405 PMMA/PLA 複合材料の特性及び中間層に使用する超音波接合評価

Weld Properties of Heterogeneous Polymers on
Poly(methyl methacrylate) and Polylactide based on Novel Ultrasonic Welding Method

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1. Introduction

Ultrasonic welding (USW) for polymer, which using vibratory energy at high frequencies to produce low amplitude mechanical vibrations, is a rapid joint method at the welding interface due to the welding stress (welding pressure). The vibrations generate heat at the parts being welded, resulting in melting of the thermoplastic materials and weld formation after cooling⁽¹⁻²⁾. Conventionally, USW is almost employed to weld the identical materials. But the welds between dissimilar polymers have been appealed to recently.

In this work, for welding polylactide (PLA) and Poly (methyl methacrylate) (PMMA), PLA/PMMA composites are prepared to employ as interposed sheets (IPS) in our proposed USW method⁽³⁻⁴⁾. The effects of injection conditions on the properties of PLA/PMMA composites are investigated.

2. Materials and experimental methods

2.1. Materials

Crystalline polylactide (PLA) and Poly (methyl methacrylate) (PMMA) are used as matrix polymers. Workpieces (WPs) are made using an injection molding machine (FANUC Ltd, ROBOSHOT S2000i 100A) in a half of dumbbell shape (half of JIS1).

2.2. IPS preparation

Besides of the WPs above, the IPS which is need compatibility with the two WPs is also important. The materials of IPS are made by PLA and PMMA blends (PLA/PMMA) according to the injection molding. PLA/PMMA is at first molded as dumbbell (JIS1) with PLA and PMMA at 1:1 volume ratio. The molding conditions are nozzle temperature of 190°C, extrusion rate of 15%, mold temperature of 40°C and cooling time of 30 s. After molding again to modify its thickness to 1mm with the hot-press machine (Imoto Ltd. molding parameters: temperature of 200°C and heating time of 10 minutes), the plastic layers are cut as a rectangle (12×8×1mm³; length × width × thickness) in order to install them on the IPS holder of the apparatus. In the front edge at the middle of the IPS a 3mm diameter hole is drill for fixing in place with a screw.

2.3. Experimental methods

WPs are fixed on the holders of the slide guide, and the IPS is installed on the sheet-holder with the screw. After the IPS is set between the two WPs, the apparatus is turned on and the joints are made (Fig. 1).

2.4. Measurements and characteristics

Tensile strength tests of IPS and WPs are carried out using a universal tester (Instron Model Series 3360) at the crosshead speed of 5mm/min and temperature of 23°C±2°C. The correlation

of the load, deformation and the curve of nominal stress and strain can be calculated, and the breaking stress can also be obtained from the peak load. The rupture surfaces before and after tensile tests are observed using a scanning electron microscope (SEM; Hitachi, Model S-4300) to analyze the relation between interfacial morphology and strength. Before the SEM observations, specimens have a Pt and Au coating on surface. The FT IR test and TG test are all carried out in order to investigate the properties of the composites.

Fig.1 Novel USW principle schematic drawing

3. Results and discussion

3.1. Mechanical properties

Fig.2 Nominal strains versus tensile strengths of matrix polymers and composites

According to the curves, we can see that the strains are all at about 10% except ones of the composite with 40% and 50% content of PLA. Specifically, strain of composite with 50% PLA is dramatically enhanced to about 180%. The yield strengths of PLA and PMMA are 58MPa and 61MPa, respectively, and the nominal strains of these two matrixes are all about 10%, showing only a brittle characteristic compared with the ductile PLA/PMMA. It is indicated that the strength and plasticity of the composite have been much enhanced compared with the matrix polymers. Specially, composite of 50% PLA shows the optimum strength and plasticity, which is very helpful to relax the residual stresses.

3.2. Effects of injection speed on the tensile strengths

Fig.3 plots of tensile strengths versus injection speed of the PLA/PMMA composites (50% of PLA). Tensile strengths decrease as the injection speeds increasing. We can also see that the reducing ratios of the strengths are 7.8% for the injection temperature 190°C, 7.2% for 215°C and 4.6% for 240°C. It is suggested that the injection speeds give small effects on the tensile strengths.

Fig.3 Effects of injection speeds on the tensile strengths of the PLA/PMMA composites (Vol. 50% of PLA)

According to our previous work⁽⁵⁾, three types of layers, which are skin, intermediate and core layer, are always found in the injection specimens. Usually, mechanical properties of injection specimens are influenced by the intermediate layer, whose degree of molecular orientation and hardness are higher than those of other layers. So the strengths are dependent mostly on the thickness of the intermediate layer. Therefore, the decrease of intermediate layers weakens the strengths.

3.3. Interfacial structures and mechanism

Fig.4 Rupture surfaces of PLA (a) and PLA/PMMA (1:1) composites (b).

The rupture surfaces of PLA and PLA/PMMA (1:1) composites are showing in Fig.4. From the SEM photos we can see that the two materials are very compatible, there is no phase separation. Compared with the photo of PLA, there are large plastic deformations in PLA/PMMA composites, resulting into better plasticity. Moreover, the ductile characteristic of the composite can also be observed compared with brittle PLA.

3.4. Weld properties

We have studied the effects on the welding strengths with different welding times and welding stresses, and the results are shown in Fig.5 and Fig.6. From the curves in Fig.5 we can see that the welding strength is increasing first and decreasing afterwards with welding time prolonging. The peak welding strength of 45MPa can be obtained at the welding time of 4s. Then the

welding strength decreases as the welding time increase. That is to say, the optimum welding time is 4s and in these conditions the maximum welding strength can be obtained.

Fig.5 Welding strengths versus welding times when welding stress is 0.6MPa

Fig.6 Welding strengths versus welding stresses when welding time is 4s

Effects of welding stress on welding strength are shown in Fig.6. From the curves we can see that welding strength is enhanced as the welding stresses increase. But when the welding stresses are small, the welding strengths enhance large. From stress of 0.4MPa, the strengths enhance smaller and tend to steady. That is suggested that weld stress of 0.4MPa may be enough for weld. Further, the highest strength in our test is about 52MPa when stress is 0.6MPa and time is 4s.

4. Conclusions

We used PLA/PMMA blends as the IPS to achieve welds between the dissimilar materials PLA and PMMA. The effects of injection conditions and other properties of PLA and PMMA composites are studied. PLA/PMMA blends are valid to employ as IPS according to its better mechanical and thermal properties.

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References

1. An Chao-Chyun, Chen. Ren-Haw, The experimental study on the defects occurrence of SL mold in injection molding, *J. Mater. Process Technol.*, (2008), p706-709.
2. Wang, X. C., Sanchez, Isaac C., Welding immiscible polymers with a supercritical fluid, *Langmuir*, (2007), p12192
3. Qiu J.H., Wu Y., Japan Patent pending, (2007), 2007-156866.
4. Qiu J.H., Zhang, G., Wu Y., Proposal of ultrasonic welding technique and weld performances applied to polymers, *Polym. Eng. Sci.*, (2009), p1755
5. Qiu, J.H., Takahata H., Huang Y.D., Pan Y.B., The Relationship between Interfacial Structure and Welding Strength of Hot Plate Welding Crystalline Polymer, *Kobunshi Ronbunshu*, (2008), p235