polymer report

The effect of temperature on the fatigue crack propagation behaviour of cellulose esters

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The fatigue crack propagation (*FCP*) behaviour of a plasticized cellulose acetate-propionate (CAP) was determined as a function of temperature. Changes in *FCP* behaviour with temperature were analogous to changes produced by varying plasticizer concentration. A temperature–plasticizer concentration equivalence based on their effect on yield strength was proposed to predict the *FCP* behaviour of CAP over limited plasticizer concentration and temperature ranges.

(Keywords: cellulose acetate–propionate; craze; shear yielding)

INTRODUCTION

The effect of plasticizer concentration on the fatigue crack propagation (*FCP*) behaviour of cellulose acetate-propionate (CAP) was reported in a previous study[1]. Two *FCP* mechanisms were identified: a crazing mechanism which dominated at low values of stress intensity factor range, ΔK, and a plane strain shear yielding mechanism which dominated at high values of ΔK. Interestingly, the value of ΔK at the onset of the transition from the crazing mechanism to the shear yielding mechanism was found to increase with decreasing plasticizer concentration. In general, it is known that the mechanical properties of plasticized cellulose esters are a strong function of plasticizer concentration and type[2]. Indeed, in the prior study[1], the yield strength of CAP decreased from 46.3 MPa at a plasticizer concentration of 6.3 wt% to 31.4 MPa at a plasticizer concentration of 14.2 wt%.

It is well known that the yield strength of plastics decreases with increasing temperature[3]. Therefore, it would be useful to determine whether the *FCP* behaviour of plasticized CAP is affected by temperature in the same manner as it is affected by plasticizer concentration. If so, such a temperature–plasticizer concentration equivalence could be used to predict the *FCP* behaviour of plasticized CAP.

EXPERIMENTAL

The CAP used in this study was a product of Eastman Chemical Company, Kingsport, TN, USA. The degrees of esterification (number of groups per glucose residue) for propionate, acetate and hydroxy were 2.65, 0.1 and 0.25, respectively. The CAP contained 8.8 wt% dioctyl adipate plasticizer and will be designated CAP9.

Compact tension specimens were machined from 6.2 mm thick injection-moulded plaques. *FCP* tests were performed on an MTS closed-loop servohydraulic testing machine using a sinusoidal waveform with a frequency of 1 Hz and a minimum-to-maximum load ratio of 0.1. Details of the sample preparation and *FCP* testing procedure were reported previously[1]. The *FCP* tests were conducted in a Thermotron environmental chamber and the temperature was controlled with a Barber–Colman 560 Series Microprocessor Controller to within ±1°C. Yield strength, σ_y, was measured using ASTM Standard D638 tensile bars and a crosshead speed of 50 mm min^{-1}.

RESULTS AND DISCUSSION

The effect of temperature on the yield strength of CAP9 is shown in *Figure 1*. Yield strength varies linearly with temperature, T, according to the relation:

$$\sigma_y = 53.7 - 0.54T$$

In addition, yield strength values at 23°C for polymers containing 14.2 (CAP14), 12.1 (CAP12), 8.8 (CAP9), and

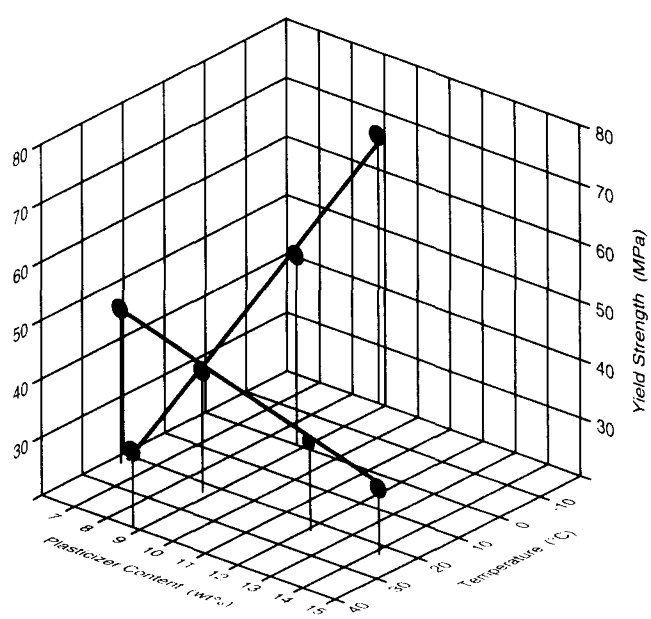

Figure 1 The effect of temperature and plasticizer concentration on the yield strength of CAP

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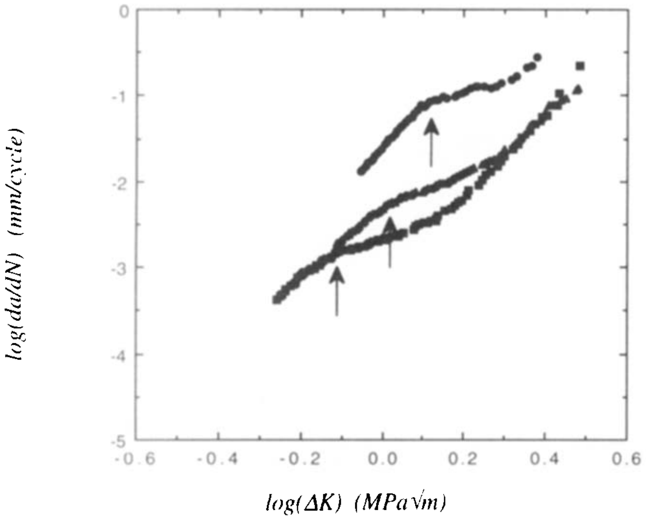

Figure 2 Log–log plot of d*a*/d*N* *versus* ΔK for CAP9 at 13°C (●), 23°C (▲) and 35°C (■). Arrows indicate the onset of the transition regime

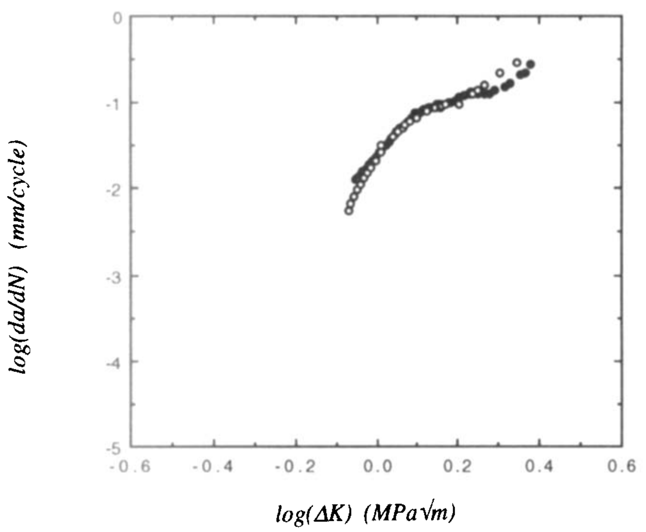

Figure 3 Log–log plot of d*a*/d*N* *versus* ΔK for CAP6 at 23°C (○) and CAP9 at 13°C (●)

6.3 (CAP6) wt% plasticizer, taken from the prior report[1], are also shown in *Figure 1*. These values vary linearly with plasticizer concentration, P_z, according to the relation:

$$\sigma_y = 58.2 - 1.92P_z$$

FCP tests were performed on CAP9 at 13 and 35°C. These temperatures were selected because the yield strength of CAP9 at 13°C is identical to the yield strength of CAP6 at 23°C, and the yield strength of CAP9 at 35°C is identical to the yield strength of CAP12 at 23°C. A log–log plot of fatigue crack growth rate, d*a*/d*N*, *versus* ΔK is shown in *Figure 2*. Each curve begins with a linear regime at low ΔK, followed by a curved transition regime, and another linear regime at high ΔK. The transition regime is a result of a change in fatigue crack growth mechanism from a crazing mechanism to a plane strain shear yielding mechanism[1]. It is clear from *Figure 2* that the value of ΔK at the onset of the transition regime

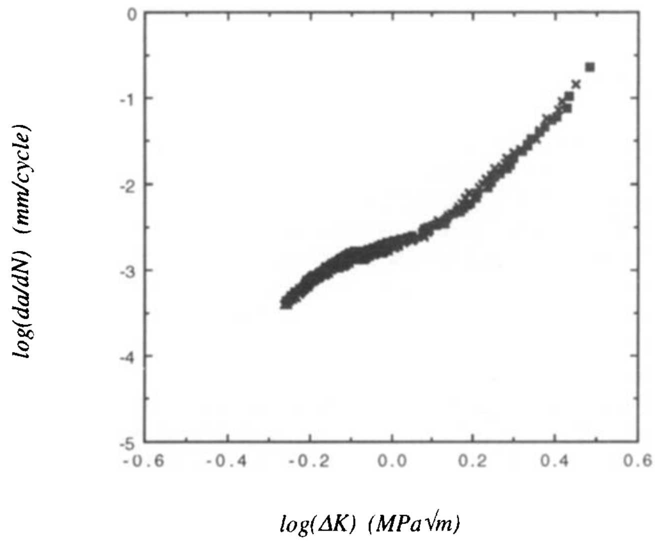

Figure 4 Log–log plot of d*a*/d*N* *versus* ΔK for CAP12 at 23°C (×) and CAP9 at 35°C (■)

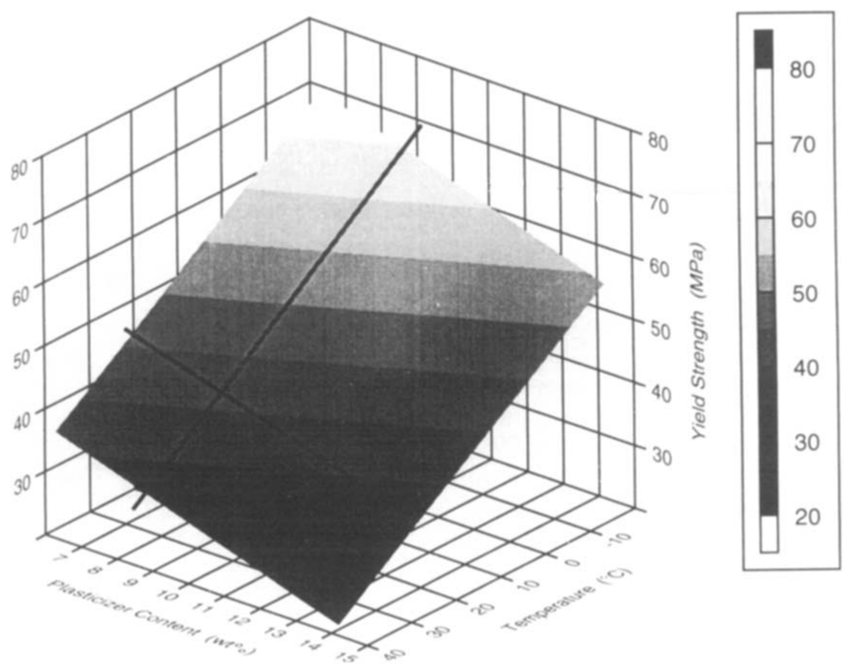

Figure 5 Iso-yield strength regions as a function of temperature and plasticizer concentration

increases with decreasing temperature. The *FCP* data for CAP9, recorded at 13°C, are compared to the *FCP* data for CAP6, recorded at 23°C, in *Figure 3*. The agreement between the two sets of data is excellent. The *FCP* data for CAP9, recorded at 35°C, are compared to the *FCP* data for CAP12, recorded at 23°C, in *Figure 4*. Once again, the agreement between the two sets of data is excellent.

These results strongly suggest that yield strength dictates the value of ΔK at which the transition in fatigue crack growth mechanism occurs. An equivalence exists between plasticizer concentration and temperature through their effects on yield strength of CAP. The plane defined by the intersection of the two straight lines in *Figure 1* is given by:

$$0.54T + 1.92P_z + \sigma_y - 70.57 = 0$$

and is shown in *Figure 5*. The iso-yield strength regions show combinations of temperature and plasticizer concentration that will give the same *FCP* response. Thus, the *FCP* behaviour of a plasticized CAP at any temperature can be predicted from the *FCP* behaviour of a plasticized CAP containing an 'equivalent' plasticizer concentration at room temperature, eliminating the need to perform *FCP* tests under non-ambient conditions.

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