Effect of Surface Roughness and Fiber-Volume Fraction Variation on Strain Measurements

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Abstract

Variability in material properties is a well-known difficulty encountered when dealing with carbon fiber reinforced polymer (CFRP) composites and is of interest to the Fertig Research Group. Digital image correlation (DIC) is used by the group in order to measure 2-D strain fields on the surface of CFRP specimens. In the course of testing, strain bands, areas with higher or lower strain than expected, were observed. This project focused on possible explanations for this observation. Two possible causes were analyzed using finite element analysis (FEA) techniques. The effect of both thickness variation and variations in fiber-volume fraction (FVF) in the specimen were examined. Data on the degree of variation of both thickness and FVF in various specimens was obtained using a ROMER measurement device and computer analysis of images obtained through digital microscopy, respectively. Analyzing FEA models built using the gathered data yielded similar results in both cases. Both models exhibited strain bands very similar to those obtained using DIC. These results represent a step toward understanding the effects of minor variation in both thickness and FVF on strain, and therefore stress, in CFRPs.

Background

Carbon fiber reinforced polymer composites are highly desirable for a number of engineering applications ranging from aeronautics and the wind energy industry to sporting goods products. The primary attraction of CFRPs is their high strength-to-weight ratio. However, anisotropic material behavior of CFRPs is somewhat difficult to predict, as is long term durability. Unpredictability in material properties necessitates the use of large factors of safety, which in turn defeats the purpose of using a material with high strength-to-weight ratio. This is undesirable and drives research to better understand and quantify material property variation. Two examples of macroscopic variation are variations in composite thickness and variations in fiber-volume fraction.

Thickness Variation

The first form of variation examined was thickness variation. This originated primarily from uneven distribution of fibers in the pre-impregnated composite used. It was suspected that thickness variation was the cause of "strain bands" observed in data, shown in Figure 1, obtained via digital image correlation, a form of optical strain measurement. A ROMER measurement device was used to obtain data on the amount of thickness variation and was quantified using Fourier analysis. Finite element analysis, a powerful and highly accurate computer modeling technique, was used to model a small portion of a test specimen displaying thickness variation. The results of the model are shown in Figure 2. Note that the pattern of strain bands is similar to that seen in Figure 1. It is apparent that the usual assumption of orthotropic material properties is highly suspect if any sort of thickness variation is present in the specimen.

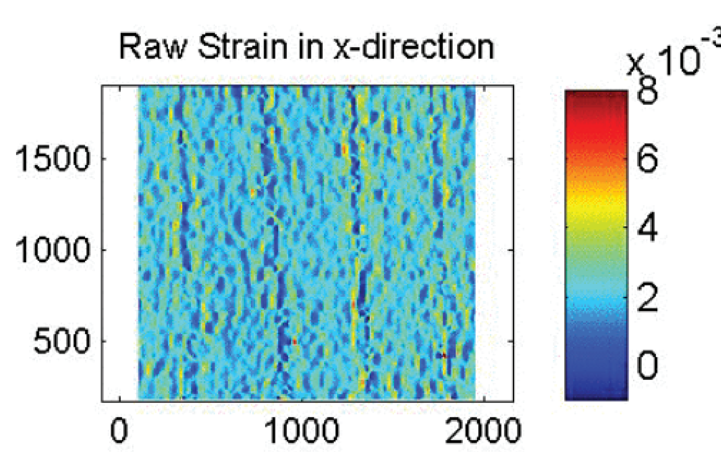

Figure 1 - Strain banding in DIC image

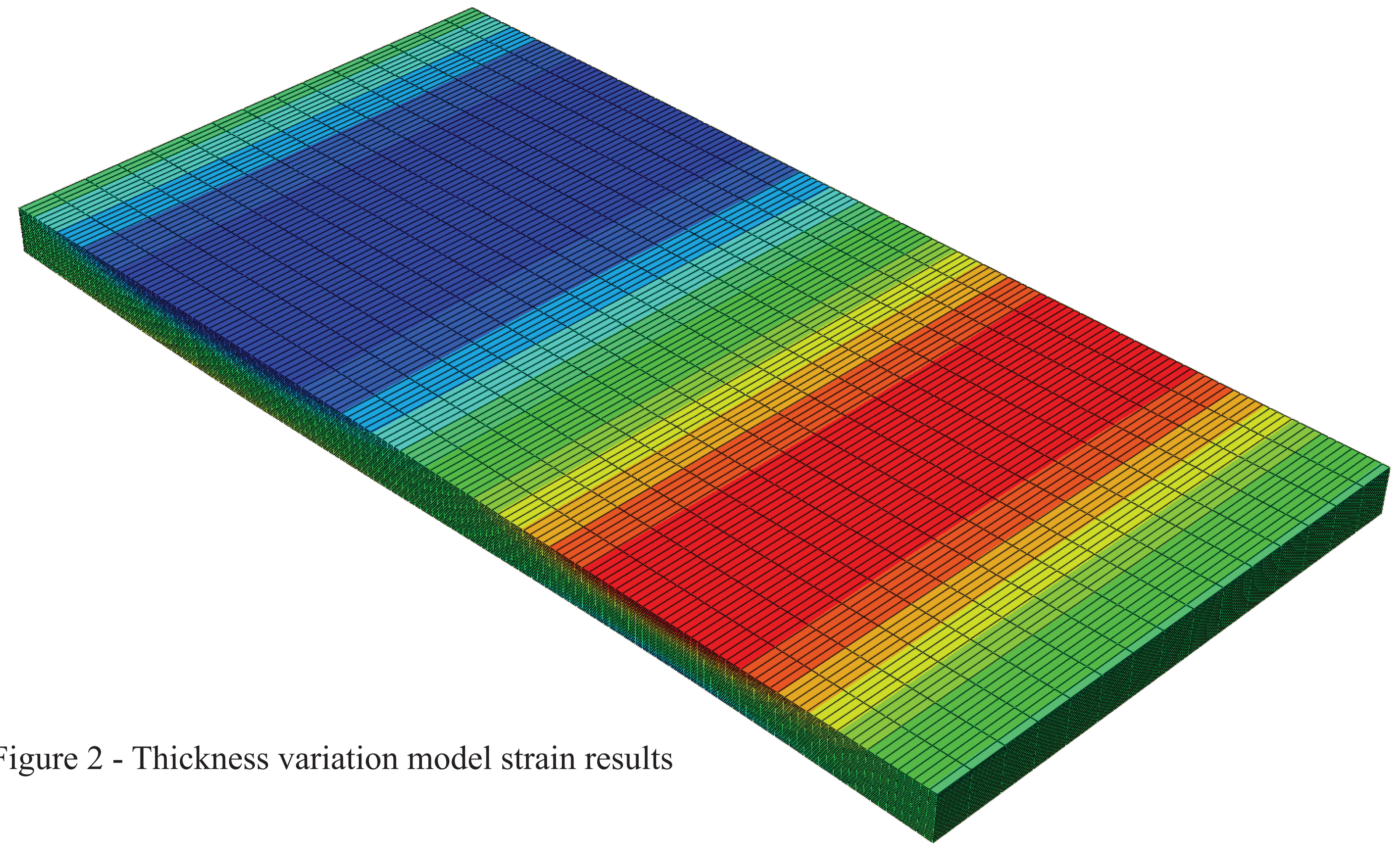
Figure 2 - Thickness variation model strain results

FVF Variation

The second form of variation examined was variation in fiber-volume fraction, the ratio of the volume of fiber to the total volume of the specimen. An example is given in Figure 3. Fertig Research Group proposed that thickness variation could be minimized by a cure process utilizing two flat plates to sandwich the composite during the cure cycle, as opposed to the vacuum bag process normally used. It was noted by the research group that this would introduce variation in FVF throughout the specimen. A plate was constructed using the process previously mentioned and data was obtained via digital microscopy on the amount of fiber volume variation. A second FEA model, shown in Figure 4, was constructed using this data. Note that the same sort of strain bands are still present. The primary difference between the models is that the thickness variation model displays a complex strain state throughout the thickness.

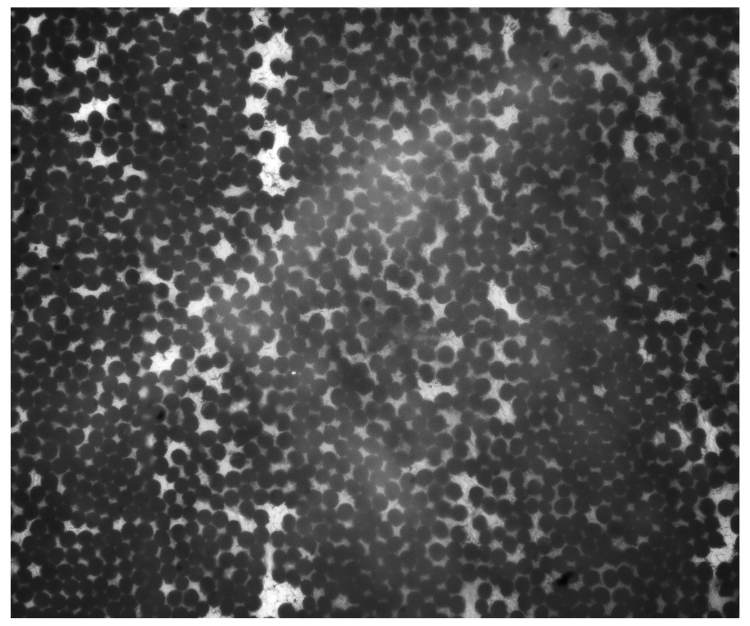
Figure 3 - Fiber-volume fraction variation

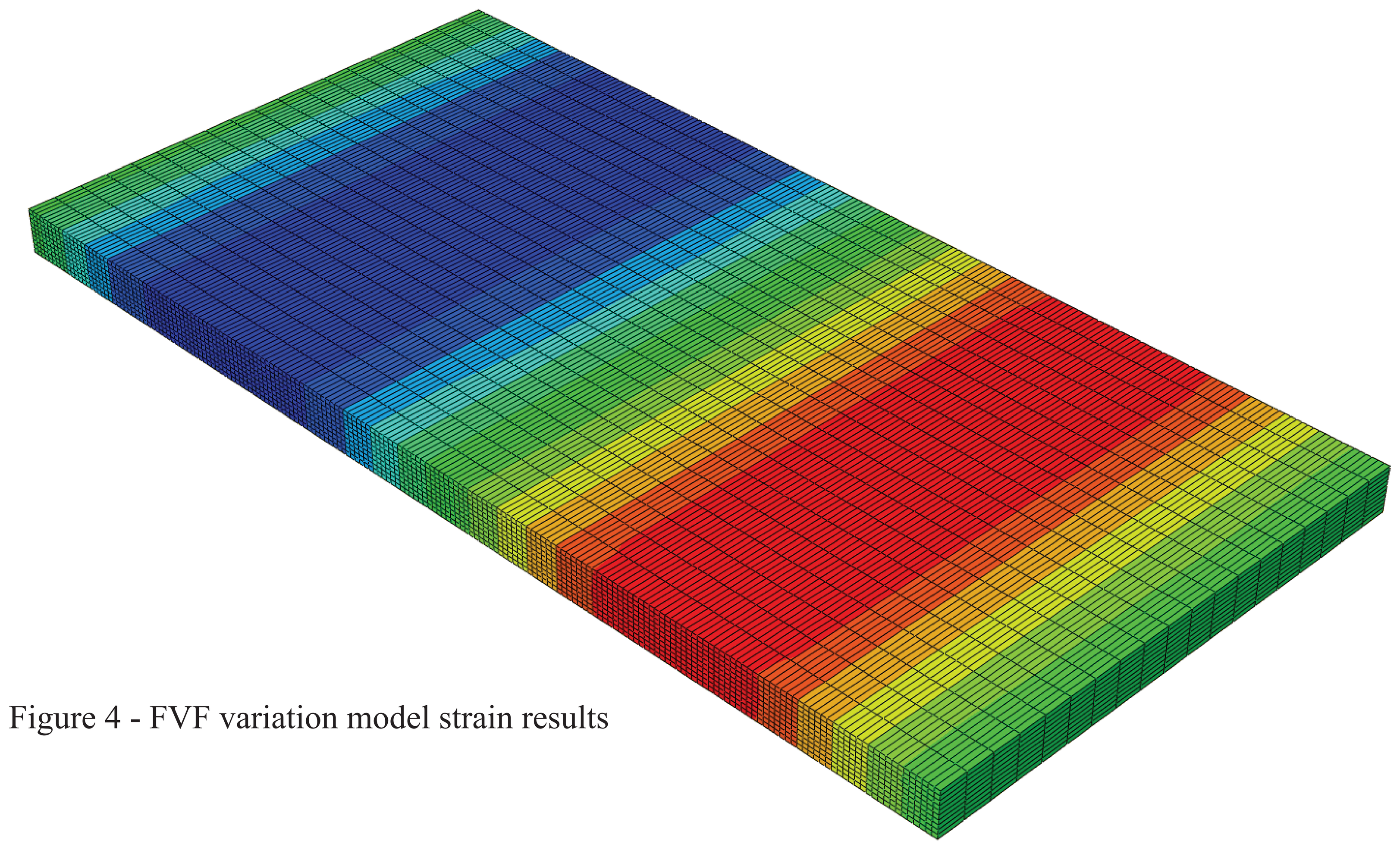
Figure 4 - FVF variation model strain results

Summary/Conclusions

Figures 5 and 6 below show a side view comparison of the two FEA models developed. There are a number of important conclusions that can be drawn from the comparison. An examination of the strain values reveals that not only do both models exhibit strains with the same order of magnitude, the values themselves are very similar. This is significant, as the flat plate cure approach was originally proposed as a solution to the thickness variation problem. This in turn created a much greater variation in FVF. However, as these figures show, both cure methods produce very similar strain values.

Also of note, if these models were specimens in the lab, the surface being imaged via DIC would be the top surface. The strain banding pattern observed on that surface is nearly identical for both models despite the much more complex strain state present through the cross-section of the thickness variation specimen. This means that the DIC results for the two specimens would be very similar.

Finally, it should be noted that in an actual lab specimen both of these variables will be a factor simultaneously. Even a compressed flat plate cure will not yield a specimen with no thickness variation. And a normal vacuum bag cured specimen will still exhibit FVF variation throughout. Further modeling of this combination is being pursued by the Fertig Research Group.

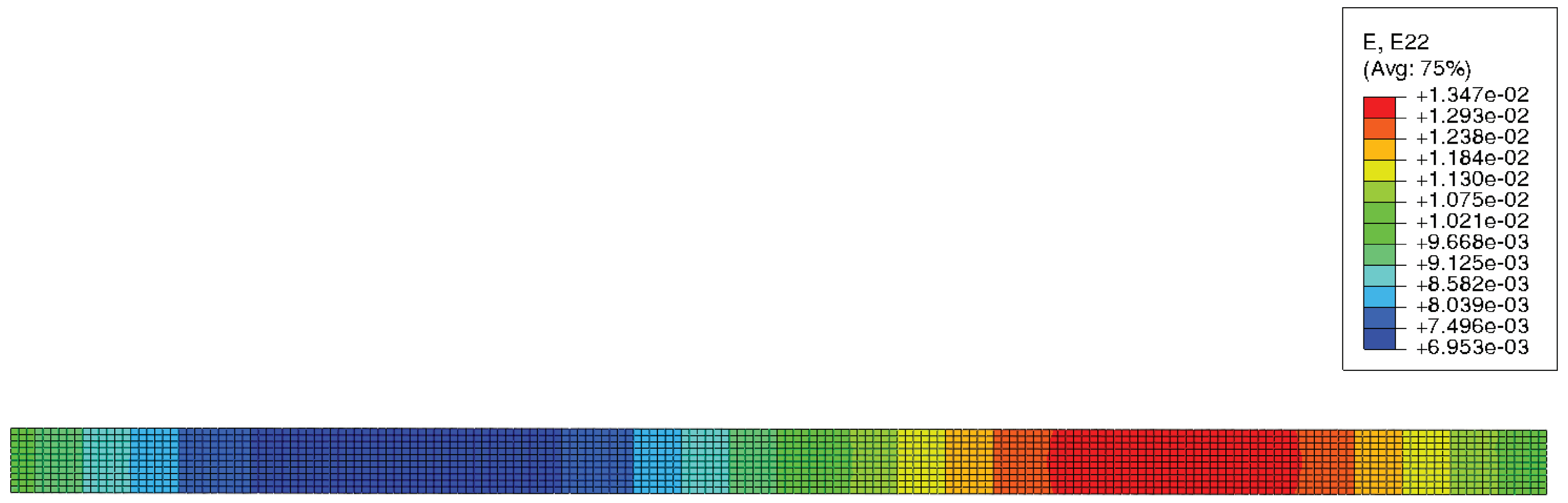

Figure 5 - FVF variation side view

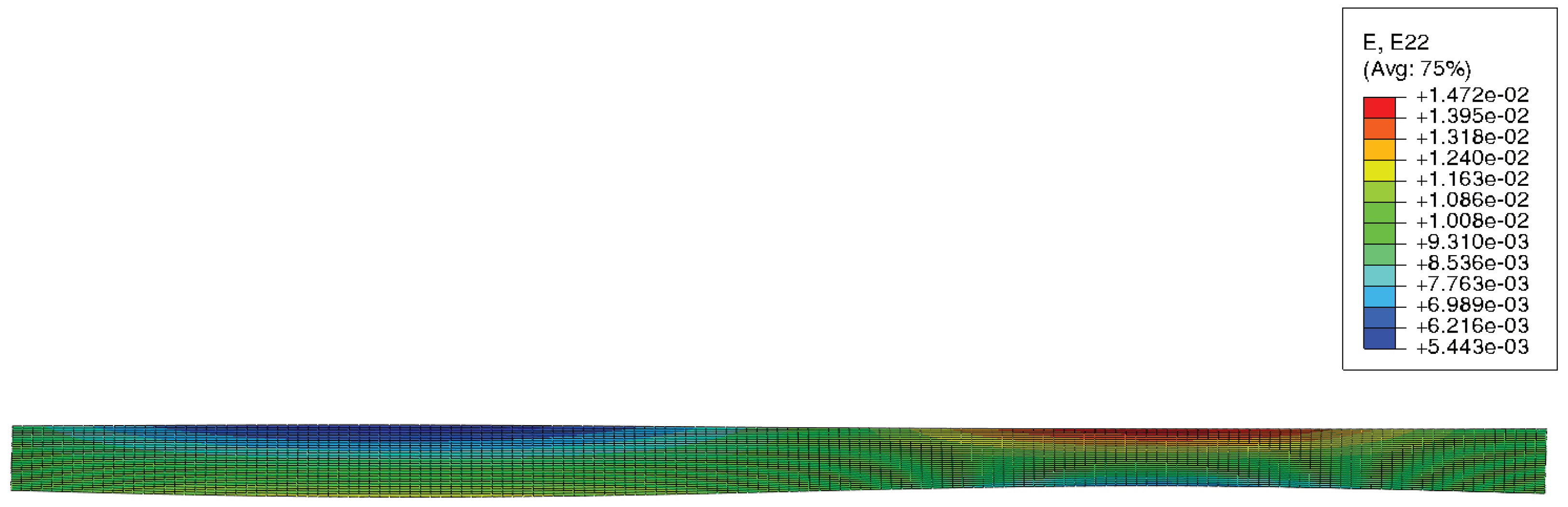

Figure 6 - Thickness variation side view

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