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Prediction by a Genetic Algorithm of the Fiber–Matrix Interface Damage for Composite Material. Part 2. Study of Shear Damage in Graphite/Epoxy Nanocomposites

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Прогнозирование повреждения композита на стыке матрицы и волокон с помощью генетического алгоритма. Сообщение 2. Анализ повреждений от сдвиговых напряжений в графито-эпоксидных нанокомпозитах

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Описанная в сообщении 1 генетическая модель используется для оптимизации повреждения в плоскости максимальных сдвиговых напряжений на стыке волокон и матрицы в нанокомпозитном графито-эпоксидном материале. Получена хорошая корреляция между численными расчетами и экспериментальными данными для композита и нанокомпозитов на основе графита, усиленного нанополимерами. Экспериментальные данные также хорошо согласуются с результатами, полученными на основании расчетной методики Ясмина. В дальнейших исследованиях планируется изучение влияния термических напряжений на подобную оптимизацию.

Ключевые слова: сдвиговое повреждение, стык, волокно, матрица, генетический алгоритм, нанокомпозиты.

Introduction. The approach described in our work [1] is applied to nanocomposites. Nanocomposites refer to composites in which one phase has nanoscale morphology such as nanoparticles, nanotubes or lamellar nanostructure [2–5].

The improvement of the properties by the addition of particles can be achieved when:

a) adequately good interaction between the nanoparticles and the matrix;

b) good dispersion of particles within the matrix.

In nanocomposites, covalent bonds, ionic bonds, Van der Waals forces, hydrogen bonding could exist between the matrix and filler components [4, 5]. One of the classifications is based on the nanomaterial's dimensional morphology:

1. Zero dimensional nanomaterial such as nanoparticle [4, 6, 7].
2. One dimensional nanomaterial such as nanowire and nanotube [8].
3. Two dimensional nanomaterial such as silicate layers.
4. Three dimensional nanomaterial such as zeolites [9–11].

A classification based on kind of synthesis procedure:

1. Direct incorporation of nanoscale into a polymer melt or solution, such as addition several type metal oxide and hydroxide to polymeric matrix [6].

2. In situ generation of nanoscale building blocks in a polymer matrix (reduction of metal ions in polymer matrix) [6].

In this study, we use the experimental results on graphite epoxy nanocomposites found by Asma Yasmine [12] to validate our approach genetic.

Various Technical Manufacturing of E-Graphite. A number of techniques were used to process the E-Graphite/epoxy nanocomposites and the equipment used to process the nanocomposites. These manufacturing techniques are presented by Asma Yasmine [12].

Direct Mixing. The E-Graphite (EG) was first added to the hardener due to its low viscosity and stirred continuously using a magnetic stirrer at room temperature for one day. DGEBA was then added and stirred for another 2 h on a hot plate at 60°C. An accelerator was added to the solution at ambient temperature and stirred for 0.5 h with slow agitation followed by overnight degassing. The solution was cast in a teflon mold prepared following the ASTM standard D638-99. The tensile specimens were 165 mm long and 2.5 mm thick with a gauge length of 50 mm and width of 13 mm. The mold was then placed in a hot press and the specimens cured at 148°C for 1 h.

Sonication Mixing. The EG was first sonicated in an acetone bath for 5 h and stirred on a hot plate using a magnetic stirrer until all the acetone was evaporated. Graphite nanosheets were added to DGEBA and mixed with a magnetic stirrer for 3 h. Next, hardener was added and stirred for another 2 h. Finally, an accelerator was added and the solution was degassed overnight. The solution was then cast and cured as described before for the direct mixing. If otherwise not stated, the results for sonication mixing came from nanocompositess processed by this technique. In another attempt, DGEBA was added to the acetone bath of graphite nanosheets and sonicated for 0.5 and 5 h to observe the effect of sonication mixing in comparison to magnetic stirrer mixing. The solution was then heated and stirred on a hot plate at approximately 60°C until all acetone was gone followed by processing as discussed above.

Shear Mixing. In the present study, EG was used instead of nanoclay particles as the reinforcement. The epoxy resin (DGEBA) was first placed between the feed and center rolls. Once the rolls started moving, the EG was spread gradually on the resin to achieve the maximum contact with the rolls. In the beginning, the solution is highly viscous and immiscible. However, with continued mixing, it becomes a homogeneous, shiny, miscible and less viscous solution. Compounding was carried out at room temperature for 2 h with a rotation speed of 500 rpm. The final product from the mill was then collected and mixed with the hardener at 60°C for 1 h on a hot plate. After adding accelerator and mixing for a few minutes, the solution was left overnight for degassing. After degassing, the solution was cast and cured as described for the direct mixing.

Combined Sonication and Shear Mixing. In this method, a solution of DGEBA and graphite nanosheets was first processed by sonication mixing followed by shear mixing as described above. This process combines the benefits of both sonication and shear processes.

Figure 1 show variation elastic modulus for different processing techniques.

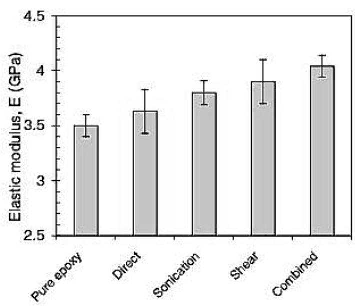

Fig. 1. Variation of elastic modulus of 1 wt.% EG/epoxy nanocomposites for different processing techniques.

Analytical Models. Modeling of the interface and model based on the statistical approach [13–22] is given in [1].

Numerical Simulation by GA.

Development. The idea is to optimize the shear damage to the fiber–matrix interface of graphite epoxy nanocomposites with the variation of modulus of elasticity in the three manufacturing techniques made by Asma Yasmine [12] (direct mixing, sonication mixing, and shear mixing). For this, we chose to use a genetic optimization using the result sets of Yasmine for $E = 3.6$, 3.7, and 3.9 GPa and a set of mathematical and analytical tools defined by the Cox model and the Weibull probability theorem.

The evaluation of each generation is made by an objective function based on the Cox model, which includes all the variables defined at the beginning of the algorithm (mechanical properties of each component of the composite, the Young modulus, etc.), and each value of the modulus of elasticity in shear damage of the interface over the entire length of the fiber is determined.

Figure 2 presents the flowchart of genetic algorithm.

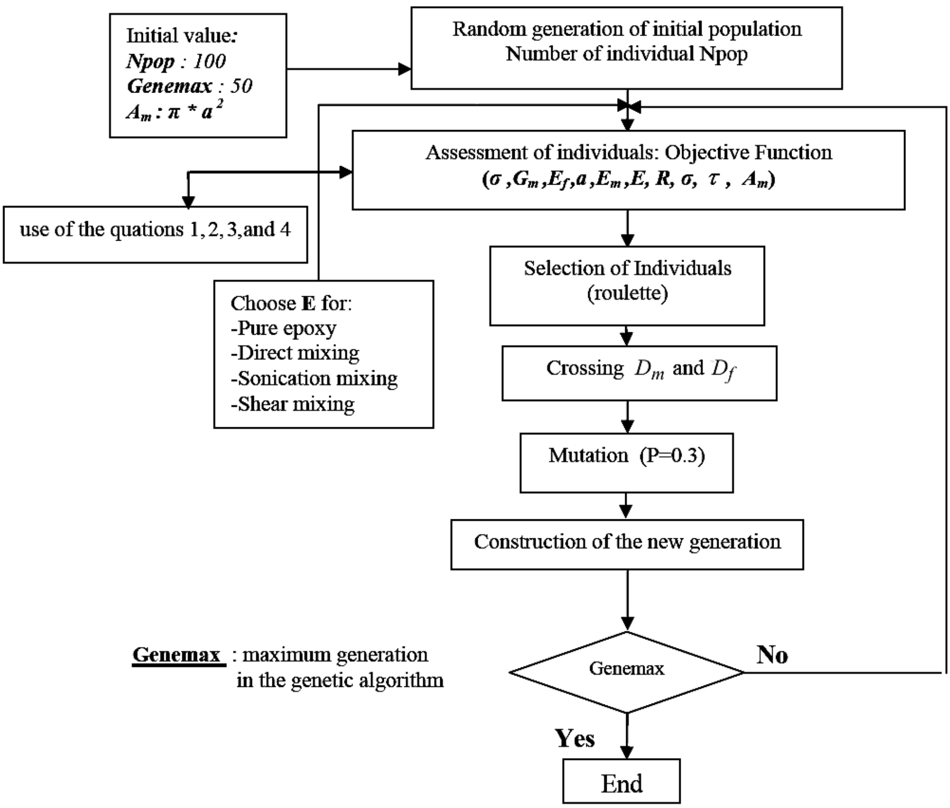

Fig. 2. The flowchart of genetic algorithm.

Simulation Results. A calculation was performed on two types of materials pure epoxy composite and graphite epoxy nanocomposites. We calculate the shear damage to the interface for pure epoxy ($E = 3.5$ GPa) and for graphite epoxy nanocomposites ($E =$ $= 3.6$ GPa, direct mixing, $E = 3.7$ GPa, sonication mixing, and $E = 3.9$ GPa, shear mixing).

Figures 3–6 show each value of E for the level of damage to the interface of pure epoxy and graphite epoxy nanocomposites.

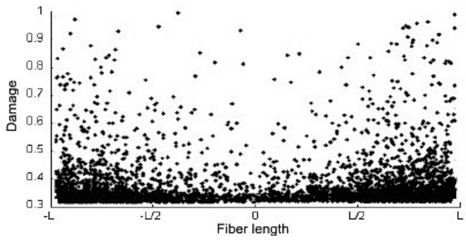

Fig. 3

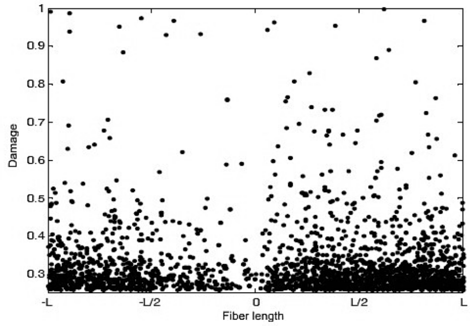

Fig. 4

Fig. 3. Level of shear damage to the interface of a pure epoxy ($E = 3.5$ GPa).
Fig. 4. Level of shear damage to the interface of a graphite/epoxy nanocomposites ($E = 3.6$ GPa).

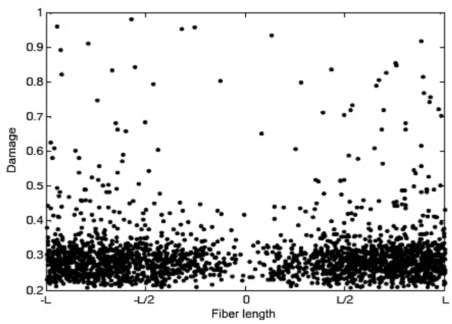

Fig. 5

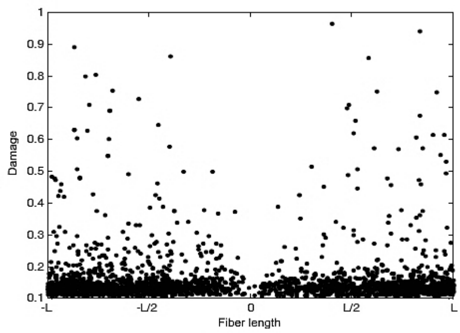

Fig. 6

Fig. 5. Level of shear damage to the interface of a graphite/epoxy nanocomposites ($E = 3.7$ GPa).
Fig. 6. Level of shear damage to the interface of a graphite/epoxy nanocomposites ($E = 3.9$ GPa).

Figures 3–6 indicate the same pattern for all materials under study. The damage of D interface starts at a certain point and then increases to the maximum value. The respective values are: 0.3 and 0.6 for for pure epoxy (Fig. 3), 0.25 and 0.5 for graphite epoxy/direct mixing (Fig. 4), 0.2 and 0.4 for graphite epoxy/sonication mixing (Fig. 5), and 0.1 and 0.3 for graphite epoxy/shear mixing (Fig. 6).

In all cases under study, this damage is symmetric, attains zero values in the middle of the fiber, and manifests a high density of calculated points at the ends.

Conclusions. The results of genetic calculation show that the level of damage is related to the nature of the material used. The nanocomposites have higher resistance to mechanical stress which interface damage is insignificant compared with those of the composite materials subject of study in Part 1. Numerical simulation, as compared with the result obtained by genetic algorithm, has shown that the graphite epoxy is stronger than the pure epoxy. The figures show the level of damage along fiber length and indicate that the values found for graphite epoxy are far inferior to those of pure epoxy. We can therefore say that the model well describes the phenomenon of damage for both composite and nanocomposite materials.

Р е з ю м е

Описана в повідомленні 1 генетична модель використовується для оптимізації пошкодження в площині максимальних зсувних напружень на стику волокон і матриці в нанокомпозитному графіто-епоксидному матеріалі. Отримано хорошу кореляцію

між числовими розрахунками й експериментальними даними для композита та нанокомпозитів на основі графіту, підсиленого нанополімерами. Експериментальні дані також добре узгоджуються з результатами, що отримані на основі розрахункової методики Ясміна. У подальших дослідженнях планується вивчення впливу термічних напружень на подібну оптимізацію.

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