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Effect of test temperature on fatigue crack propagation in injection molded plate of short-fiber reinforced plastics

Keisuke Tanaka[a]*, Kazuya Oharada[b], Daiki Yamada[b], and Kenichi Shimizu[a]

[a]*Department of Machanical Engineering, Meijo University, Nagoya 468-8502, Japan*
[b]*Graduate School, Meijo University, Nagoya 468-8502, japan*

Abstract

The crack propagation behavior was studied at 298K (RT), 343K, 373K, and 403K with center-notched specimens which were cut from an injection-molded plates of short carbon-fiber reinforced PPS at two fiber angles relative to the loading direction, *i.e.* θ = 0° (MD) and 90° (TD). Macroscopic crack propagation path was nearly perpendicular to the loading axis for both MD and TD. Microscopically, cracks in MD were blocked by fibers, circumvented fibers, and rarely broke fibers, showing zigzag path. For TD, the crack path was less tortuous following the fiber interface. The relation between crack propagation rate, *da/dN*, and stress intensity factor range, ΔK, at RT and 373K were similar for both MD and TD, while *da/dN* at temperatures above glass transition temperature, T_g (=360K), were two to three orders higher than that at temperatures below T_g. When compared at each temperature, *da/dN* was two orders lower in MD than in TD. At temperatures above T_g, inelastic deformation took place; the relation between load and displacement became nonlinear, accompanied by hysteresis loop expansion. When *da/dN* was correlated to the *J*-integral range, ΔJ, *da/dN* at four temperatures came closer for each case of MD and TD. Especially for the case of TD, the relations at four temperatures merge together. When compared at each temperature, *da/dN* of MD was lower than that of TD, even though the difference between MD and TD was smaller. According to SEM observation of fatigue fracture surfaces, many fibers were pulled out from the matrix on fatigue fracture surface of the skin layer of MD, and parallel fibers were observed on the fracture surface of TD. High temperature environment increased matrix deformation both in MD and TD, but did not change the fracture path or the micromechanism of fatigue crack propagation.

Keywords: Fatigue crack propagation, Fracture mechanics, Short-fiber reinforced plastics, Fiber orientation, Tempearture effect, *J*-integral range

* Corresponding author. Tel.: +81 52 832 1151; fax: +81 52 832 1235.
E-mail address: ktanaka@meijo-u.ac.jp

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1. Introduction

Short-fiber reinforced plastics (SFRP) are expected to be used more widely in order to reduce the weight of vehicles such as automobiles. The injection molding process makes the production of SFRP components more economical and at higher rates. Their applications in fatigue-sensitive components are steadily increasing in automobile industries. The propagation behavior of fatigue cracks is highly anisotropic, depending on the fiber orientation produced by injection molding. The crack propagation rate perpendicular to aligned fibers is much slower than that parallel to fibers when compared at the same stress intensity range. Energy release rate (Wyzgoski and Novak, 1990) and crack-tip opening parameter (Akiniwa et al., 1992, Tanaka et al., 2014, 2015) have been proposed as a controlling parameter for crack propagation. To apply SFRP to engine components, the influence of high temperature environment on fatigue properties need to be explored.

In the present paper, the effect of high temperature on the fatigue crack propagation behavior was studied with center cracked specimens of PPS (polyphenylene sulfide) reinforced with carbon fibers by 30wt%. Specimens were cut from injection-molded plates of 1mm in thickness at three angles of the loading axis relative to the molding flow direction, i.e. θ=0°(MD) and 90°(TD). The glass transition temperature, T_g, of SFRP was 360K. The crack propagation behavior was investigated at four temperatures of 298K (RT), 343K, 373K and 403K. The crack propagation rate is correlated to the stress intensity range and the J-integral range. The J-integral range was used to take into account of inelastic deformation at high temperatures.

2. Experimental procedure

2.1. Material and specimen

The experimental material is thermoplastics, PPS, reinforced with carbon fibers. Fatigue specimens were cut from an injection-molded plate (IMP) with the in-plane dimensions of 80×80 mm and the thickness of 1 mm. Figure 1 shows the shape of test specimens which has a center notch of length 6 mm. The regions of length 15 mm at both ends were used for chucking to the testing machines through aluminium tabs. The angle between the molding direction and the longitudinal direction of specimens was set to be two values: θ = 0° (MD) and 90° (TD). IMP has a three-layer structure where two shell layers sandwich the core layer. The thickness of the core layer of the present plates was about 0.16 mm, which is 15% of the plate thickness (Tanaka et al., 2014). The crack propagation behavior will be controlled by the shell layer. The fiber direction on the shell layer of injection-molded plates is nearly along the molding flow direction, and that of the core layer is perpendicular. The angle θ means the angle between the fiber direction in the shell layer and the loading axis.

2.2. Fatigue crack propagation tests

Fatigue crack propagation tests were performed with a tension-compression electro-servo-hydraulic testing machine. Fatigue testing was done in air at four temperatures, RT, 343K, 373K and 403K, under load-controlled conditions with the stress ratio R of 0.1. The waveform of the cyclic load was triangular and the frequency was 4 Hz. Table 1 indicates the maximum stress adapted for fatigue tests, where the stress is calculated for the cross section of the specimen without notch. Tests were conducted in an environment chamber whose temperature was controlled by circulating air and the fluctuation of the environment temperature was maintained less than 0.5 K. The load-point displacement during fatigue tests was measured by an extensometer, and the relation between load and load-point displacement was recorded by a digital data recorder.

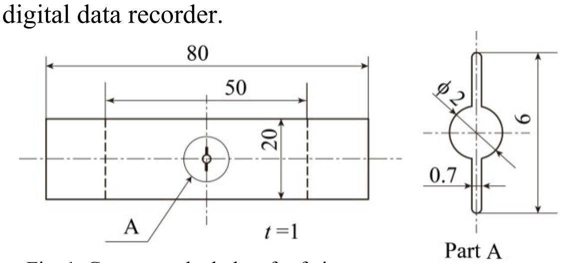

Fig. 1. Center notched plate for fatigue tests.