The Effect of Folding on the Mechanical Properties and Internal Structures of Fibers Used in Ballistic Applications

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[Introduction] The failure of a first responder's soft body armor (SBA) composed of poly (*p*-phenylene benzobisoxazole) (PBO) fibers prompted researchers to assess the long-term durability and effectiveness of current and future SBA products. Based on existing data, suspicion for the failure of this SBA fell on the hydrolytic degradation of the fiber. However, in follow-up ballistic tests, no threat level projectiles passed through a hydrolytically-aged SBA. Therefore, other possible degradation mechanisms such as folding have been considered. In this study, the effects of folding were investigated as one of the possible degradation methods.

[Experimental] Poly (*p*-phenylene terephthalamide) (PPTA) and PBO fibers which are commonly used in SBAs were tested. The folding tests were conducted by using a folding machine reported by Kim et al.[1] which was designed to model the folding that may be experienced in use. A fabric extracted from the SBA was placed in the folding machine and was folded 5,500 times and another fabric was folded 80,000 times. After folding, the changes of mechanical properties and structures were investigated by performing single fiber tensile tests and small-angle X-ray (SAXS) measurements. The single fiber tensile tests were based on ASTM C1557-03 and were conducted with a 60 mm gauge length and a strain rate of 3.33 %/min. In the SAXS measurements, stretched fiber bundles containing approximately 3,000 filaments were used as the specimens. The two-dimensional images of SAXS were taken with an imaging plate. The analyses method reported by Shioya and Takaku[2] were used to calculate the size parameters of the voids from the SAXS data.

[Results and Discussion] As shown in Figure 1, while the PPTA fiber showed little change in the tensile strength upon folding, the tensile strength of PBO fiber decreased significantly as the number of folds increased. At 80,000 folds, the tensile strength, strain-to-failure, and tensile modulus of PBO fiber decreased by 41%, 40%, and 5%, respectively. As shown in Figures 2 and 3, while no signs of structural changes for PPTA fiber were observed by the SAXS techniques, decreases of the average size of the voids and fibrils of the PBO fiber were observed. Note that the error bars refer to one standard deviation. From these results, it can be surmised that the fibrils in the PBO fibers were subdivided when the fibers were folded. This subdivision creates new surfaces inside the fibers, and may influence not only mechanical properties, but also hydrolytic degradation and other failure pathways.

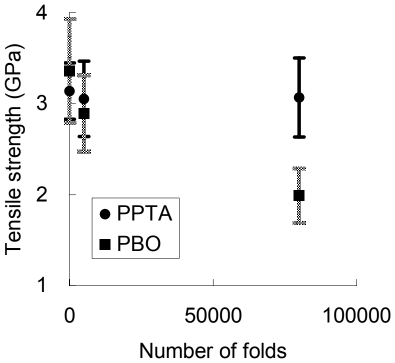

Fig. 1 Tensile strength vs. number of folds.

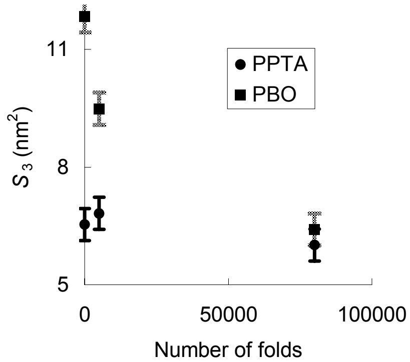

Fig. 2 The average of cross section area of void S_3 vs. number of folds.

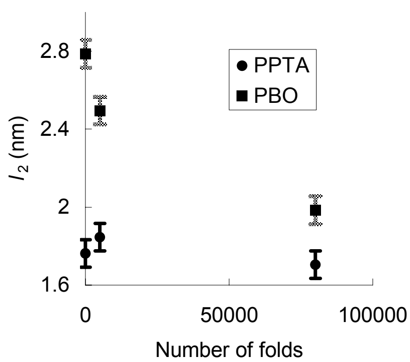

Fig. 3 The average length of segment l_2 vs. number of folds.

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[Reference] [1] Kim, J. H., Brandenburg, N., McDonough, W., Blair, W., Holmes, G.A., *Journal of Applied Mechanics*, **75**(1) (2008).
[2] M. Shioya, A. Takaku, *Journal of Applied Physics* **58** (1985) 4074-4082.

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