and as the physical contact between the fillers increases.

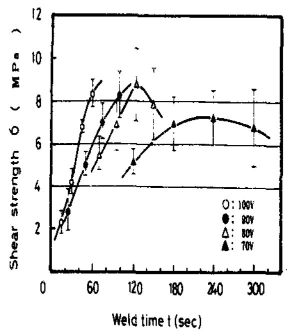

Fig.8 Relation between weld time and strength

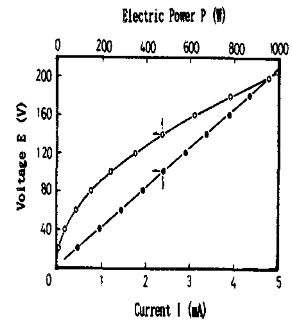

Fig.9 Relation between voltage, current and elctric power(s−1)

Figure 8 shows the relationship between voltage application time and bonding strength. The maximum bonding strength was approximately 8 MPa except for at 70V. The strength at 70V and the strength at 80V have peaks. Most parts of each failure surface were carbonized when they were observed after the peaks were reached. This is because the temperature of the glue layer becomes high as shown in Fig. 6. The error bars in Fig. 8 indicate standard deviation, and show that the adhesive cured at a higher voltage has less deviation of bonding shear strength, that is, faster curing of the adhesive reduces the deviation in bonding shear strength.

3.3.2. Heat development test

Figure 9 shows the relationship between voltage, current, and power with a voltage of 200V applied to panel S−1. The power with a voltage of 100V applied was 241W for panel S−1, 117W for S−2, and 90W for S−3. We measured the surface temperature of the panels for an applied voltage of 90V for S−1, 130V for S−2, and 150V for S−3 for 120 minutes. These voltage values correspond to an output of 200W. The surface temperatures became constant within 20 to 30 minutes and did not increase thereafter. The surface temperature increased by 22° C, 17° C, or 11 ° C depending on the panel type.

Figure 10 shows the total temperature distribution on the surface of panel S−3 after applying the voltage for 30 minutes. The temperatures of the upper parts are a little higher in this figure. We conjecture that this

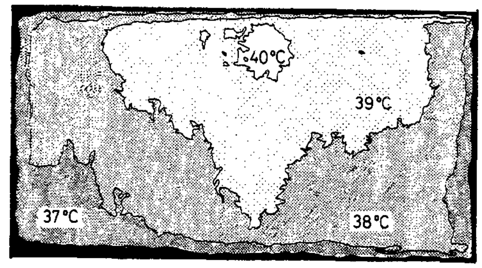

Fig.10 Distribution temperature of in bonded panel

result was due to the influence of the room temperature difference between the upper and lower parts because the voltage was applied with the panel kept upright during the temperature increase measurement. The surface temperature varied between 2° C and 3° C, indicating that the panel is an acceptable heating unit. The range of temperature increase differs between the panel types. The power necessary to raise the surface temperature by 1° C was 17W, 13W or 10W depending on the panel type.

4. CONCLUSIONS

We investigated how the Joule heat generated by applying an electric current to a glue layer can be used to increase the efficiency of the bonding process, and how it can be applied to a surface heating unit. The efficient bonding process technique can be used to bond objects with complex forms such as curved surfaces, and also reduces the bonding time. We will investigate how the Joule heat technique can be used to develop new woody products.

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