Supporting file:

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

Samir Mandal[a], Ketaki Samanta*[,a], Kunal Manna[a], Subodh Kumar*[,a] and Suryasarathi Bose *[,a]

[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 1615cm^{-1} for the carbonyl, hydroxyl group, epoxy group and aliphatic alkene group (Fig. S1).

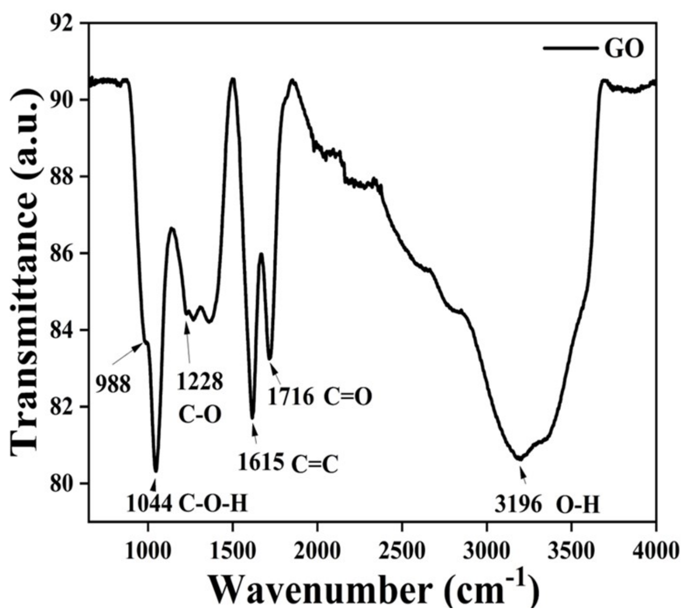
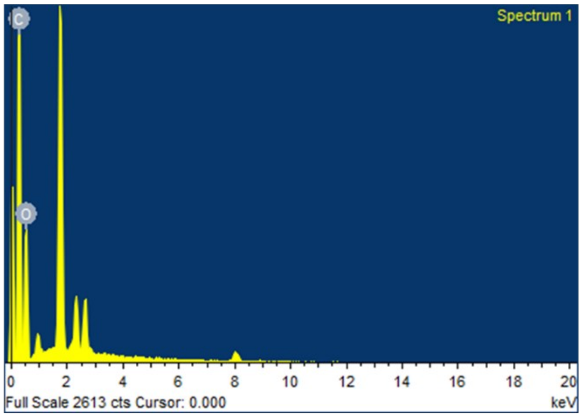


Fig. S1. FTIR spectra of GO.

2. EDX of GO and BAGO

Here in Fig. S2, we can observe the elemental composition of GO and BAGO.

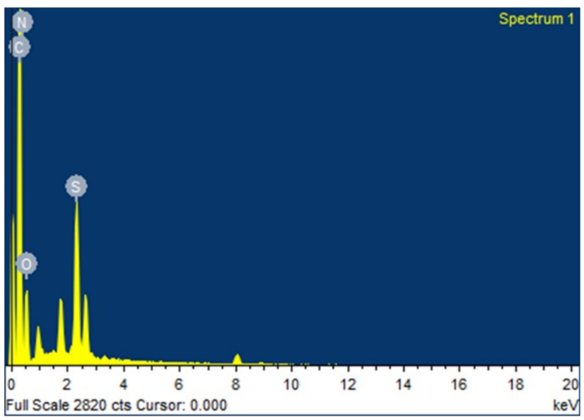
(a)



(b)

Element	Weight%	Atomic%
C K	56.70	63.56
O K	43.30	36.44
Totals	100.00	

(c)



(d)

Element	Weight%	Atomic%
C K	60.83	68.02
N K	10.83	10.39
O K	23.10	19.39
S K	5.24	2.19
Totals	100.00	

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 3.5µm, whereas these are 6.2 and 4.5µm 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.

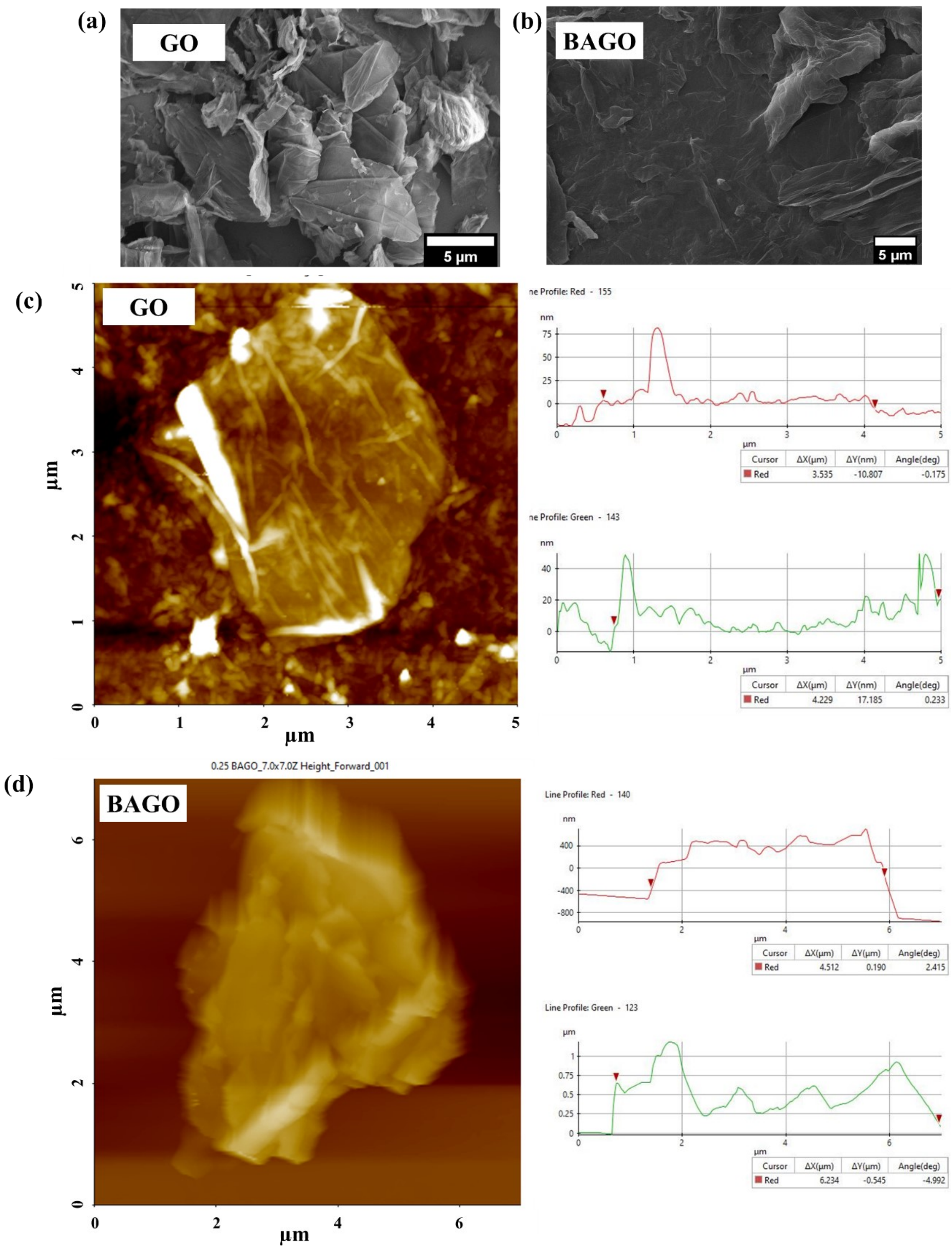


Fig. S3 SEM morphology of (a) GO and (b) BAGO, and AFM image of (c) GO and (d) BAGO.

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

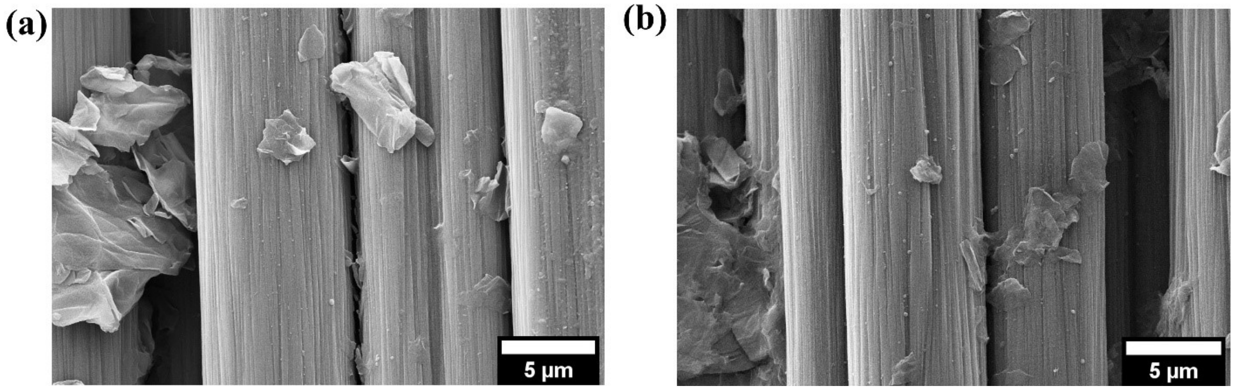


Fig. S4 (a) and (b) SEM micrograph of 0.5-BAGO-CF and 1-BAGO-CF

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

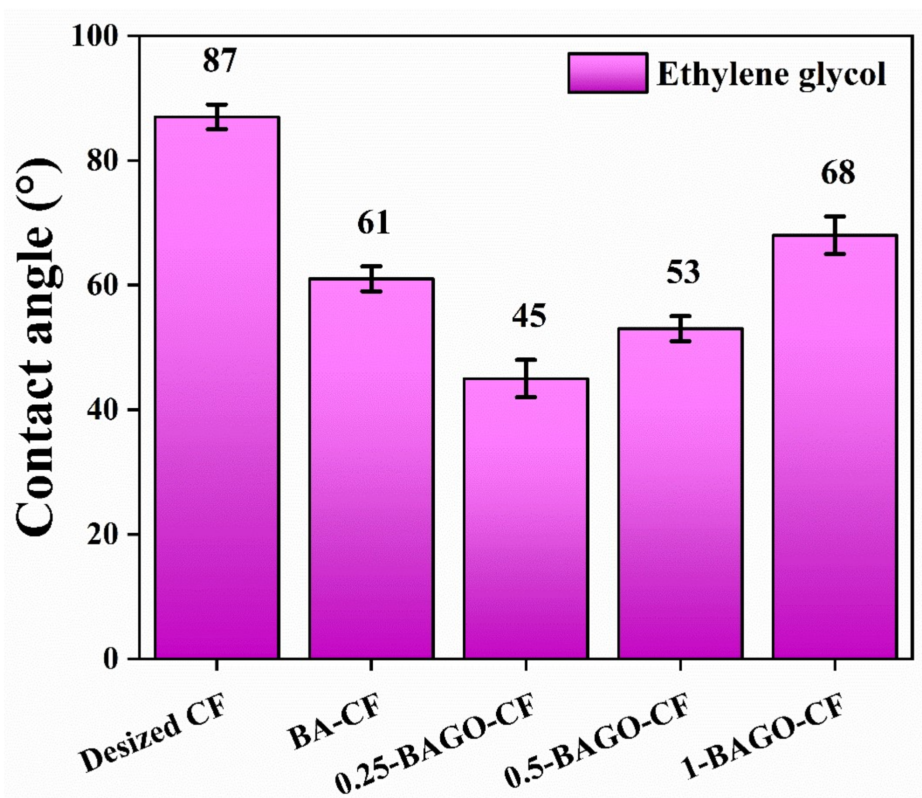


Fig. S5 Ethylene glycol contact angle of desized, and BAGO deposited CF.

6. Self-healing of BA-CFRE

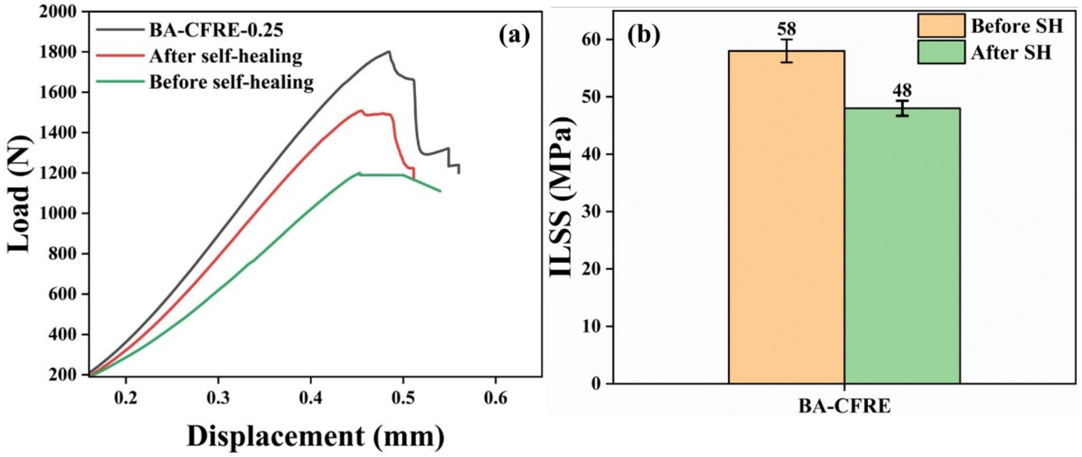


Fig. S6 (a) load displacement graph, (b) bar graph of BA-CFRE

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;

$$SE_T = SE_R + SE_A + SE_M \quad \text{(S1)}$$

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].

$$SE_R = 10log\left(\frac{1}{1-R}\right) = 10log\frac{1}{1-|S_{11}|^2} \quad \text{(S2)}$$

$$SE_A = 10log\left(\frac{1-R}{T}\right) = 10log\frac{1-|S_{11}|^2}{|S_{21}|^2} \qquad \text{(S3)}$$

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

$$Shielding\ Efficiency\ \% = 100 - \left(10^{\frac{SE}{10}}\right)^{-1} \times 100 \qquad \text{(S5)}$$

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.

$$R = |S_{11}|^2 = |S_{22}|^2 \qquad \text{(S6)}$$

$$T = |S_{21}|^2 = |S_{12}|^2 \qquad \text{(S7)}$$

$$A = 1 - R - T \qquad \text{(S8)}$$

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

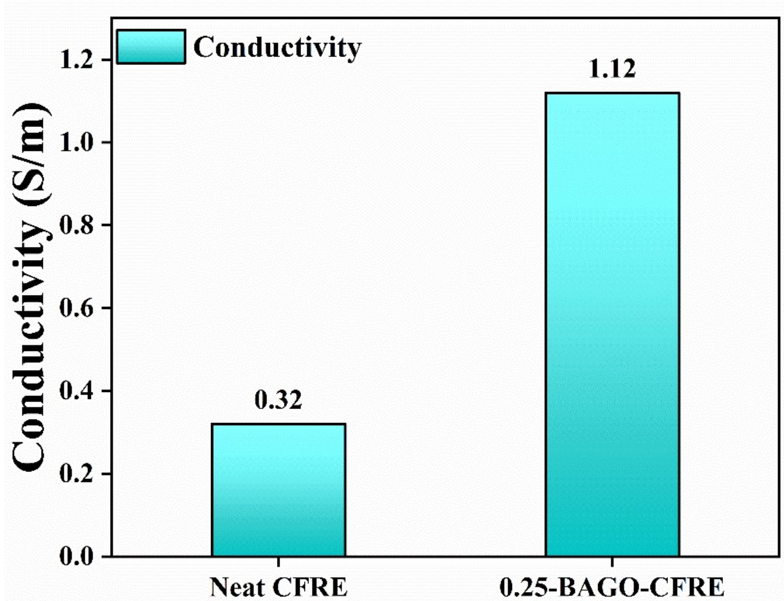


Fig. S7 Surface conductivity of the neat CFRE and 0.25-BAGO-CFRE

References

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