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Discussion

Discussion: "Computationally Efficient Micromechanical Models for Woven Fabric Composite Elastic Moduli" (Tanov, R., and Tabiei, A., 2001, ASME J. Appl. Mech., 68, pp. 533–560)

Z.-M. Huang
Department of Engineering Mechanics, Tongji University,
1239 Siping Road, Shanghai 200092, P. R. China
e-mail: huangzm@mail.tongji.edu.cn

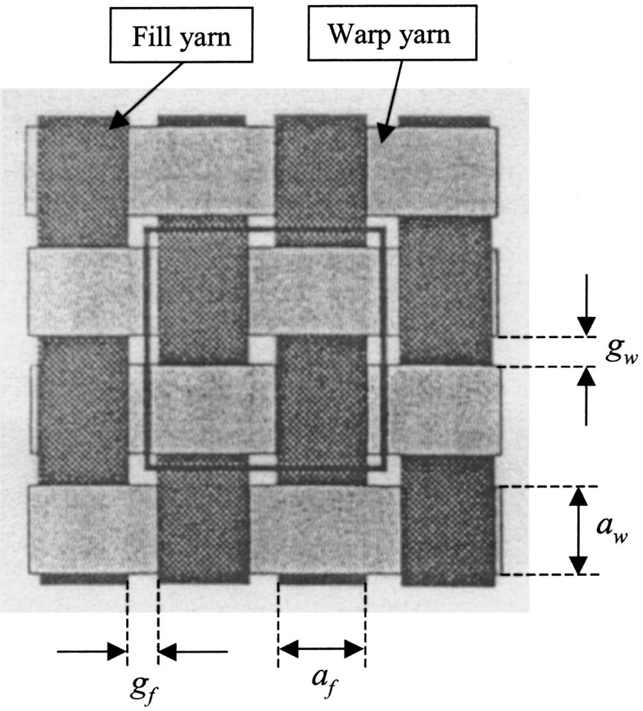

Fig. 1 Schematic of a plain woven fabric

In their paper, Tanov and Tabiei presented two micromechanics-based models to evaluate the elastic moduli of woven fabric reinforced composites. After going through their numerical examples shown in the paper, the present reader has a strong feeling that the accuracy and hence the efficiency of their models is suspect.

The fabric investigated by Tanov and Tabiei is schematically shown in Fig. 1, where a_f and a_w are the fill and warp yarn widths, and g_f and g_w are the inter-yarn gaps between the fill and warp yarns. After the fabric is impregnated with a polymer matrix, the areas in between the inter-yarn gaps have no reinforcement. Namely, they become pure matrix regions in the woven composite. Apparently, these pure matrix regions can significantly reduce the overall stiffness and strength of the woven composite. The amount of reduction depends on the gap-yarn ratios g_f/a_f and g_w/a_w. It has been shown by this author (see [1]) that when the gap-yarn ratio g/a (supposing $g_f/a_f=g_w/a_w=g/a$) is only 4%, a reduction of as high as 22% in the in-plane elongation modulus can be recognized. The larger the gap-yarn ratio, the lower the in-plane modulus of the resulting woven composite. Therefore, in order to achieve as high a mechanical performance as possible, the woven composites have been generally fabricated with as small (if not zero) inter-yarn gaps as possible.

However, the three examples of woven fabric reinforced epoxy (with modulus between 3.45 to 4.51 GPa) matrix composites investigated by Tanov and Tabiei were all assumed to have very large gap-yarn ratios (using the term of Ref. [2], the gap-yarn ratio was given by $(1-V_y)/V_y$, see Fig. 1 and Fig. 2 of Ref. [2]), being 85.7%, 284.6%, and 72.4%, respectively. From the input data of the yarns, epoxy matrices, and the yarn volume fractions provided in Ref. [2], we can easily estimate the maximum possible in-plane moduli for the three woven composites without any inter-yarn gaps, which are given by those of the corresponding cross-plied laminates [0 deg/90 deg]. The estimation for the properties of the unidirectional (0 deg) lamina is made based on the bridging micromechanics model (Ref. [3], with bridging parameters $\beta=0.35$ and $\alpha=0.45$) by assuming that it is fabricated from the yarn (fiber) and the matrix with the given yarn (fiber) volume fraction. The classical lamination theory is then applied to obtain the in-plane modulus of the cross-plied laminate. The maximum possible in-plane moduli for the three woven composites thus obtained are: 18.21 GPa, 11.77 GPa, and 45.1 GPa, respectively. In light of the fact reported in Ref. [1] that a 50% gap-yarn ratio would cause nearly 300% reduction in the in-plane modulus of a woven composite, the predicted moduli of the woven composites with the aforementioned very large gap-yarn ratios, i.e., 17.85 GPa, 11.86 GPa, and 45.08 GPa from Tanov and Tabiei's four-cell model, or 18.21 GPa, 11.93 GPa, and 45.17 GPa from their single-cell model, would be hardly possible.

References

[1] Huang, Z. M., 2000, "The Mechanical Properties of Composites Reinforced With Woven and Braided Fabrics," Compos. Sci. Technol., **60**, pp. 479–498.
[2] Tanov, R., and Tabiei, A., 2001, "Computationally Efficient Micromechanical Models for Woven Fabric Composite Elastic Moduli," ASME J. Appl. Mech., **68**, pp. 553–560.
[3] Huang, Z. M., 2001, "Simulation of the Mechanical Properties of Fibrous Composites by the Bridging Micromechanics Model," Composites, **A32**, No. 2, pp. 143–172.

Closure to "Discussion of 'Computationally Efficient Micromechanical Models for Woven Fabric Composite Elastic Moduli' " (2002, ASME J. Appl. Mech., 69, p. 867)

R. Tanov[1]

A. Tabiei
Associate Professor and Director

Center for Excellence in DYNA3D Analysis, Department of Aerospace Engineering and Engineering Mechanics, University of Cincinnati, Cincinnati, OH 45221-0070

It is with great embarrassment and humiliation that we write these lines. We, the authors of the above paper, do strongly believe that truth is born through doubt and dispute. However, we were very disappointed to read the "Discussion of 'Computationally Efficient Micromechanical Models for Woven Fabric Composite Elastic Moduli by R. Tanov and A. Tabiei (*J. Appl. Mech.*, **68**, pp. 553–560, 2001)' " by Zheng-Ming Huang. We do not believe that raising trivial questions in front of a large audience as the readers of this journal would contribute in any way to science in general, and computational mechanics in particular. We think that the normal and less embarrassing for both sides way to address such issues is through personal communication, but since this did not happen we see these lines as our only opportunity to defend our work. As much as we want to say, replying to the above discussion, we will limit our response to only pointing the answers to the questions therein raised. We apologize for trying to explain what we think is obvious and trivial and what the reader might have already deduced if reading the referenced lines.

In his writing Huang is questioning the accuracy and therefore the applicability of our work on composites micromechanics, published in this journal. Needless to say, in developing this work we ourselves have gone through a long and rigorous process of questioning, testing, and comparing, to get enough confidence in the presented approaches and their assumptions and formulations. To illustrate that, we have compared our results to previously published data from theoretical, finite element, and experimental studies. However, the author of the above discussion felt that the data presented in our work is "hardly possible" based on his notions for woven composites. He has tried to illustrate his point by first using a micromechanics-based homogenization scheme to determine the values of the moduli presented by us. The values he has come up with, come within a reasonable proximity to our results. However, after determining these values, he further references a woven composite "parameter," which he calls "gap-yarn ratio," and based on which he claims that the above calculated moduli should additionally undergo a "nearly 300% reduction." If the reader is to read Ref. [1] of his discussion he would immediately recognize that what is referenced there as "gap-yarn ratio" is just a different way of expressing the composite yarn volume fraction, the ratio of the volume of the yarns to the volume of the entire composite layer. By homogenizing the composite constituent yarns and matrix in his initial calculations Huang has already taken into consideration this ratio. In this process he, as most micromechanical approaches including ours do, has arrived to a fictitious continuous and homogeneous composite layer. The continuity and homogeneity of this layer would, of course, imply no gaps within it, whatsoever. However, Huang has failed to recognize that by claiming that due to gaps in the initial yarn periodic arrangement the properties should further be significantly reduced. At this point of the analysis, after the homogenization is complete, there is no yarn, no matrix, no gaps, but only one continuous and homogeneous layer, which, to repeat yet again, excludes the presence of any gaps. These gaps, used as basis for Huang's suspect in our work, make his claims incorrect and ungrounded. Another proof of which is that he failed to determine any definite value of the parameters he states as inaccurate apart from that "nearly 300% reduction," which even from a strictly arithmetical point of view makes no sense whatsoever.

We would hereby like to thank the Editor of the *Journal of Applied Mechanics* for the provided opportunity to defend our work. And finally, we would like to again express our confidence in the methods in subject that we have previously developed and published.

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[1] Presently at IMMI, Westfield, IN.