Effects of Water Absorption on Impact Value of Aluminum Dispersed Composite Nylon6

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Composite polymers, which are nylon6 materials with aluminum powders dispersed homogeneously, are prepared. Influences of water absorption on Charpy impact value of composite polymers have been investigated. Although the aluminum dispersion from zero to 40 vol%Al decreases the impact value, the water absorbing treatment for $10^5$ s at boiling point largely increases the impact values of all composite polymers. It is explained that water molecules in nylon6 mainly relaxes the impact force. If the water absorption also enhances the interfacial energy to form the crack in nylon6 and its composites, the high impact value with smooth undulating surface can be explained.

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1. Introduction

Industrial waste is one of the serious environmental problems, currently. As a solution, the injection process of composite materials with high volume fraction of dispersed particles of industrial waste has been suggested. When I utilize building scrap by this new composite material, it is effective to solve the environmental problem.

Polymer materials are useful substances with lightweight, ductility, low cost and high productivity.1–3) The cheap composite polymer dispersed by metal powders often feels like heavy and cold such as metals.4) Namely, the mixing metal powders in polymer often induce an attractive image to make practical use of articles for new markets.

The most important point is how to increase the volume of scrap in polymer. To increase the volume fraction of scrap in polymer, a new injection molding with homogeneous distribution of particles has been developed.5) The most attractive point of the injection-molding machine is the preparation method for the metal particles dispersed composite polymer, because the volume ratio of metal-particles in nylon6 is more than 80 mass%. Thus, it is possible to make practical uses of various articles with different combinations of the composite polymers. The composite polymer prepared by the injection machine has been applied to exterior articles, which is often existed outside of buildings. The mechanical property, especially impact brittleness, is also a serious problem to make a practical use of the exterior articles. However, the water absorption softens the polymers. In order to evaluate the brittleness and to clear the serious problems of many demands from various markets with high quality controlling, the fundamental data related to impact value has been expected.

Influences of water absorption on Charpy impact value for aluminum (Al) powders dispersed composite polymers have been investigated.

2. Experimental Procedure

2.1 Sample

The composite polymer was homogeneously mixed with nylon6 powders (UNITIKA, Ltd., A1030JR) and Al powder. Thereafter, drying was performed for 10 hours at 363 K. The specimen, which shape was JIS K7111, was molded at 533 K after melting. The molten polymer was injected into the die, which temperature was 323 K by injection molding machine equipped with mixing screw (TKK Co., Ltd., mold locking force 980.7 kN). The dispersed volume ratios of Al powders in nylon6 were 10, 20, 30 and 40 vol%Al. Average diameter of Al particle size was 28.8 μm. Figure 1 shows Charpy specimen.

The sample size was 10 mm in width, 80 mm in length and 4 mm in thickness. The V notch in sample was precisely formed. The size of the V notch is 2 mm.

2.2 Mass measurement for water absorption

Water absorption into composite nylon6 was performed for $10^5$ s at 373 K. Mass measurement time was 0 s, $10^2$, $2 \times 10^2$, 5 × $10^2$, $10^3$, $2 \times 10^3$, 5 × $10^3$, $10^4$, $2 \times 10^4$, 5 × $10^4$, and $10^5$. The water absorption ratio was expressed by the following eq. (1).

$$C = \frac{(m_1 - m_0)}{m_0} \times 100$$  (1)

Here, $C$, $m_0$ and $m_1$ were water absorption ratio (%), mass values before and after water absorption, respectively.

2.3 Charpy impact test

To evaluate the impact fracture toughness,5,6) the Charpy impact values of the composite polymer were measured using

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a standard impact fracture energy measurement system (JIS K7111). The Charpy impact value was expressed by the following eq. (2). By this measurement, a simple revision method for energy is used at the time of the Charpy impact. Since this method corrects an energy loss, the absorption energy is directly calculated by using the simple blank test angle $\alpha'$.

$$ E = WR[(\cos \beta - \cos \alpha) - (\cos \alpha' - \cos \alpha)(\alpha + \beta/\alpha + \alpha')] $$  \hspace{1cm} (2)

Here, $E$, $W$, $R$, $\beta$, $\alpha$ and $\alpha'$ were impact fracture energy (kJ), hammer weight (N), length (m) of hammer weight point from rolling center, start angle before impact, the maximum angle after impact and the maximum angle of the blank test, respectively. The Charpy impact value (kJ·m$^{-2}$) was expressed by the following eq. (3). Charpy specimen

$$ a_{uc} = (E/b_N)/t \times 10^3 $$  \hspace{1cm} (3)

Here, $E$, $b_N$ ($= 8$ mm) and $t$ ($= 4$ mm) were impact fracture energy (J), sample width (mm) and span distance (sample thickness, mm), respectively. The distance between supporting points was 60 mm.

### 2.4 Change in fracture morphology

The fracture surface morphology of composite polymers (0, 10 and 40 vol%Al powders in nylon6) before and after water absorption was observed by using the scanning electron microscope (SEM: S-3200N, HITACHI). To observe the fracture surface, the samples have been coated for 60 s by Au-Pd alloy.

### 3. Results

#### 3.1 Mass increase by water absorption

Figure 2 shows changes in water absorption ratio against water absorption time in composite nylon6 dispersed at each volume% of Al powders. As a result, all samples confirmed water absorption and became to be approximately saturated at $10^5$ s of water absorption time.

Figure 3 shows changes in water absorption ratio at $10^5$ s of treated time against dispersed volume from 0 to 40 vol% of dispersed Al powders in nylon6. It is confirmed that the water absorption ratio decrease when powder mass increases.

#### 3.2 Impact value improvement by water absorption

Figure 4 shows changes in Charpy impact value of composite polymers before and water absorption for $10^5$ s against volume change from 0 to 40 vol% of dispersed Al powders in nylon6. It is investigated that the water absorption ratio decrease when powder mass increases.
for $10^5$ s at boiling point largely increases the impact values of all composite polymers.

### 3.3 Change in fracture morphology by water absorption

The fracture surface of the sample has been observed by SEM. Figure 5 shows SEM photographs of water absorbed composite polymers (0, 10 and 40 vol% Al powders in nylon6), together with the composite polymers before water absorption. The peculiar undulating surface photographs are observed on the impact fractured surface of nylon6 samples with and without water absorption.

Furthermore, the water absorption confirmed that macroscopic local deformation with smooth undulating surface could be observed in the nylon6.

Although the water absorbed composite samples also exhibit smooth undulating surface rather than the dry samples, the Al particles addition generally shows the fine morphology on the fractured surface. Furthermore, the ultra fine patterns with homogeneous roughness are observed on the fractured surface of composite polymer dispersed with 40 vol% Al powders with and without water absorption.

### 4. Discussion

#### 4.1 Reinforcement induced by water absorption

The result of Fig. 3 confirms that the water absorption ratio decreases, when the powder mass increases. Therefore, the amount of nylon6 roughly corresponds to amount of
water absorption. In addition, the water absorption substantially increases the impact value, although volume fraction of the nylon6 is small from the Fig. 4. The impact value of water-absorbed sample of 40 vol% Al dispersed nylon6 corresponds to that of dry sample of 10 vol% Al dispersed nylon6. Therefore, substantial increases of impact value by water absorption and its dependence were discussed.

If the free molecules of residual water essentially cause the impact force relaxation, the results can be explained by the following discussion. Figure 6 shows changes in experimental and estimated mole fraction (M(H\(_2\)O)/M(Nylon6 + Al + H\(_2\)O)) of absorbed water in composite polymers against dispersed volume of Al powders in nylon6. The water treatment time is for 10\(^5\) s at 373 K. (■: experimental value, □: estimated value)

Fig. 6 Changes in experimental and estimated mole fraction (M(H\(_2\)O)/M(Nylon6 + Al + H\(_2\)O)) of absorbed water in composite polymers against dispersed volume of Al powders in nylon6. The water treatment time is for 10\(^5\) s at 373 K. (■: experimental value, □: estimated value)

that water molecules in nylon6 effectively relaxes the impact force.

4.2 Influence of water absorption on impact value of composite nylon6

The interfacial energy (\(\gamma\)) to form crack is strongly correlated to the critical stress intensity parameter (\(K_c\)) to propagate the crack, as expressed by a following equation.

\[
\gamma = (1 - \nu^2)K_c^2/2E
\]

Here, \(\nu\) and \(E\) are poison ratio and Young modulus, respectively. The temperature (\(T/K\)) dependence of critical stress intensity parameter (\(K_c\)) related to fracture toughness is applied to the thermal activation process and is often expressed by a following equation.

\[
K_c = K_e \exp(-T_o/T)
\]

Here, \(T_o\) is constant. As shown in Fig. 5, the macroscopic local deformation photographs with smooth and peculiar undulating surface are observed on the impact fractured surface of composites with and without water absorption. Although the Al particles addition generally fines the morphology on the fractured surface, the water absorption coarsens the morphology of nylon6. As shown in Fig. 4, the water absorbed nylon6 with smooth undulating surface exhibit the high impact values rather than that of the dry nylon6 with peculiar undulating surface.

When the crack with stress intensity tip in nylon6 propagates at room temperature and/or with low strain rate, the crack propagation time is often long enough to select the fractured passes. As a result, the undulating surface in the nylon6 exhibits the peculiar. Namely, since the crack gradually propagates the nylon6 matrix through the fractured passes at different directions, the peculiar undulation surface can be gotten, as shown in Fig. 5.

On the other hand, if fracture with the stress intensive tip occurs at low temperature and/or with high strain rate, the crack propagation time is probably short to select the fractured passes at different directions. Namely, since the impact fracture is dominated by the thermal activation process, it is not easy to turn the crack directions at low temperature and/or with high strain rate. Thus, the fractured area of smooth undulating surface becomes to be small (see Fig. 5).

The larger impact value is required to propagate the crack of water absorbed composites nylon6, as shown in Fig. 4. Namely, the smooth undulating surface of water absorbed composites nylon6 corresponds to their high impact value. The water absorption probably generates the relaxation sites induced by both free and intermolecular bonded water molecules in nylon6. If the water absorption also enhances the interfacial energy to form the crack in nylon6 and its composites, the high impact value with smooth undulating surface can be explained.

5. Conclusion

In summary, composite polymers, which are nylon6 matrix with Al powders dispersed homogeneously, are prepared. To evaluate the mechanical properties of nylon6
polymer with Al powders homogeneously dispersed, the impact value has been obtained. Influences of water absorption on Charpy impact value for composite polymers have been investigated.

(1) As a result, all samples confirmed water absorption and became to be approximately saturated at $10^5$ s of water absorption time. It was confirmed that the water absorption ratio decreases when powder mass increases.

(2) Although the Al powders dispersion from 0 to 40 vol% Al decreases the impact value, the water absorbing treatment for $10^5$ s at boiling point largely increases the impact values of all composite polymers.

(3) It is explained that water molecules in nylon6 mainly relaxes the impact force.

(4) If the water absorption also enhances the interfacial energy to form the crack in nylon6 and its composites, the high impact value with smooth undulating surface can be explained.

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