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Investigation of Mechanical Properties of Composite Materials Reinforced With Carbon Fibers

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Abstract - Theoretical and experimental methods for obtaining and investigating effective thermo-mechanical characteristics - residual stresses and deformation in panels made of nanomodified materials with asymmetrical reinforcement scheme have been developed in this paper. The study of the residual stress-strain state of structural elements made of carbon plastic using the values of thermo elastic characteristics of composite mono layers identified on the basis of the developed methods made it possible to reveal the possibility of reducing the residual stress-strain state in structures with asymmetric reinforcement schemes.

Key Words: Composites, stress-strain state, strength, elastic properties.

1. INTRODUCTION

The primary obstacles in the fabrication of nano-composites involve the establishment of mass-manufacturing processes that ensure reliability and efficiency while producing materials with stable properties [1-12]. One of the most widely adopted techniques is the hand lay-up process, also referred to as the wet lay-up technique, which is the simplest and most conventional approach for manufacturing planar reinforced composites [13-19].

This process entails sequentially layering carbon-fiber-reinforced polymer sheets with an epoxy resin matrix. The wet lay-up technique integrates layers of carbon fiber with epoxy resin, producing a superior laminated structure. Before beginning the layering procedure, it is essential to prepare the mold. This includes surface cleaning and applying a release agent to prevent adhesion [20-22]. The hand lay-up method consists of four primary phases: mold preparation, epoxy resin application, layering of reinforcement and curing process. The initial step, mold preparation, is critical for ensuring high-quality composite formation. It requires the use of dry reinforcement fabric, which is impregnated with an epoxy matrix acting as the bonding agent to form a consolidated material [23-25].

2. MATERIALS AND EXPERIMENTS

The properties of the matrix were determined in the experiments:
Modulus of elasticity: 2 GPa
Tensile strength: 20 MPa Limit deformation: 0.01
KTR (25-50 ºC): 36.8 10^{-6} C^{-1}
KTR (50-60 ºC): 64.72 10^{-6} C^{-1}
Density: 1.2 g/cm^3
Poisson's ratio for epoxy resin from the reference data: 0.2.

The properties of the nanomodified matrix were determined in experiments: Modulus of elasticity: 2.5 GPa
Tensile strength: 30 MPa Limit deformation: 0.013
KTR (25-50 ºC): 46 10^{-6} C^{-1}
KTR (50-60 ºC): 70 10^{-6} C^{-1}

3. MODELLING THE MECHANICAL PROPERTIES OF COMPOSITES

To simulate the behavior of the reinforced matrix, we utilized the spherical inclusion model, assuming that the fullerene carbon black reinforcement particles are spherical and structurally rigid. The initial volume fraction of the filler was set at 0.6%. Using the Digimat-MF module and the Mori-Tanaka averaging technique, we estimated the mechanical response of the composite.

Modeling showed that at 0.6% filler content, the mechanical characteristics of the matrix remained largely unchanged. However, considering the effects of the interfacial layer, we adjusted the calculations by incorporating an effective volume fraction (the sum of filler volume and interfacial layer volume) that aligned with experimental data for stiffness and strength.

For an ultimate tensile strength of 30 MPa, the effective filler content was 50%, with a corresponding modulus of 6 GPa. Alternatively, when matching the modulus of 23 MPa, the filler content was 11%. This suggests that increasing the interfacial layer influences both the strength and modulus of the composite.

A graphical representation of stress-strain (σ-ε) curves for different filler concentrations, derived using Digimat-MF, is presented in Figure 1 and 2 showing the variations for 50%, 11%, and 0% inclusion content.

To further analyze the composite's thermal behavior, the coefficient of thermal expansion (CTE) was evaluated for 11% filler content, yielding a filler CTE of 85×10^{-6} °C^{-1}. The observed increase in composite CTE with nano-modification is likely due to structural alterations in the polymer matrix or possible chemical interactions between the filler and matrix components.

The degradation of mechanical characteristics was modeled using monolayer properties, with input parameters based on the NTA 40 fiber and EDT 10 matrix, whose properties are detailed in Tables 1, 2 and 3.

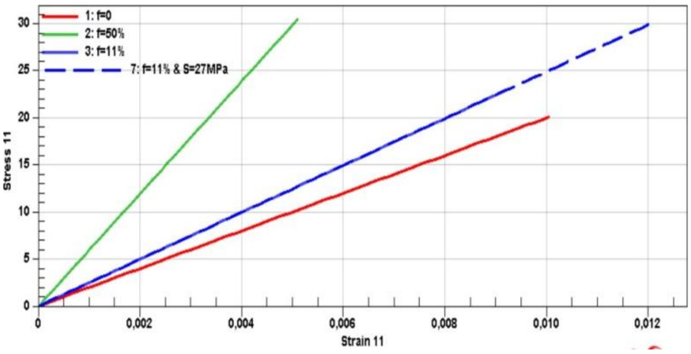

Fig - 1 σ-ε diagram of samples with different inclusion volume contents (in "DIGIMAT- MF"), (green-50%, blue-11%, red -0%)

Table 1: Properties of NTA 40 fibre

Features	Unit	Value
*E*1	*MPa*	257000
*E*2	*MPa*	24000
*G*12	*MPa*	16000
µ21	----	0.279
µ23	----	0.49
$\alpha\cdot10^{-6}$	*oC*-1	-0.1
ρ	g/cm^2	1.7
σb	*MPa*	1200

Table 2: Properties of EDT 10 matrix

Features	Unit	Value
E	*MPa*	2900
µ	----	0.2

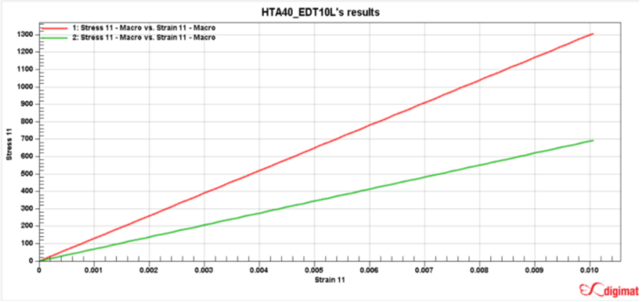

Fig – 2: σ-ε diagram of the unidirectional sample and the stacked sample in "DIGIMAT MF"

Table 3: Found stiffness matrix from Digimat

C11=133980	C12=5993.5	C13=5993.5	-	-	-
C21=5993.5	C22=11153	C23=6723.9	-	-	-
C31=5993.5	C32=6723.9	C33=11153	-	-	-
-	-	-	C44=2658	-	-
-	-	-	-	C55=2214.7	-
-	-	-	-	-	C66=2658

Find the average modulus using the formula:

$$E_{11} = C_{11} - \frac{2C_{12}^2}{C_{22} + C_{23}} = 133979$$

The calculated average Young's modulus of the composite package deviates from the experimental test results. It is well recognized that when utilizing test data from unidirectional materials, discrepancies may arise in estimating the mechanical properties of laminated composite structures. To improve accuracy, it is generally necessary to incorporate stiffness values from multiple layer configurations rather than relying solely on modulus values.

Since using modulus values alone does not adequately represent the experimental data, this study employs an adjusted transverse modulus of 28 GPa for monolayer properties. This value exceeds the experimentally determined 6.5 GPa from unidirectional samples. By applying this higher transverse modulus, we can more accurately replicate the Young’s modulus of composite specimens with symmetrical layer stacking, aligning the computational results with experimental observations.

4. CONCLUSION

This study successfully analyzed the residual deformations in asymmetrically reinforced panels through both analytical modeling and computational simulations. The comparison of theoretical and numerical results with experimental data validates the accuracy of the developed mathematical models. These findings offer valuable insights into optimizing the thermo-mechanical properties of layered nano-modified composite structures.

REFERENCES

1. A.N. Astapov, V.A. Pogodin. Russian Metallurgy (Metally), 2021, Vol. 2021, No. 12, pp. 1529-1533.
2. N.A. Bulychev, S.A. Kolesnik. IOP Conference Proceedings, 2022, Vol. 2231, article number 012012.
3. N.A. Bulychev. Nanoscience and Technology: An International Journal, 2022, Vol. 13, I. 1, pp. 55-65.
4. S.A. Kolesnik, N.A. Bulychev. Journal of Physics: Conference Series, 2020, 1474, article number 012024.
5. B.A. Garibyan. International Journal of Pharmaceutical Research, 2020, Vol. 12, Supplementary Issue 2, pp. 1825-1828.
6. M.O. Kaptakov, E.A. Pegachkova, A.V. Makarenko. AIP Conference Proceedings, 2021, Vol. 2402, article number 020038.
7. N.A. Bulychev. Nanoscience and Technology: An International Journal, 2021, Vol. 12, No. 3, pp. 91-97.
8. B.A. Garibyan. International Journal of Pharmaceutical Research, 2020, Vol. 12, Supplementary Issue 2, pp. 1829-1832.
9. S.A. Kolesnik. AIP Conference Proceedings, 2021, Vol. 2402, article number 020026.
10. M.O. Kaptakov. International Journal of Pharmaceutical Research, 2020, Vol. 12, Supplementary Issue 2, pp. 1821-1824.
11. O.A. Butusova. International Journal of Pharmaceutical Research, 2020, Vol. 12, I. 4, pp. 2292-2296.
12. A.N. Tarasova. International Journal of Pharmaceutical Research, 2020, Vol. 12, Supplementary Issue 2, pp. 1160-1168.
13. O.A. Butusova. International Journal of Pharmaceutical Research, 2020, Vol. 12, Supplementary Issue 2, pp. 1147-1151.
14. N.A. Bulychev. International Journal of Hydrogen Energy, 2022, Vol. 47, I. 50, pp. 21323-21328.
15. N.A. Bulychev. High Temperature, 2022, Vol. 60, Suppl. 1, pp. S98–S126.
16. G.A. Kalugina, A.V. Ryapukhin. Russian Engineering Research, vol. 41. no. 7, pp. 627-630, 2021.
17. M.O. Kaptakov. AIP Conference Proceedings, 2021, Vol. 2402, article number 020027.
18. N.A. Bulychev, A.Yu. Burova. International Journal of Hydrogen Energy, 2022, Vol. 47, I. 63, pp. 26789-26797.
19. A. Zayatzev, A. Lukianova, D. Demoretsky, Y. Alexandrova. Ceramics, 2022, 5(4), pp. 1242-1254.
20. A.N. Zayatzev, A.N. Lukianova, D.A. Demoretsky. Solid State Phenomena, 2022, 337, pp. 35-41.
21. A.N. Zayatzev, Y.P. Alexandrova. Journal of Friction and Wear, 2020, 41(3), pp. 242– 246.
22. V.F. Formalev, S.A. Kolesnik, B.A. Garibyan. Herald of the Bauman Moscow State Technical University, Series Natural Sciences, 2022, (1), pp. 107–121.
23. V.F. Formalev, B.A. Garibyan, S.A. Kolesnik. Herald of the Bauman Moscow State Technical University, Series Natural Sciences, 2022, (4), pp. 80–94.
24. S. Radaev. International Journal of Mechanics, 2021, 15, pp. 196-203.
25. A.Y. Burova, V.V. Kabakov. TEM Journal, 2022, 11(1), pp. 328–333.