Dynamic Mechanical Properties and Corrosion Resistance of Epoxy Coatings Enhanced with MXene and Diverse Nano-fillers

Mohd Shahneel Saharudin

Robert Gordon University, Aberdeen, UK

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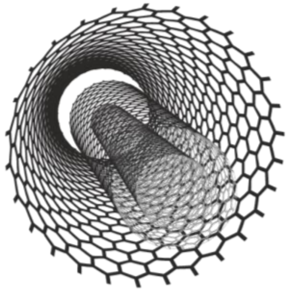
Introduction: Overview of epoxy coating

- Overview of epoxy coatings and their applications
- Need for enhancing mechanical properties and corrosion resistance
- Introduction to nanofillers:
  - MXenes
    - (2D materials composed of transition metal carbides, nitrides, or carbonitrides.
    - Layered structure similar to graphene.
  - Graphene Nanoplatelets (GNPs)
    - Thin stacks of graphene layers, typically a few nano-meters thick and up to several micrometers in lateral size)
  - Carbon Nanotubes (CNTs)
    - Cylindrical nanostructures made of graphene. Can be single-walled (SWCNTs) or multi-walled (MWCNTs).
  - Halloysite Nanotubes (HNTs)
    - Naturally occurring aluminosilicate nanotubes. Hollow tubular structure with a typical length of 1-15 micrometers and an outer diameter of 30-70 nanometers.

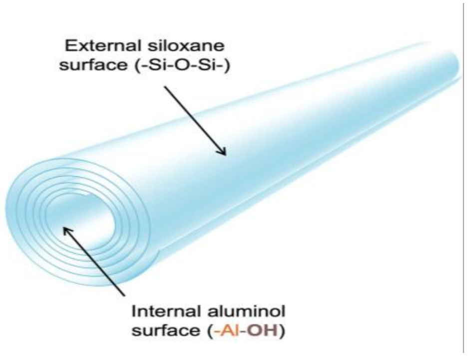
Objective

- To explore and compare the dynamic mechanical properties and corrosion resistance of epoxy composites enhanced with different nanofillers at lower content.

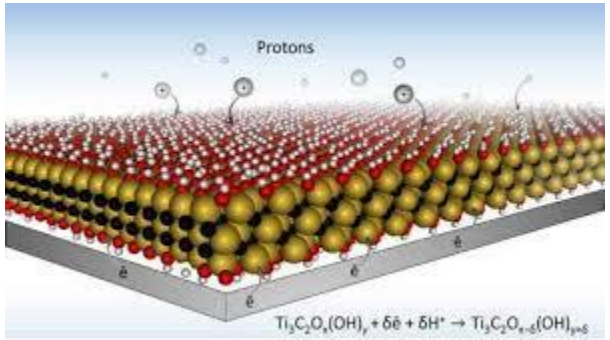
GnPs



MWCNTs



HNTs



MXenes

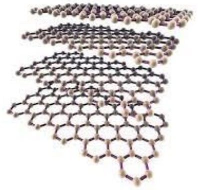
Motivation of research

- Dispersion Issues
  - Tendency of nanomaterials to agglomerate or cluster together.
  - Poor dispersion can result in weak points within the composite, compromising its mechanical, electrical, and thermal properties.
  - This can hinder their effective dispersion within the composite matrix, leading to non-uniform properties and reduced performance.
- Nanocomposites can offer improved corrosion resistance
  - The incorporation of MXenes, graphene, HNTs and CNTs can create coatings that provide a strong barrier against corrosive elements.

Materials

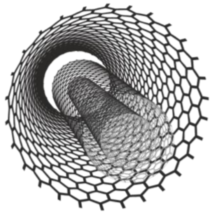
Graphene

- Graphene is a single layer of carbon atoms arranged in a hexagonal lattice, like a honeycomb structure.
- Incredibly thin, strong (about 200 times stronger than steel), lightweight, and conducts electricity very well.
- Used in electronics (like flexible screens), energy storage (like supercapacitors), and even in medical devices (like biosensors).



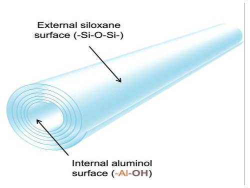
Carbon Nanotubes (CNTs)

- A tube-like structure.
- Lightweight, strong (like graphene), and have excellent electrical conductivity.
- Used in sports equipment, in electronics (like transistors), and in sensors, drug deliveries.



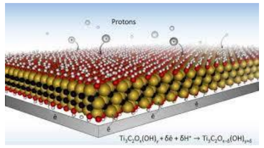
Halloysite Nanotubes (HNTs)

- Tiny tubes made from a natural clay mineral called halloysite, which has a tubular shape.
- Natural hollow structure and are known for absorbing liquids.
- Used in packaging, water treatment and mechanical reinforcement



MXenes

- MXenes are a relatively new family of 2D materials made from layers of transition metals (like titanium or niobium) sandwiched between carbon or nitrogen atoms.
- They are strong, lightweight, and have good electrical conductivity.
- MXenes are used for energy storage devices (like batteries and supercapacitors), in electromagnetic shielding, and also for water purification due to their high surface area.



Methodology

- Preparation of Nanocomposite Samples:
  - Synthesis process for 0.1 wt.% nanocomposites with various nano-fillers.
  - Use of NMP solvent for enhancing nanofiller dispersion.
- UV-Vis Spectrophotometer Analysis
  - Light transmittance measurements to assess dispersion.
- Dynamic Mechanical Analysis (DMA)
  - DMA process to measure storage modulus, loss modulus, and glass transition temperature (T_g).

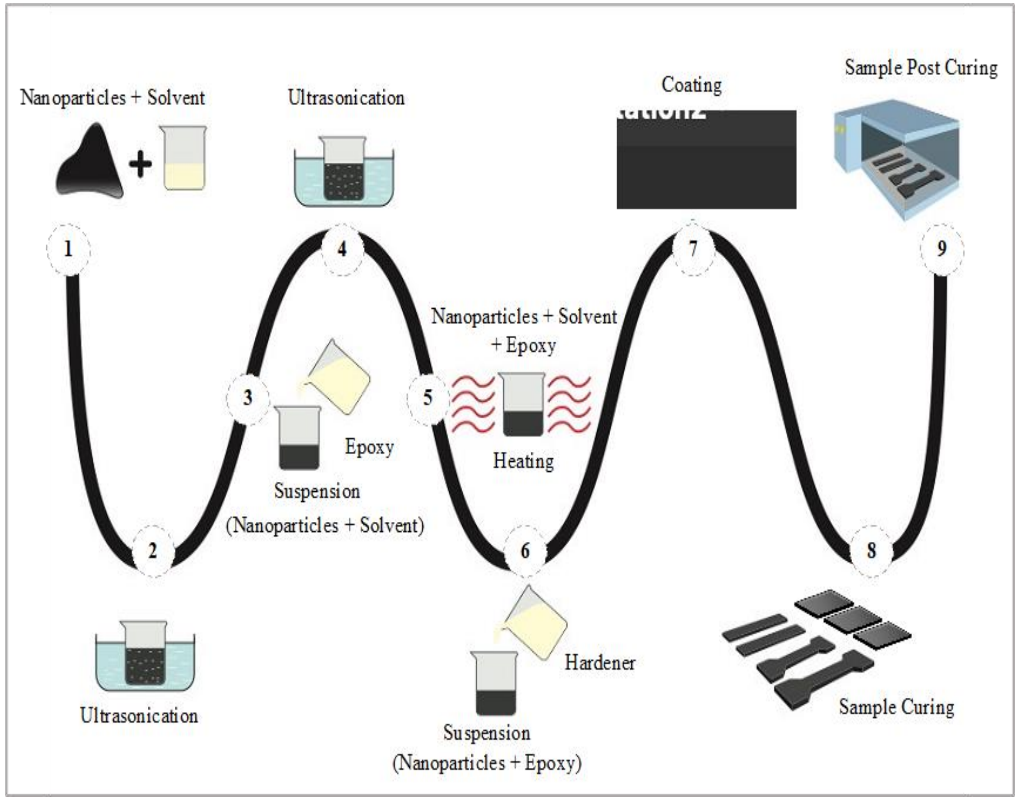


Figure 1. Preparation of nanocomposite samples

Figure 2. Spectrophotometer NANOCOLOR UV/VIS II

Methodology *cont*: Dispersing nanomaterials using NMP

- N-Methyl-2-pyrrolidone (NMP) is a widely used solvent for dispersing nanomaterials such as graphene, MXenes, and carbon nanotubes (CNTs).
- Effective at dispersing nanomaterials like graphene and CNTs, achieving higher concentrations and more stable suspensions compared to many other solvents.
- NMP helps to delaminate and disperse layered structures and stabilize the individual nanosheets/bundles

Methodology: Wire bar coating

- The wire bar coating method is as per ASTM D1084 standard.
- The freshly coated samples were cured for 7 days at room temperature and then post-cured in the oven for 5 h at 100ºC, followed by 3 h at 160ºC to accomplish a complete cross-linking.
- The epoxy nanocomposite coatings were prepared with various nanofillers in the same way.

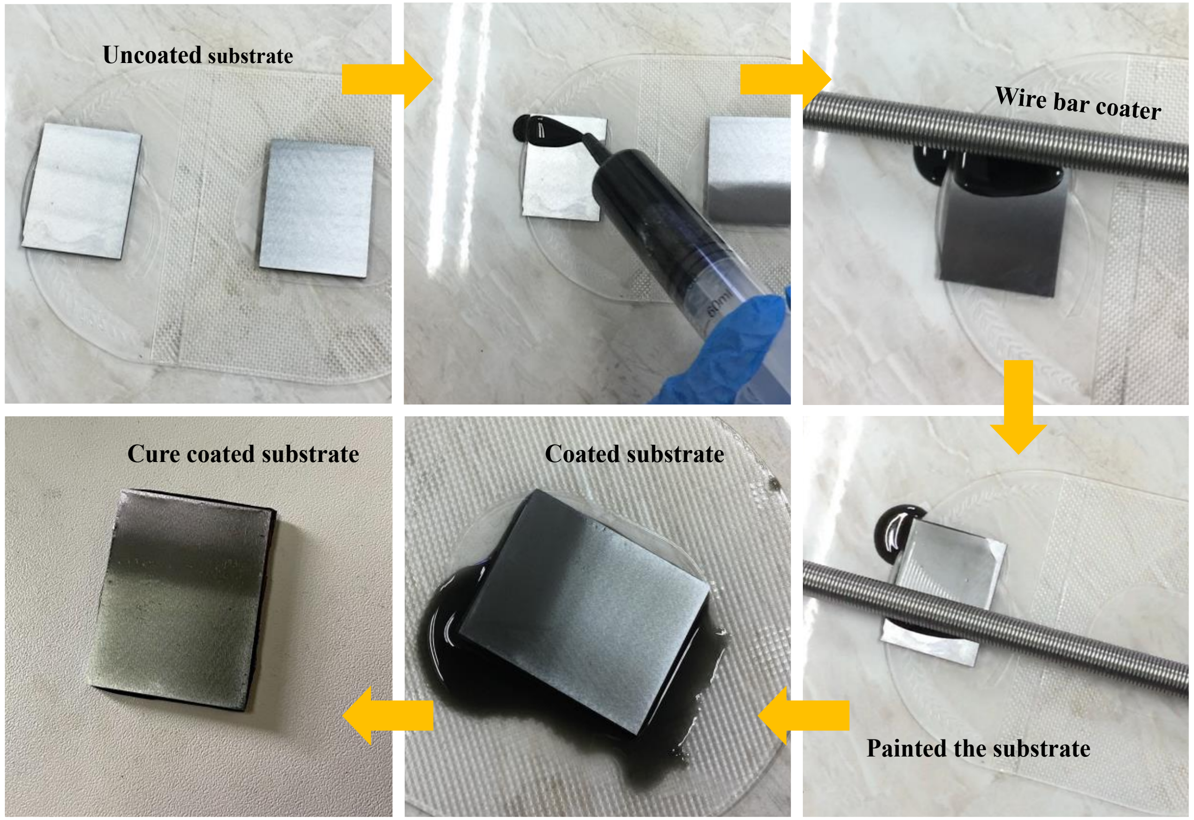


Figure 3. Wire bar coating

Results: UV-Vis Spectrophotometry

- Graph showing light transmittance values with and without solvent.
- Reduced light transmittance indicating better dispersion.
- HNTs are the best candidates among the materials analyzed for applications requiring high transparency.
- MXenes could be considered for applications where moderate transparency is acceptable.
- GNPs and CNTs are not suitable for applications where transparency is a requirement due to their very low to negligible light transmittance.

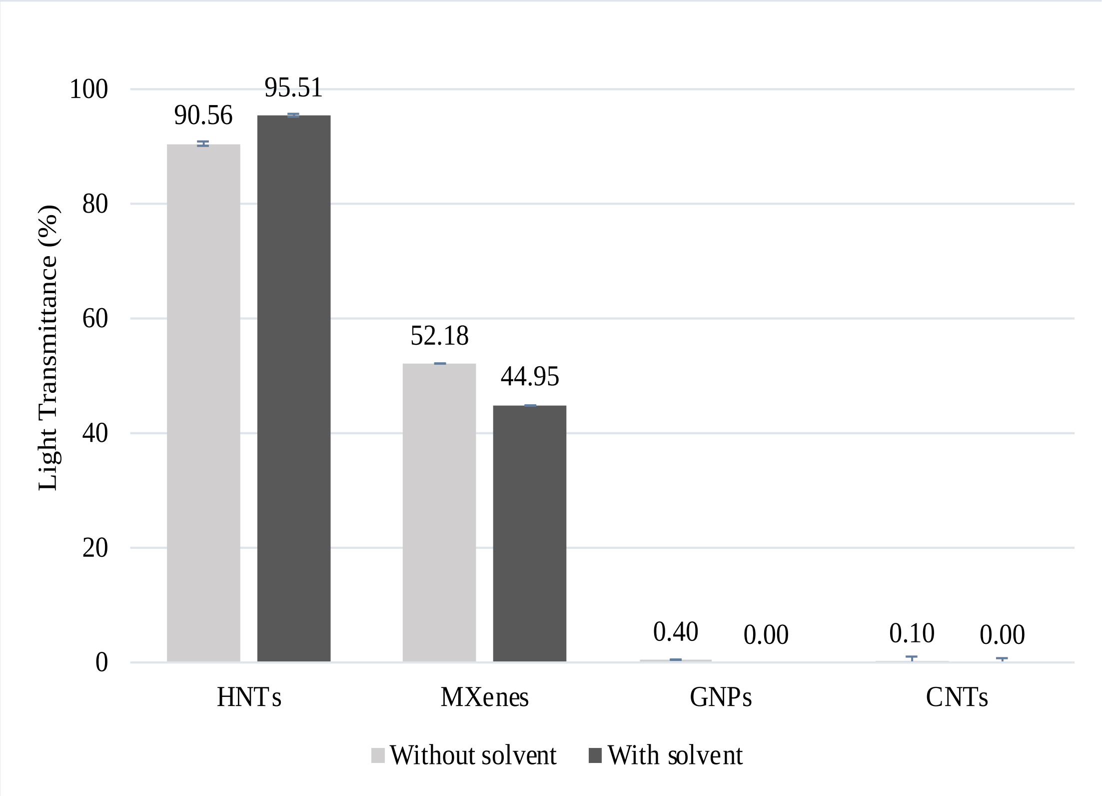


Figure 4. Light transmittance from UV-Vis Spectrophotometry analysis

Results: Dynamic Mechanical Analysis

- Graphs showing storage modulus and tan delta for nanocomposite samples.
- Epoxy has a distinctly different behaviour with a much earlier decline in storage modulus, suggesting it is less thermally stable compared to nanomaterials

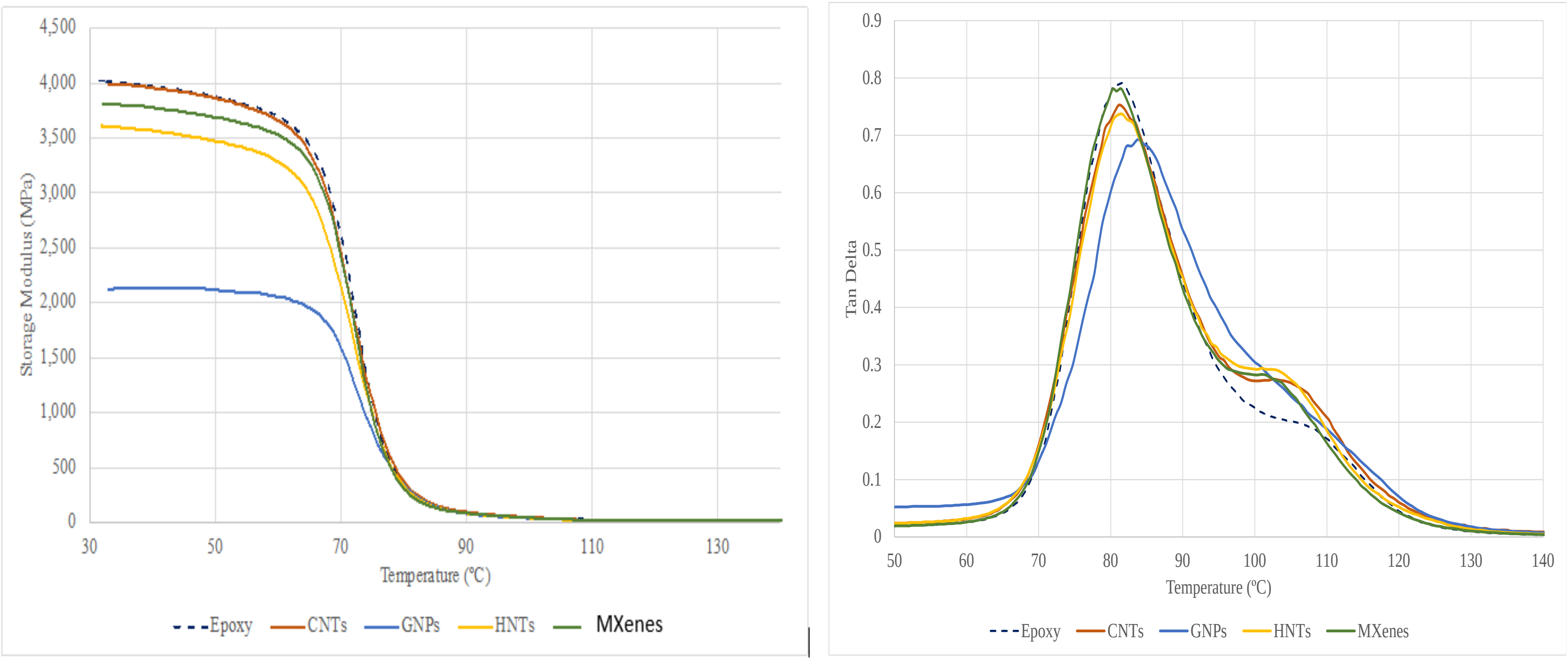
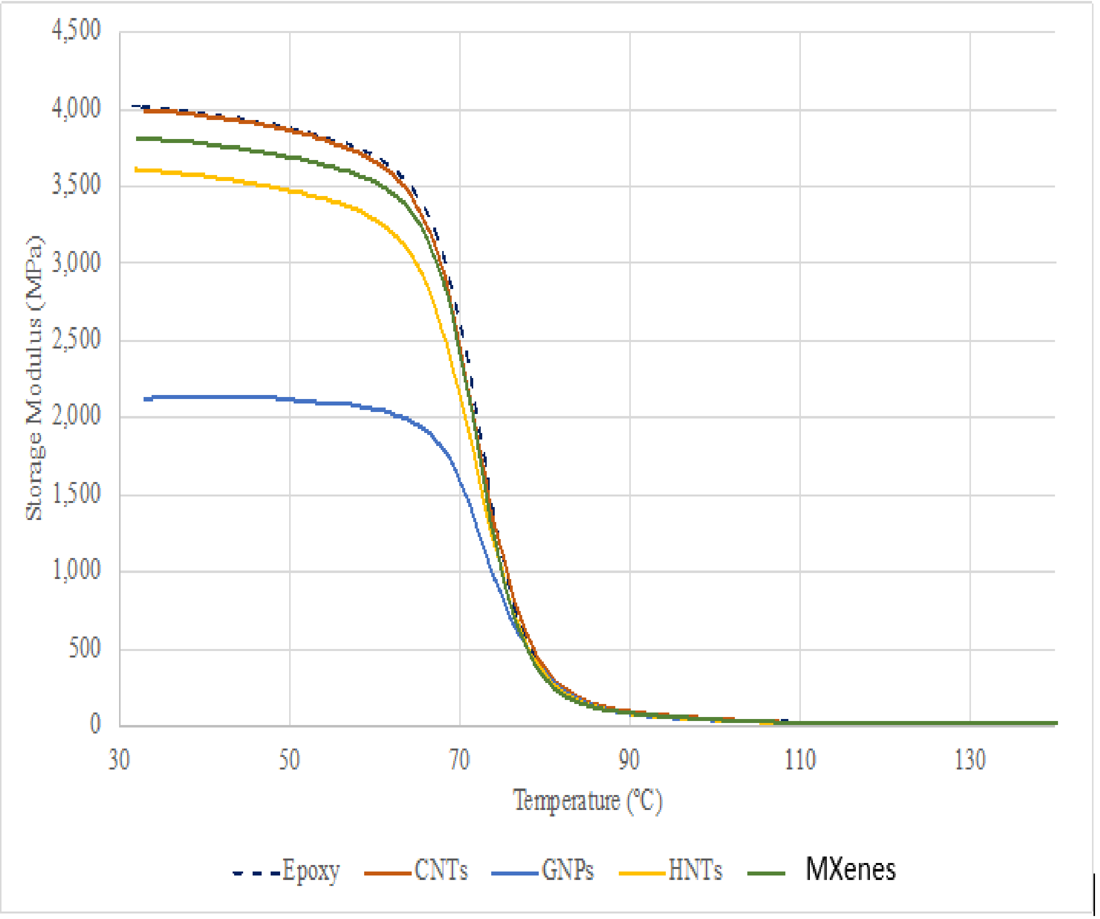


Figure 5. Dynamic mechanical analysis; storage modulus and Tan Delta

Results: Storage Modulus vs Temperature



CNTs, GnPs, HNTs, and MXenes

- They maintain a relatively stable storage modulus up to a certain temperature threshold (around 90°C), beyond which there is a sharp decline. This suggests that these materials can maintain their structural integrity up to moderate temperatures but may experience a reduction in stiffness at higher temperatures.

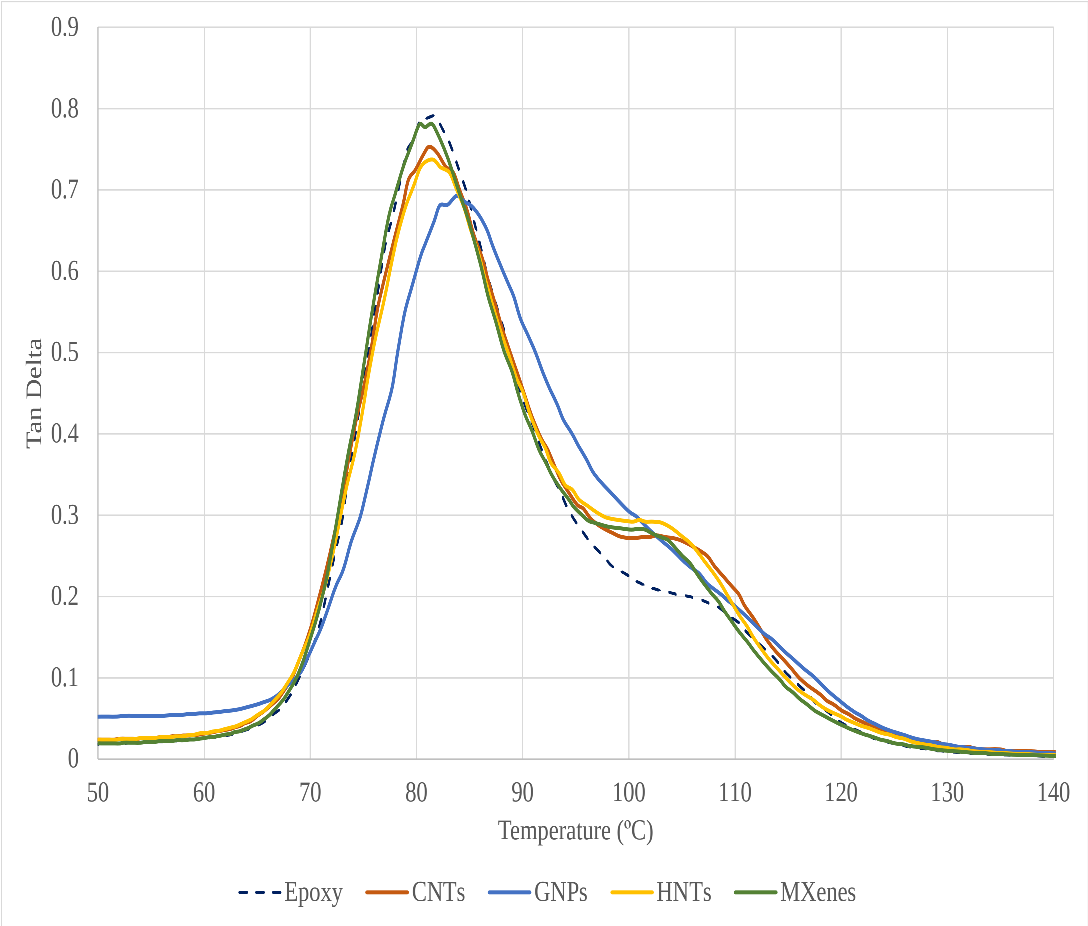
Comparison

- Epoxy has a distinctly different behaviour with a much earlier decline in storage modulus, suggesting it is less thermally stable compared to the nanomaterials (CNTs, GNPs, HNTs, and MXenes).
- The nanomaterials, while showing a sharp decline at around 90°C, maintain higher storage modulus values at temperatures below this threshold, indicating better performance in applications requiring thermal stability at lower temperatures.

Conclusion

- The graph indicates that while Epoxy is less effective in maintaining its mechanical properties at elevated temperatures, the nanomaterials (CNTs, GNPs, HNTs, and MXenes) exhibit superior thermal stability up to about 90°C.
- This makes the nanomaterials more suitable for applications where higher temperature resistance is required, whereas Epoxy might be more suitable for applications operating within lower temperature ranges.

Damping factor Tan Delta



- T_g indicate the point at which each material transitions from a glassy to a rubbery state, which is critical for applications that depend on material properties changing with temperature.
- All materials follow a similar pattern: as they heat up, their ability to absorb energy increases, reaches a peak, and then decreases.
- MXene is the best at absorbing energy at peak temperature (around 80°C)

Results: Potentiondynamic polarization-TAFEL Curve Analysis

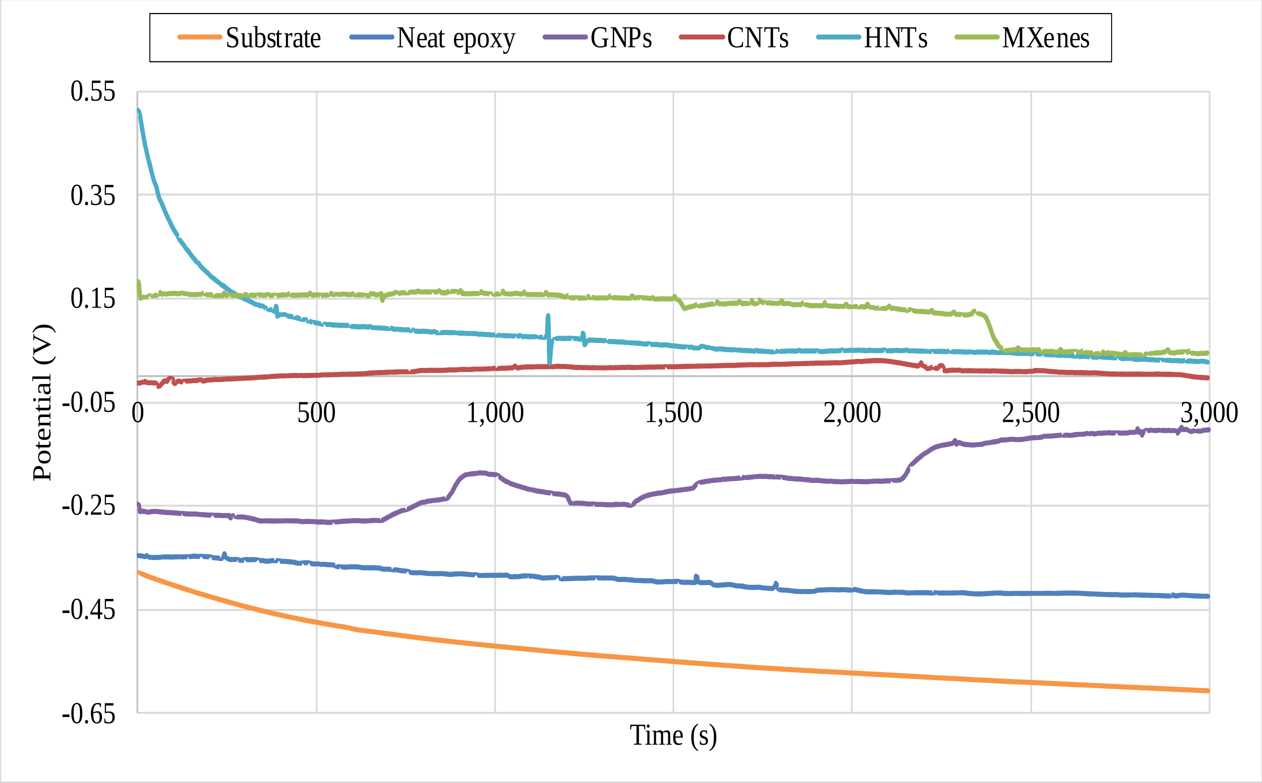


Figure 6. Potentiondynamic polarization-TAFEL Curve Analysis

Provides detailed insights into the corrosion behaviour of materials

- Substrate
  - Steadily decreases over time
- Neat Epoxy
  - Stays fairly constant but at a negative level
- GNPs
  - Starts negative but gradually improves
- CNTs
  - Remains slightly positive and stable throughout
- HNTs
  - Starts very positively but quickly drops and stabilizes
- MXenes
  - Maintains a consistent, positive level throughout

SEM Images

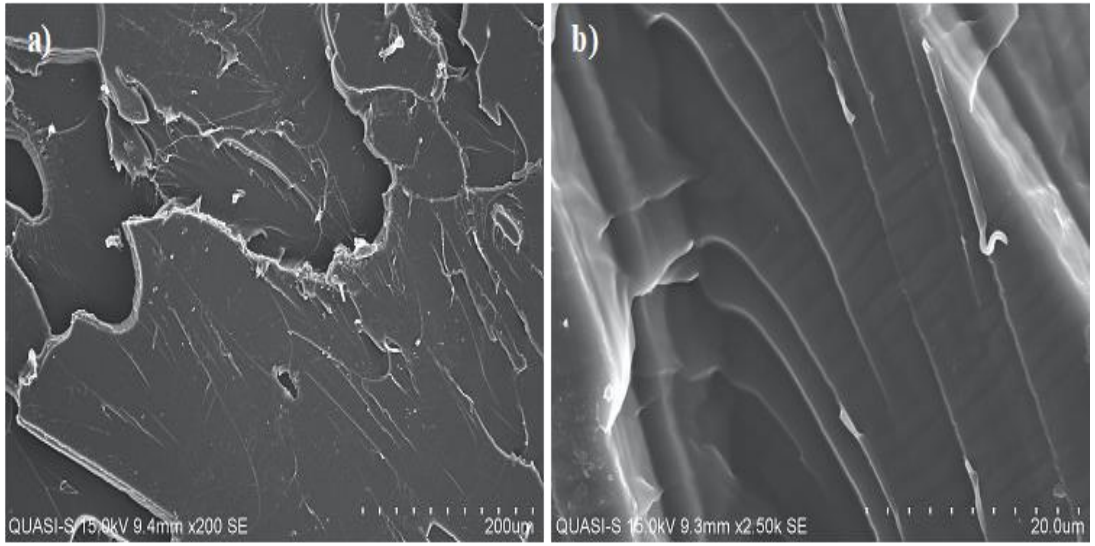


Figure 7. SEM images of neat epoxy fractured surfaces (a) low magnification and (b) at high magnification.

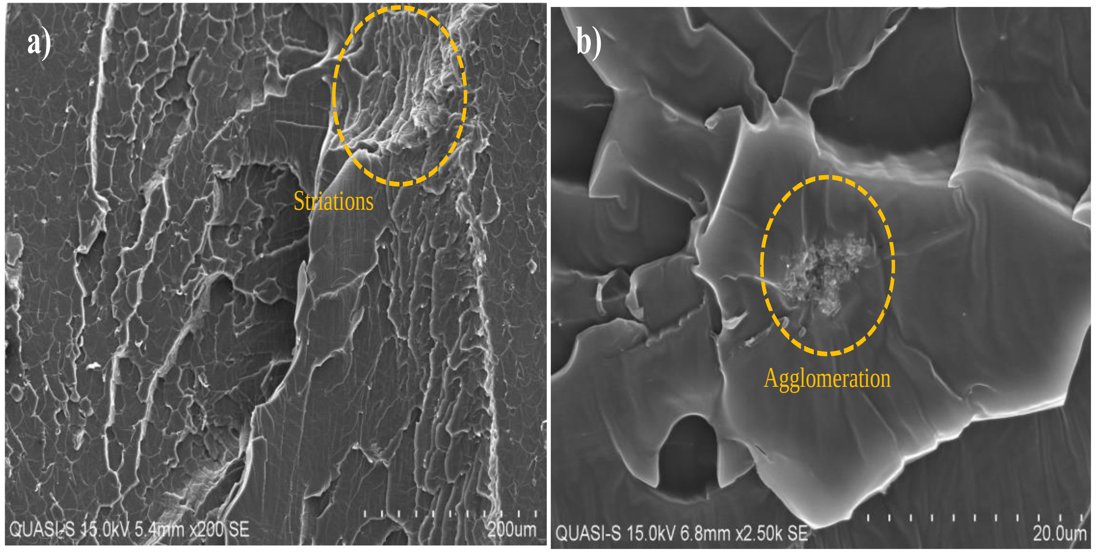


Figure 8. SEM images of MXenes/epoxy fractured surface (a) low magnification and (b) high magnification

SEM Images *cont.*

- The epoxy/MXenes nanocomposite fractured surface morphology (Fig. 7(a)) exhibits a rough surface with striations generated by changes in the direction of crack propagation (i.e., the crack deviated from its original plane).

- It indicated that MXenes were apparently implanted in the epoxy matrix, manifesting two phases' interfaces between MXene and epoxy, indicating greater energy absorption and higher fracture toughness of nanocomposite.

- As shown in Fig. 7(b), MXenes agglomeration was embedded within the epoxy matrix. The epoxy penetrated agglomeration voids to produce spherical particles with a high MXenes volume fraction.

- The appearance of agglomerates in composites then reduced the efficiency of load transfer and crack propagation at the agglomerate-matrix interface, reducing the stiffness of the material.

Conclusion

- Dynamic mechanical analysis revealed lower storage moduli but higher glass transition temperatures, with GnPs/epoxy displaying the highest T_g of 83.79 ^oC.
- Corrosion resistance was enhanced in all nanocomposites, with MXenes/epoxy exhibiting the highest inhibition efficiency.
- Dispersion analysis through SEM and UV-Vis spectrophotometry highlighted the influence of nanofiller dispersion on composite properties.
  - HNTs showed lower corrosion resistance
- MXenes, a 2D materials, demonstrated good corrosion protection.
- The study emphasizes the importance of nanofiller geometry and dispersion in tailoring the properties of epoxy nanocomposites, highlighting their potential for multifunctional reinforcements, including applications in corrosion protection.

Future Research

- Incorporating MXenes into polymer to enhance their mechanical, electrical, and thermal properties is a promising area of research. Future work could focus on optimizing MXene dispersion, interfacial interactions, and the overall properties of MXene-based composites.
- Addressing the issue of agglomeration and achieving stable dispersions of MXenes in various solvents and matrices will be crucial for their practical applications. Future research could explore new dispersing agents, surface modifications, and processing techniques.
- Combining MXenes with other nanomaterials, such as graphene, carbon nanotubes, and metal oxides, could lead to hybrid materials with enhanced or novel properties. Research could explore synergistic effects and potential applications of these hybrid materials.

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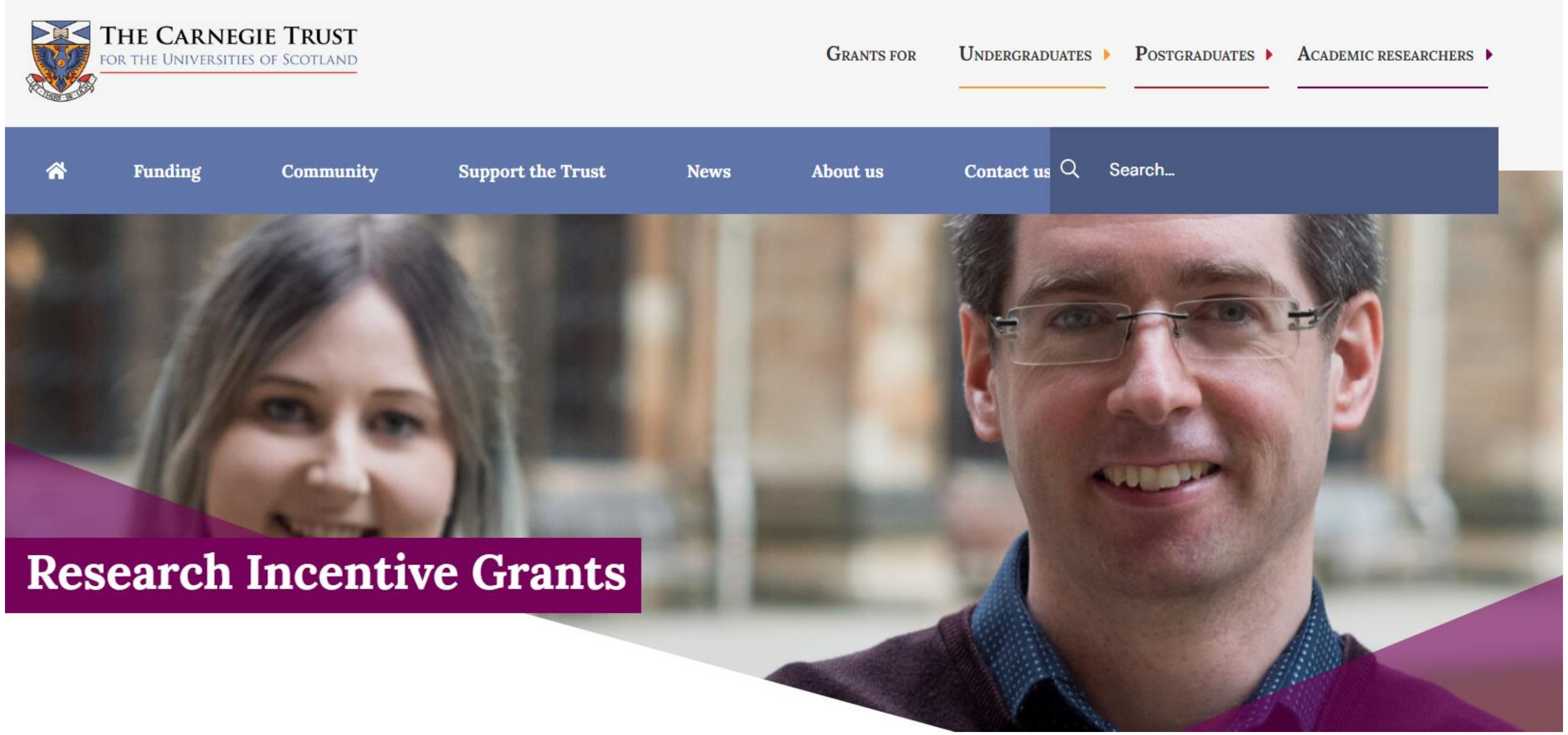

Thank you

Email: s.saharudin@rgu.ac.uk

The Sir Ian Wood Building, Robert Gordon University, Garthdee Rd, Garthdee, Aberdeen AB10 7GE