INHERENT DEFECT SIZE: CALCULATION AND USE FOR COMPOSITE MATERIALS

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ABSTRACT
The multi-step production of composite materials tends to increase the number of manufacturing defects. Composite materials considered here contained a variety of structural defects. Stresses induced by structural defects interact with each other during component loading in that the stresses are altered, either beneficially or detrimentally.

The present method proposes a modification to the traditional ASC (Average Stress Criterion, [1]) such that an inherent defect size can be estimated. An inherent defect is defined as the strength-controlling material feature, which need not be physically present but rather represents the structural disorder of the material.

This modified ASC (MASC) was applied to several composite materials including paper, oriented strandboard (OSB), graphite- and glass-epoxy composites, and a non-composite material, a polysilicon film; estimated inherent defect sizes scaled with material characteristics. Sizes ranged from 0.29 μm for a polysilicon film to 1.94 mm for OSB composite. The polysilicon film was included to evaluate the sensitivity of the defect calculation.

INTRODUCTION
In general, the manufacturing of composites involves more manufacturing stages than for other materials. Composite materials made from organic matter include a broad spectrum of fiber dimensions and constitutive behavior. The behavior of composite materials is controlled by variations within both manufacturing and constituent materials.

This research presents a model that estimates inherent defect size of materials by a stress concentration analysis in materials with prepared holes of different radii. An inherent defect is defined as the strength-controlling material feature, which need not be physically present but rather represents the net effect of physical defects within the material. A calculated defect size larger than the characteristic length, the length that transitions between failure controlled by stress intensity to failure controlled by stress concentration, of the material suggests improvements are necessary within the manufacturing process.

Current data comes from the authors’ work and from technical articles in which the effect of a central circular hole on the tensile or compressive strength of a material was measured. Validation of the model was accomplished by comparison with known material length scales.

SUMMARY OF RESEARCH
Whitney and Nuismer [1] proposed two semi-empirical criteria, ASC and PSC (Point Stress Criterion), to characterize the effect of hole size on material tensile strength. The unknown parameter for each model is a material characteristic length. Our investigations suggest that ASC is more robust during nonlinear regression than is PSC; the integration procedure in ASC tends to smooth data. The present concept develops a modified ASC (MASC) that includes the unnotched tensile strength of the material as an additional unknown parameter. By reverse correlation, the MASC is able to estimate an inherent defect size and the defect-free tensile strength of the material.

This MASC was developed by incorporating the solution for the stress distribution in an infinite orthotropic plate under uniaxial tension [2] with the ASC [1] and a finite width correction [3] while assuming the unnotched tensile strength is unknown. MASC is applied here to several materials, including cellulose fiber materials, aerospace-type fiber-matrix composites, and a polysilicon film.

Inherent defect size is related to structural disorder of the materials, such as mass variation in cellulose materials, fiber density/packing in advanced composites, and weave layout in woven composites. The strengths of all materials considered
Table 1 lists evaluated inherent defect sizes for some selected materials and shows the capability of the MASC in elucidating material differences. The first two materials are made from the same glass-fiber epoxy system but with different ply layup. As expected, the \([\pm 45/0]_2\) material had a larger inherent defect than the \([0/90]_2\) material because it did not have any fibers aligned with loading direction. CMC inherent defect size was 0.1 mm and seems reasonable as fiber spacing was \(50-500\ \mu m\). The polysilicon film had grain size \(0.3 \mu m\) in agreement with the inherent defect size. Because the length of structural components with OSB is large (typical strand dimensions are 114–152 mm long, 12.7 mm wide, and 0.6–0.7 mm thick [8]) the large inherent defect size was expected. Both paper materials, linerboard and copy paper, had defect sizes that approximately scaled with their constituent fibers, ~3–4 mm long for linerboard and ~0.7–1.3 mm long for copy paper. Furthermore, MASC determined that inherent defect size was different for each principal orthotropic direction.

**CONCLUSIONS**

The MASC model was successfully used to determine the strength-controlling defect size, defined as the inherent defect, for several composite materials. The model effectively accounts for interactions of the consequences of multiple defects and provides a measure of material heterogeneity caused by manufacturing and constituent materials.

**REFERENCES**


