마이크로웨이브를 이용한 섬유 접착에 있어 유기용매의 영향

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Effect of organic solvents on fiber bonding of microwave heating

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1. Introduction

Microwave is a kind of electromagnetic wave within frequency range from 300MHz to 300GHz. In the common drier and heaters, heat gradually transfers from exterior to interior in the materials, as it adopts radiant heat or convection current. However, by using microwave, both the interior and exterior of fiber materials can be evenly heated simultaneously. Especially, in case of heating the material of low thermal conduction by normal furnaces, thermal loss is great and it takes long time to finish the required treatment. However, if microwave is applied to fibrous materials, it can be treated rapidly. Also, application of microwave system has the results of remarkably enhancing productivity and improving working environment owing to no air pollution.

From literature survey, there was a few results related to heat the surface of materials. About thirty years ago, industrial engineers have been developing microwave heating techniques that avoid some limitations of conventional heating.

But, there have been no studies aimed at thermal-bonding of fiber by microwave heating.[1] Thus, in this study, thermal-bonded polypropylene(PP) fibers by microwave heating using organic solvents as additives have prepared and their morphological structures and debonding force have investigated with different treatment time.

2. Theoretical Consideration

For typical conditions of many dielectric heating applications, the electronic power converted to heat per unit volume was related the frequency, the loss factor and the electric field strength such as equation(1). Thus higher power densities can be achieved by increasing loss factor of materials and electric field strength. But in the study, the frequency and electric field strength of a microwave oven have constant values of 2450MHz and 220V, respectively. Meanwhile, loss factor

has been controlled so as to increase the heat-quantity of emitted samples.

The energy absorption by materials in a microwave cavity is dependent on both the shape and the volume of samples. Thus, the absorbed power by materials can be expressed as[1]:

$$P = 2\pi f \varepsilon_0 \varepsilon'' E^2 = 55.6\times10^{-12} f \varepsilon'' E^2_{int} (W/m^3) \quad (1)$$

P : power converted to heat per unit volume

E_{int} : magnitude of the internal electric field in the material(V/m)

ε'' : relative loss factor, ε_0 : permittivity of free space(vacuum or dry air)(F/m)

Actually, because of the depolarizing field, the internal electric field is not the applied electric field(E_{ap}) supplied by the microwave source. Then:

$$\vec{E}_{int} = \frac{1}{1+b\chi}\vec{E}_{ap} \quad (2)$$

E_{ap}: applied electric field strength, b: shape factor, χ: susceptibility

By using equation(1) and (2), it can be converted power into heat-quantity with treatment time.[2]

3. Experimental

3.1. Sample Preparation

Since synthetic fibers such as PP and PET have very low loss factor, it is very difficult to bond among these fibers by microwave heating. Thus, in the study, we have used organic additives which keep high polarity. Dielectric properties of the used organic solvents are provided in Table 1.

Table 1. Dielectric properties of organic solvents

Properties / Solvent	Dielectric Constant (Loss Factor)	Polarity	Boiling Point(℃)
Water	79.7(12)	100	100
Ethylene glycol(EG)	37.7(9.48)	79	198
Diethylene glycol(DEG)	31.7(8.56)	71.3	245

The sample of bonding between two single fibers was producted in our laboratory as shown schematically in Figure 1. Additives are used EG and DEG. Crossing point between two single fibers was fallen a drop of organic solvent(0.1g). Samples were put between two glass plates and then treated in the specially designed microwave oven (2450MHz) with 0.75gf/mm^2 of applied load.

3.2. Morphological Structure

Morphological structure was observed by image analyzer(BMI).

3.3. Debonding Test

Prepared samples were measured by Instron tensile tester(Instron 4467) according to ASTM D461 method. Figure 2 showed schematic diagram for the

debonding-force measurement. Crosshead speed is 4mm/min, and load cell used 50kgf.

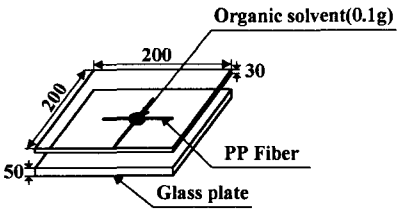

Figure 1. Schematic diagram of sample preparation (unit: mm)

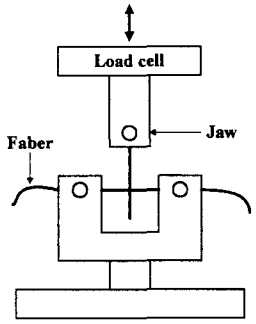

Figure 2. Schematic diagram for the debonding-force measurement by using a tensile-testing machine

4. Result & Discussion

4.1. Morphological Structure

Morphological structure on bonding region of PP fiber using microwave heating is shown in Figure 3. The photographs in Figure 3 are shown heating by indirect heat emitted polar organic solvents. The PP polymer at each corner of the bonding point gradually melted and formed a quadrant shape. At the same time, the amount of melt polymer in the vicinity of the bonding point decreased, and the fiber diameter at this position was a minimum.

The formation of a circular shape indicates that the polymer flow near the bonding point was induced by the surface tension. In other words, it can be deduced that the geometry of the polymer changed so as to minimize its surface energy.

(a) 420 (b) 510 (c) 570

Figure 3. Photographs(×50) of PP samples bonded by microwave heating with treatment time(unit: second)

4.2. Debonding Behavior

Figure 4 showed stress-strain curves of untreated and treated PP samples by microwave heating. As treatment time was increased up to 510s, the stress and strain of sample increased. Above 510s, the stress was rapidly decreased. The effect of treatment time on the bonding behavior is primarily attributable to the change on the viscosity of PP polymer.

4.3. Debonding Force

Changes in debonding force with treatment time for thermal-bonded PP fiber by

microwave using EG and DEG are shown in Figure 5. As treatment time increased, debonding force increased. On the other hand, if treatment time was too long, debonding force decreased.

When the treatment time is short and the amount of polymer flowing into the bonding part is small, the fracture occurs at the interface between the two fibers. If the treatment time became longer and the bonded interface became stronger, the effect of stress concentration at the bonding part where the fiber diameter decreased. This is due to the flow in the fiber-axis direction of the polymer to the bonding part. Since the fiber diameter at this part, where the fracture would start, becomes smaller with increasing bonding time, the debonding force also decreases.[3)]

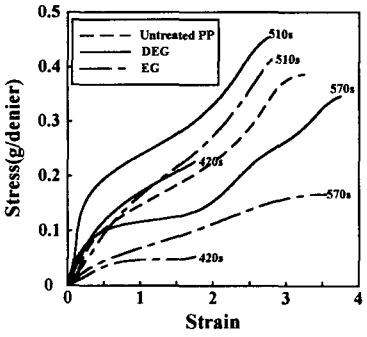

Figure 4. Stress-Strain curves of untreated sample and treated sample

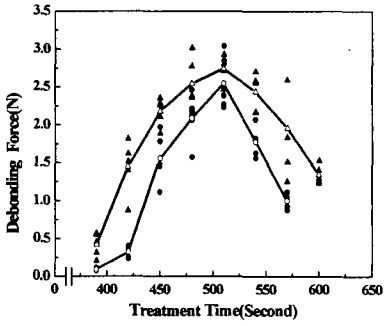

Figure 5. Effect of treatment time on debonding force of PP sample bonded by microwave heating (▲: DEG, ●: EG, Open: Mean)

5. Conclusion

(1) In the thermal bonding of microwave bonded PP-fibers arranged at right angle, the PP polymer flowed into the crossing point to minimize the surface energy and formed a quadrant shape at each corner of the intersection.

(2) When the treatment time was too short, the amount of polymer flowing into the bonding region was too small, and breaking of the bonding part occurred at the interface between two bonded fibers.

(3) When the treatment time was too long, fracture started from the position of minimum fiber diameter near the bonding point. Finally, in the study we obtained treatment time of 510s for the best condition.

5. References

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