POSTER

RELATION OF FIBER CONTACT ARRAYS TO CARBONIZATION SHRINKAGE

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Many C/C laminates are made from carbon-fiber prepregs, usually with a thermosetting resin. The prepregs are stacked, compacted and cured, and then baked to carbonize the matrix. Shrinkage of matrix during its conversion to carbon usually (but not always) results in a decrease of composite volume, sometimes by several percent. The situation is complex, involving not only restraint by the dimensionally-stable fibers, but also the evolution of pyrolysis gases and the potential release of elastic energy stored in the compacted reinforcement array.

For complex shapes, there seems to be an optimization problem: on one hand, higher shrinkage results in reduced porosity and therefore tends to higher composite strengths; on the other hand, higher shrinkage, usually anisotropic, results in higher thermal stresses with attendant risk of in-process damage. Faced with choices in the selection of constituents and processes, we may ask, "What factors determine whether (and in what relative degrees) matrix shrinkage leads to composite shrinkage, composite porosity, microdamage, or composite delamination? and how may these be controlled to our advantage?" Our study of carbonization shrinkage seeks to provide some of the understanding needed to answer such questions.

IMPORTANCE OF FIBER ARRAYS

A unidirectional composite cannot shrink significantly when the fiber array provides a continuous network of contacting cross-sections [1]. Although any fully populated regular array would, at its limiting fiber-volume fraction, provide a contact network, such networks can exist in incompletely populated arrays. Percolation theory [2,3] shows continuous contact paths can exist at volume fractions as low as about 0.45; most carbon-carbons have fiber contents higher than that. At fiber volume fractions less than the close-packing limit, two types of arrays may be imagined: *well-separated* arrays of non-contacting fibers, or *clustered* arrays. To the extent that contact decreases the fiber-matrix surface area, clustering and contact networks would be promoted by poor wetting of fibers by matrix liquid. In [1], it was postulated that well-separated arrays experience greater cross-sectional shrinkage during carbonization. Here, we provide some quantitative corroboration.

IMAGE ANALYSES OF FIBER CLUSTERING

To help quantify clustering of fibers within composite bundles, two measures have been defined. *Fiber-contact density* is the number of fiber-fiber contacts per fiber cross-section. For example, a fiber cross-section in contact with two neighboring cross-sections has a fiber-contact density of two. *Fiber-contact angle* is the angle between the plane of the laminate and the line joining the centroid of a fiber cross-section to the center point of the contact with a neighboring section. A semi-automated computer-aided procedure is applied to digitized SEM images that show fiber cross-sections. An example of the results is shown in Figure 1. We see that fiber-contact density distributions are quite different for the two composites, a result that encourages the use of the method for correlating to shrinkage behaviors

As the fiber array geometry will, on average, be the same on any cross-section through a yarn, the fiber-contact density distribution gives an estimate of the fraction of fiber length that is unsupported by neighboring fibers.

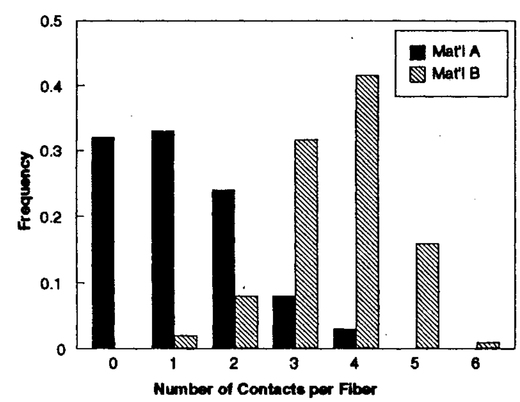

Fig. 1. Histograms for fiber-contact densities of two composites. A: T300/phenolic, with .58 fiber volume fraction; B: T40R/phenolic, with .79 fiber volume.

For example, from the frequency of zero-contact fibers, Material A in Fig. 1 has about 32% of the fiber length unsupported; Material B has virtually no unsupported length. The unsupported length is expected to be a factor relevant to estimating the elastic deformations of the fibrous reinforcements, via models of fiber bending and/or contact deformation.

For the samples measured so far, the fiber-contact-angle distributions appear isotropic. That is, contact angles appear unaffected by compaction direction.

EFFECT OF WETTING

Cross-sections of unidirectional composites made with high-modulus non-surface-treated fibers shrink less, at the same fiber-volume fraction, than do those made with high-strength surface-treated fibers [4,5,6]. The trend is seen also in bi-directional cloth laminates [6].

Samples of the composites studied in [6] were examined in their as-cured condition. The fiber volume fractions of these samples, estimated by point-count and area-fraction analyses of SEM images, were unusually high (approximately 0.78 to 0.80). Thus, the potential effects of surface treatment on fiber-contact density are much attenuated, because such high volume fractions tend to full packing. Nevertheless, as Fig. 2 shows, there is a tendency for the less treated fibers to have higher contact densities, in keeping with the hypothesis advanced earlier. When given the "1.2 treatment", the cross-sectional shrinkage on carbonization was about 3%; with the "0.4 treatment", the laminate expanded about 1% on carbonization [6].

CONCLUDING REMARKS

Composite shrinkage during carbonization is an example of composite behavior that is affected significantly by details of fiber-array geometry (not just the fiber-volume fraction).

Therefore, fiber packing and its effects in carbon-carbon processing are being studied further. Questions being addressed include: How is fiber packing affected by fiber-section shape and size variations? by deviations from fiber parallelism? How can packing be quantified and its effects on shrinkage be modeled? Is carbon-volume yield of matrix affected by packing and fiber content? How important are fiber-fiber contact deformations and stresses? Do contact stresses and deformations influence graphitizability of inter-fiber matrix? How do filler additions affect matrix and composite shrinkage?

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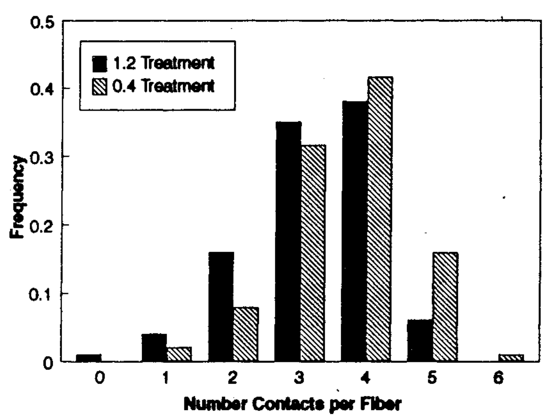

Fig. 2. Fiber contact density distributions for two T40R/phenolic laminates of different surface treatments.