Supporting file:

Nanoparticle GO-tagged PEI sizing agent imparts self-healing and excellent mechanical properties to carbon fiber reinforced epoxy laminates

Samir Mandal\textsuperscript{a}, Ketaki Samanta*\textsuperscript{a}, Kunal Manna\textsuperscript{a}, Subodh Kumar*\textsuperscript{a}\textsuperscript{,} and Suryasarathi Bose *\textsuperscript{a}

\textsuperscript{a}Department of Materials Engineering, Indian Institute of Science, Bangalore, India - 560012

*Corresponding Author Email: (ketakisamanta123@gmail.com, skumar@iisc.ac.in, sbose@iisc.ac.in )

1. FTIR of GO

GO has characteristic peaks at 1716, 3196, 1228 and 1615 cm\textsuperscript{-1} for the carbonyl, hydroxyl group, epoxy group and aliphatic alkene group (Fig. S1).

![FTIR spectra of GO](image)

**Fig. S1. FTIR spectra of GO.**

2. EDX of GO and BAGO

Here in Fig. S2, we can observe the elemental composition of GO and BAGO.
Fig. S2. EDX analysis of GO (a & b) and BAGO (c & d)

3. Microstructure and Morphology of GO and BAGO:

SEM was employed to examine the morphology and microstructure of GO and BAGO nanosheets, as depicted in Fig. S3(a, b). GO nanosheets exhibit a characteristic flat shiny surface. However, after tagging GO on BA, BAGO exhibits a dull wrinkled surface. While mixing PAA and GO, epoxy rings within GO can undergo ring-opening reactions at room temperature. Hence, grafting between GO and BA occurs during the synthesis process.\(^1\) Energy dispersive spectroscopy (EDS) analyses in Fig. S2 Shows 64 at% carbon and 36 at% oxygen in GO and 68 at% carbon, 19 at% oxygen, 10 at% nitrogen and 2 at% sulfur in BAGO confirming the tagging of GO with BA in BAGO. Fig. S3(c, d) represents the AFM image along with the surface roughness profile of GO and BAGO sheets respectively. It is observed that the length and width of the GO sheet is 4.2 and 3.5\(\mu\)m, whereas these are 6.2 and 4.5\(\mu\)m for BAGO sheet. Thus, it is possible that the tagging of GO with BA increases the length and width, though these measurements are admittedly for a single
sheet. The tagging of GO with BA also increases the surface roughness from 9(±1.2) nm to 350 (±12) nm.
Fig. S3 SEM morphology of (a) GO and (b) BAGO, and AFM image of (c) GO and (d) BAGO.

4. SEM micrograph of 0.5 and 1-BAGO-CF

Fig. S4 (a) and (b) SEM micrograph of 0.5-BAGO-CF and 1-BAGO-CF

5. Ethylene glycols contact angle of desized and BAGO-CF

Fig. S5 Ethylene glycol contact angle of desized, and BAGO deposited CF.
6. Self-healing of BA-CFRE

![Fig. S6 (a) load displacement graph, (b) bar graph of BA-CFRE](image)

7. Theory of Electromagnetic Interference (EMI) Shielding

EMI SE is the material’s ability to attenuate the energy of the incident electromagnetic waves. When the electromagnetic radiations interact with material under test (shield), the shielding phenomenon is governed by the contributions from reflection (SE\(_R\)), absorption (SE\(_A\)), and multiple internal reflections (SE\(_M\)). The total EMI SE (SE\(_T\)) is the sum of the contributions from SE\(_R\), SE\(_A\) and SE\(_M\). The total SE\(_T\) can be written as;

\[
SE_T = SE_R + SE_A + SE_M
\]  

(S1)

For calculations, SE\(_M\) is generally considered negligible when SE\(_T\) is higher than 15 dB. In a vector network analyzer, EMI SE is represented in terms of scattering parameters which are S\(_{11}\) (forward reflection coefficient), S\(_{12}\) (forward transmission coefficient), S\(_{21}\) (backward transmission coefficient), and S\(_{22}\) (reverse reflection coefficient). The SE\(_T\) can be evaluated from the S parameters by using the following equations\(^2\).

\[
SE_R = 10log\left(\frac{1}{1 - R}\right) = 10log\frac{1}{1 - |S_{11}|^2}
\]

(S2)
\[ SE_A = 10 \log \left( \frac{1 - R}{T} \right) = 10 \log \frac{1 - |S_{11}|^2}{|S_{21}|^2} \]  

(S3)

The EMI Shielding efficiency % can be calculated by the following equation.³

\[ \text{Shielding Efficiency } \% = 100 - \left( 10^{ \frac{SE}{10} } \right)^{-1} \times 100 \]  

(S5)

Where, \( SE \) stands for total shielding efficiency i.e. \( SE_T \)

In practice, two-port network model of Vector Network Analyzer (VNA) is used to measure the scattering parameters (\( S_{11}, S_{12}, S_{21}, \) and \( S_{22} \)) wherein the reflection \( R \) and transmission \( T \) coefficients are obtained from these scattering parameters using the following equations.

\[ R = |S_{11}|^2 = |S_{22}|^2 \]  

(S6)

\[ T = |S_{21}|^2 = |S_{12}|^2 \]  

(S7)

\[ A = 1 - R - T \]  

(S8)

Where, \( S_{11} \) and \( S_{21} \) represent the reflection parameter obtained using VNA port 1 and the transmission parameter from port 1 to port 2, respectively. \( S_{22} \) and \( S_{12} \) denote the reflection parameter obtained from VNA port 2 and the transmission parameter from port 2 to port 1, respectively. \( S_{21} \) refers to the forward transmission, and \( S_{12} \) refers to the reverse transmission. If the shield material is uniform, \( S_{11} = S_{22} \) and \( S_{21} = S_{12} \).

8. Surface conductivity
Fig. S7 Surface conductivity of the neat CFRE and 0.25-BAGO-CFRE

References

