Effect of Notches and Glass Fiber Reinforcement on Fatigue Behavior of Polycarbonate

TOSHIKAZU MISAKI and JUNJI KISHI, *Osaka Prefectural Industrial Research Institute, Takaida-naka, Higashi-Osaka, 577 Japan*

Synopsis

In order to investigate the effect of a notch on the tensile properties of polycarbonate and 30% glass fiber-reinforced polycarbonate, two types of notched specimens were prepared. These notches were a sharp 60° notch and a dull notch with rounded tip 1.5 mm in radius at the base of the 60° notch. The notches decreased the tensile strength of polycarbonate. The sharp notch reduced tensile strength more effectively than the dull notch. In 30% glass fiber-reinforced polycarbonate, even the dull notch decreased the tensile strength considerably. Unnotched polycarbonate was subjected to cyclic tensile loading of 10^4 cycles at 10 Hz, with varying cyclic stress. It was found that the elongation at break decreased rapidly with increase in cyclic stress. The notches considerably decreased the tensile fatigue strengths of polycarbonate and glass fiber-reinforced polycarbonate in 10^4 cycles at 10 Hz.

INTRODUCTION

Polycarbonate and short glass fiber-reinforced polycarbonate have high mechanical strengths and good durabilities under various environments and a wide range of applicabilities to engineering purposes. However, little is known about the fatigue behavior of polycarbonate and glass fiber-reinforced polycarbonate in the presence of a notch.[1] The static tensile strengths of thermoplastics and composites are known to be reduced in the presence of notches or flaws.[2] The extent of decrease in strength was shown to be influenced by the sharpness of the notch and by the stiffness of the material.[2]

In this paper, two types of notched specimens of polycarbonate and glass fiber-reinforced polycarbonate were prepared, and the effects of notches and glass fiber reinforcement on the static and fatigue strengths of these materials were examined. It was found that a sharp notch reduces tensile and fatigue strengths of polycarbonate more effectively than a dull notch. However, in the case of glass fiber-reinforced polycarbonate, even a dull notch reduces the tensile strength remarkably. Notches decrease the fatigue strengths more effectively than the static strengths of these materials. A variation of tensile properties during cyclic tensile loading was also examined.

EXPERIMENTAL

Polycarbonate and 30% glass fiber-reinforced polycarbonate used were Panlite L-1250 and Panlite G-3130 (Teijin Chemical Ltd.), respectively. Figure 1 shows the tensile fatigue specimens, where A is dumbbell shaped, B has a sharp notch of 60°, and C has a rounded tip 1.5 mm in radius at the base of the 60° notch. These specimen shapes were chosen as representatives of unnotched, sharp-notched, and dull-notched specimens, respectively. All these specimens were

Journal of Applied Polymer Science, Vol. 22, 2063–2067 (1978)
 0021-8995/78/0022-2063$01.00

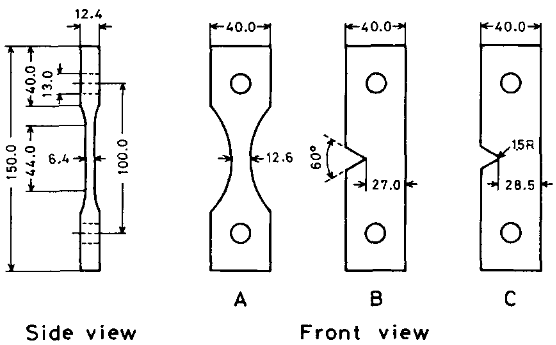

Fig. 1. Test specimens (mm).

obtained through injection molding with longitudinal flow direction. Glass fibers in reinforced specimens were found to be 0.3 mm long on average. The orientations of the glass fibers in the glass fiber-reinforced polycarbonate were determined by means of x-ray transmission photography with Softex Model CMB (Softex Ltd.), followed by 50-fold enlargement of the negative film. It was found that glass fibers were oriented mainly parallel to the surface of the specimen in the flow direction even at the sharp 60° notch tip.

The static tensile strength of a fatigue specimen was measured by an Instron Floor Model 1114 Universal Testing Instrument in an initial grip separation of 7.2 cm, at a cross-head speed of 2 cm/min at 23°C. As the grip surface was 2.5 cm wide while the test specimen was 4.0 cm wide, it was possible to apply the grips only to one side of the width of the specimen at a time, and naturally the load working directly between the grips would be greater than that working along the portion of the specimen not directly held in the grips. With B and C, the two ways of gripping resulted in considerably different values of the tensile strengths. In order to obtain the tensile strength accurately, the widths of B and C were cut to 2.5 cm by a band saw, without changing the ratio of notch depth to specimen width. Specimen A was broken in the middle between grips, while in B and C fracture began at the base of the notch. Polycarbonate specimens A and C showed necking before crack fracture, while B did not. None of the glass fiber-reinforced specimens showed any tendency to ductile failure.

Cyclic tensile loads were applied to the specimen by an Instron Model 1211 Dynamic Cycler under the conditions of load control between 0 and a certain maximum load at 10 Hz, at 23°C. Application of cyclic loads to polycarbonate, generally accompanied by a tiny craze formation at the surface of the specimen, was followed by specimen fracture. We did not investigate the craze formation in detail. However, the crazes appeared at an early stage of the cyclic fatigue.

RESULTS AND DISCUSSION

Table I shows the effect of the notch shape on the tensile strengths of polycarbonate and glass fiber-reinforced polycarbonate. The sharp 60° notch decreased the tensile strength of unnotched polycarbonate to 40%. A rounding of the 60° notch base 1.5 mm in radius improved the tensile strength to 91% of that of the unnotched specimen. The finding that A and C were rather similar

TABLE I
Effect of Notch Shape on Tensile Strength

Material	Tensile strength,[a] kg/mm² A	B	C
Polycarbonate	6.7	2.7 (0.40)	6.1 (0.91)
Reinforced polycarbonate	10.5	3.6 (0.34)	4.4 (0.42)

[a] Value in parentheses indicates the ratio of the strength of the specimen to that of the A specimen.

and B was quite different in tensile strength was found to be in agreement with the fracture behavior, namely, that A and C showed necking while B did not. Thirty per cent glass fiber reinforcement of polycarbonate increased the tensile strength from 6.7 to 10.5 kg/mm^2. In glass fiber-reinforced polycarbonate, C showed rather small tensile strength, near that of B, probably because the glass fiber-reinforced polycarbonate was stiffer than polycarbonate itself. Brittle polymers and composites tend to be more notch sensitive for strength than ductile polymers.[2] Another possibility was as follows. Even at the bases of the sharp and dull notches, glass fibers were observed to be mainly aligned in parallel to the specimen surface. However, some glass fibers might lie perpendicularly to the load direction. Since the stress was larger in the notch base, glass fibers which lay perpendicular to the load direction appeared to play an important role in crack initiation in C.

The fatigue strength was arbitrarily fixed as the stress at which a specimen fractured after cyclic tensile loading of 10^4 cycles, at 10 Hz. The fatigue strength was determined by plotting the maximum tensile stress in each specimen against the number of cycles to fracture, in the range near 10^4 cycles, by trial and error.

Table II shows the effect of notch shape on the fatigue strengths of polycarbonate and glass fiber-reinforced polycarbonate in 10^4 cycles. In the case of polycarbonate, the fatigue strength of the unnotched specimen was found to be 5.4 kg/mm^2, which was above 80% of the tensile strength. The presence of a sharp 60° notch lowered the fatigue strength of polycarbonate to 20% of that of the unnotched specimen. However, a rounding of this notch base 1.5 mm in radius improved the fatigue strength to 43%. In the case of 30% glass fiber-reinforced polycarbonate, the fatigue strengths of B and C were 18% and 30%, respectively, of that of A.

Both types of notches, B and C, lowered the tensile strength as well as the fatigue strength. However, the strength decreases in the presence of notches were about twice as large in the case of fatigue than in static tension.

TABLE II
Effect of Notch Shape on Fatigue Strength[a]

Material	Fatigue strength,[b] kg/mm² A	B	C
Polycarbonate	5.4	1.1 (0.20)	2.3 (0.43)
Reinforced polycarbonate	7.7	1.4 (0.18)	2.3 (0.30)

[a] In 10^4 cycles at 10 Hz.
[b] Value in parentheses indicates the ratio of the strength of the specimen to that of A specimen.

Most fatigue studies of plastic materials have been confined to inquiries into plots of maximum cyclic stress versus number of cycles to failure, and to obtaining fatigue limits.[3] When using plastic materials, it is frequently necessary to know how much fatigue damage they have suffered and how much strength they still possess. Unnotched specimens A of polycarbonate and glass fiber-reinforced polycarbonate were subjected to cyclic tensile loading. The tensile properties of the specimen after loading of 10^4 cycles at 10 Hz were examined for maximum stress.

Figure 2 shows the plots of the tensile strength after loading of 10^4 cycles at 10 Hz versus maximum stress. Polycarbonate did not show any significant variation in tensile strength with increase in cyclic stress. Glass fiber-reinforced polycarbonate showed a small decrease in tensile strength with increase in cyclic stress.

Figure 3 shows plots of elongation at break versus maximum stress. In polycarbonate, the elongation dropped rapidly to a certain value with comparatively low cyclic stress. After this drop, no further significant lowering of this

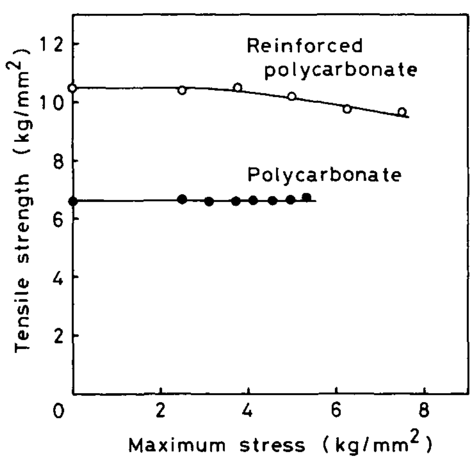

Fig. 2. Tensile strength after cyclic tensile loading of 10^4 cycles at 10 Hz.

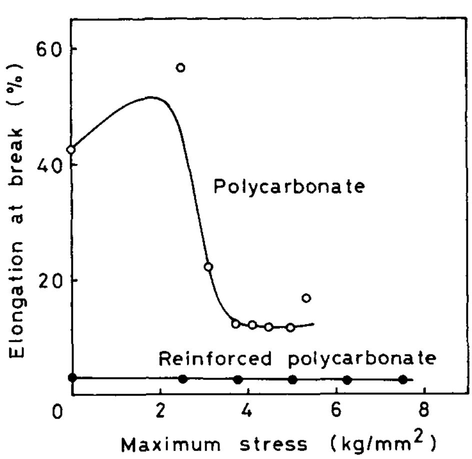

Fig. 3. Elongation at break after cyclic tensile loading of 10^4 cycles at 10 Hz.

value occurred with increase in cyclic stress. In glass fiber-reinforced polycarbonate, elongation was virtually unaltered, though the maximum stress was increased more than 90% of the fatigue strength at 10^4 cycles.

The difference between the fatigue behavior of polycarbonate and glass fiber-reinforced polycarbonate can be explained as follows. In polycarbonate, as a cyclic tensile load was applied, tiny crazes gradually appeared on the surface of the specimen. The crazes increased in number and in scale with increases in cyclic stress and in the number of cycles. As craze formation is known to be essentially a process of plastic deformation in the tensile stress direction,[3] the formation of crazes is bound to affect tensile properties of polycarbonate. Actually, the strength did not change to any significant degree and the elongation at break became small.

In glass fiber-reinforced polycarbonate, cyclic tensile loading affected both craze formation and damage to the glass fiber–polycarbonate interface. Small delamination must have occurred, and a small decrease in tensile strength was observed with increase in cyclic stress. Since glass fiber-reinforced polycarbonate fractured without necking, the elongation at break did not vary significantly. We could not confirm craze formation in glass fiber-reinforced polycarbonate, for lack of transparency of this material.

References

1. J. C. Radon, *J. Polym. Sci., Polym. Chem. Ed.*, **13**, 383 (1975).
2. M. Takano and L. Nielsen, *J. Appl. Polym. Sci.*, **20**, 2193 (1976).
3. R. P. Kambour, *J. Polym. Sci. D*, **7**, 1 (1973).

Received January 27, 1977
Revised February 23, 1977