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Paper 1114
Development of Graphene-hybrid Composite Hydrogen Pressure Tank for Gas Storage Application

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Fibre Reinforced Composites - Session 2, Meeting Room 1A

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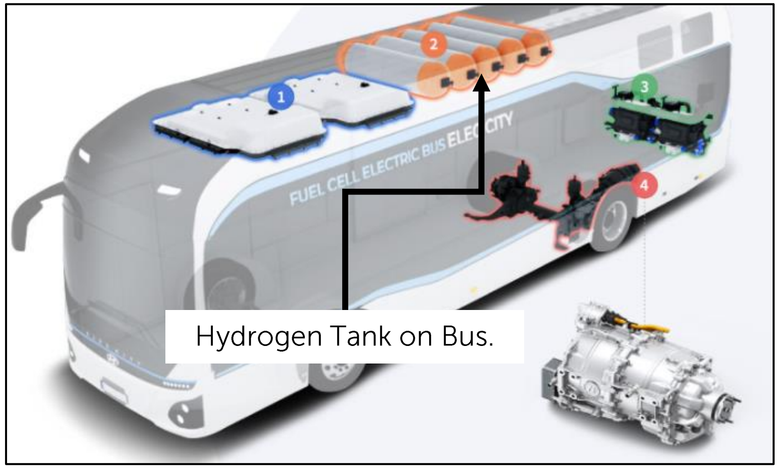
Pressure vessels for hydrogen storage is one of the fastest growing sectors in the composite industry*. Suppliers of carbon fiber may struggle to meet the new spike in demand. Graphene can function as additive to reduce the use of virgin carbon fibers in storage tanks.

- Considering hydrogen cost of USD 2 - 6/kg, a worldwide adoption of H_2 in the years ahead, up to USD 20 billion market is a reasonable estimated value of the role hydrogen will play in the race to reduce global emissions.
- This can be a challenge for Carbon fiber manufacturers to meet the new spike in demand that will require solid commitments from clientele base and a steady tangible demand of the hydrogen supply chains.
- With graphene, it is possible to improve the mechanical properties of the composite material and reduce the thickness of the vessel.
- Graphene can also help to reduce the amount of virgin carbon fibers required to manufacture the vessel, which in turn can reduce the carbon intensity of the produced tank.



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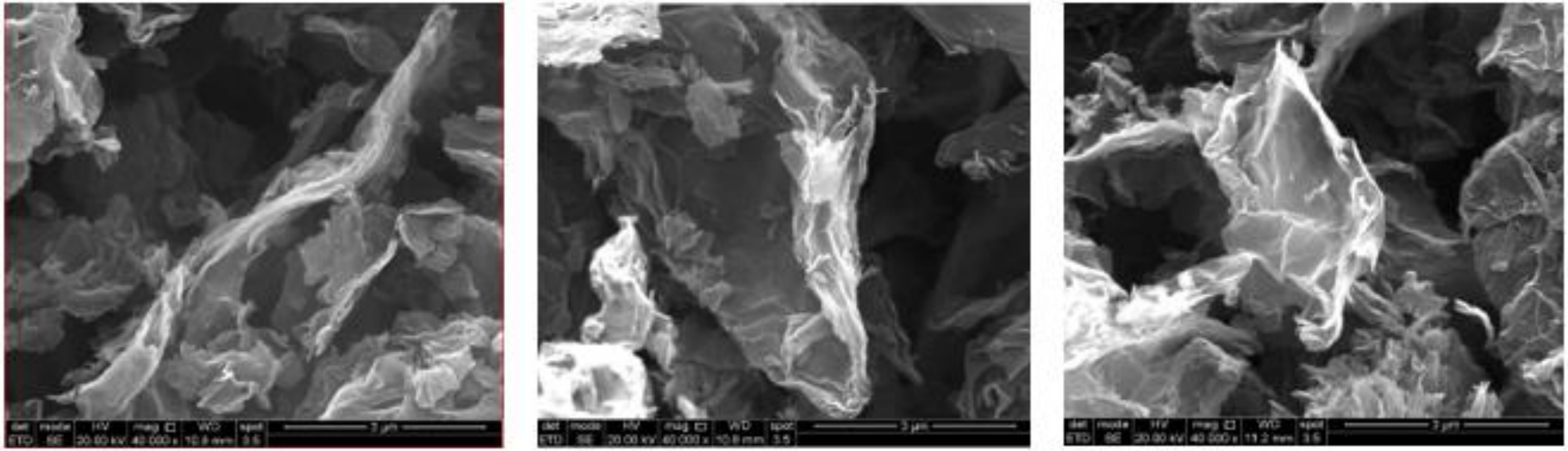
*G. Gardiner. (2020, 15/3/2023). Carbon fiber in pressure vessels for hydrogen. Available: https://www.compositesworld.com/articles/cfrp-pressure-vessels-for-hydrogen
*G. Gardiner. (2021, 15/3/2023). Hydrogen is poised to fuel composites growth, Part 2. Available: https://www.compositesworld.com/articles/hydrogen-is-poised-to-fuel-composites-growth-part-2
*G. Gardiner. (2021, 15/3/2023). Hydrogen is poised to fuel composites growth, Part 1. Available: https://www.compositesworld.com/articles/the-potential-for-hydrogen-to-fuel-composites-growth-part-1

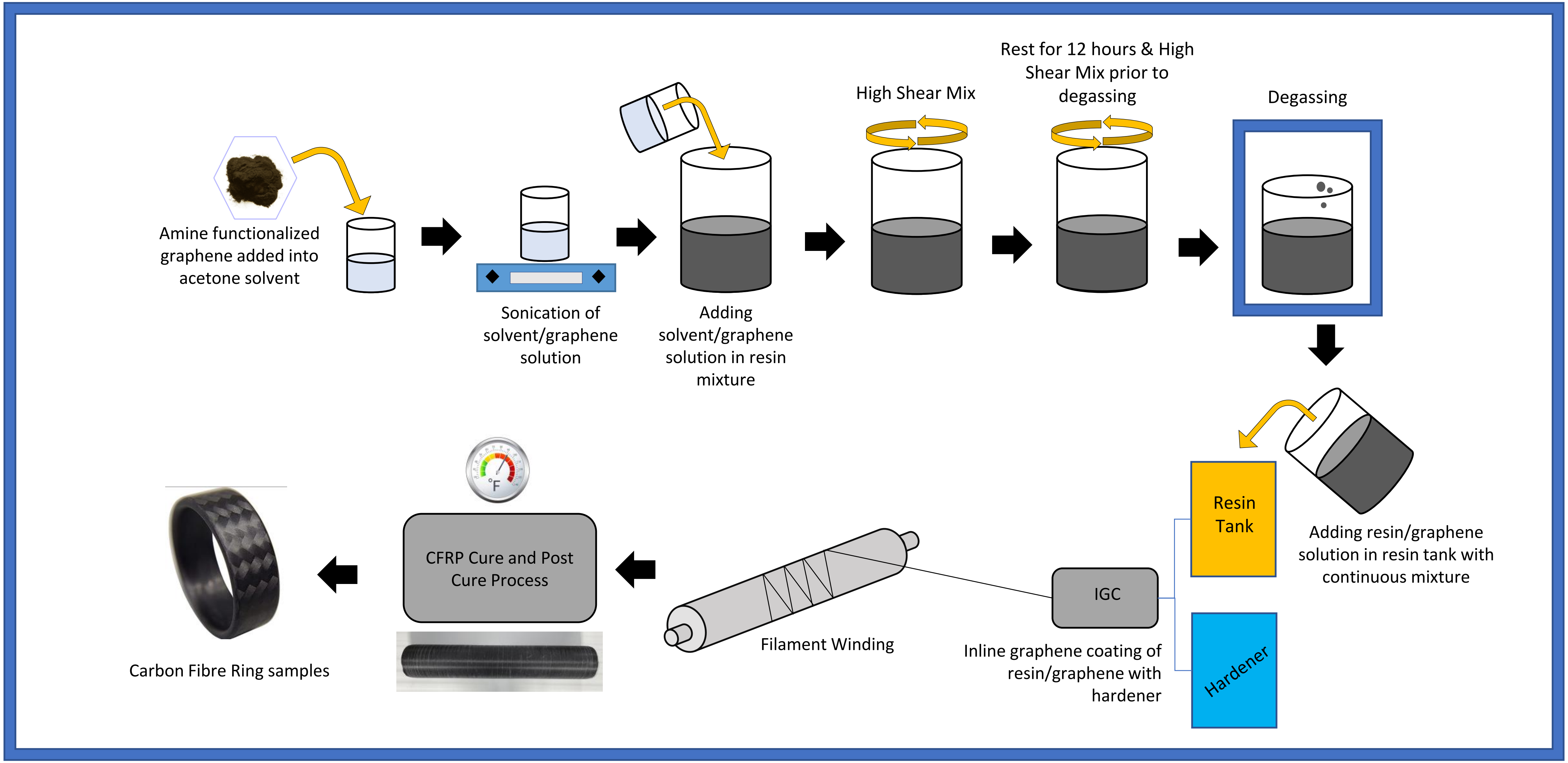
The research objective is to analysed outcomes and present findings in the development of a graphene-hybrid composite utilizing the experimental inline coating technique for compressed hydrogen pressure vessel. Application of chemically functionalized graphene nanoplatelets as reinforcement in the composite system was investigated.

- Optimize materials used for fabrication of pressure vessels through filament winding by graphene addition.
- Determine performance of graphene-coated pressure vessels compared to control composite pressure vessels.
- Investigate the optimum percentage of graphene and type of graphene to improve the pressure vessel system relative to the control pressure vessel in similar conditions.

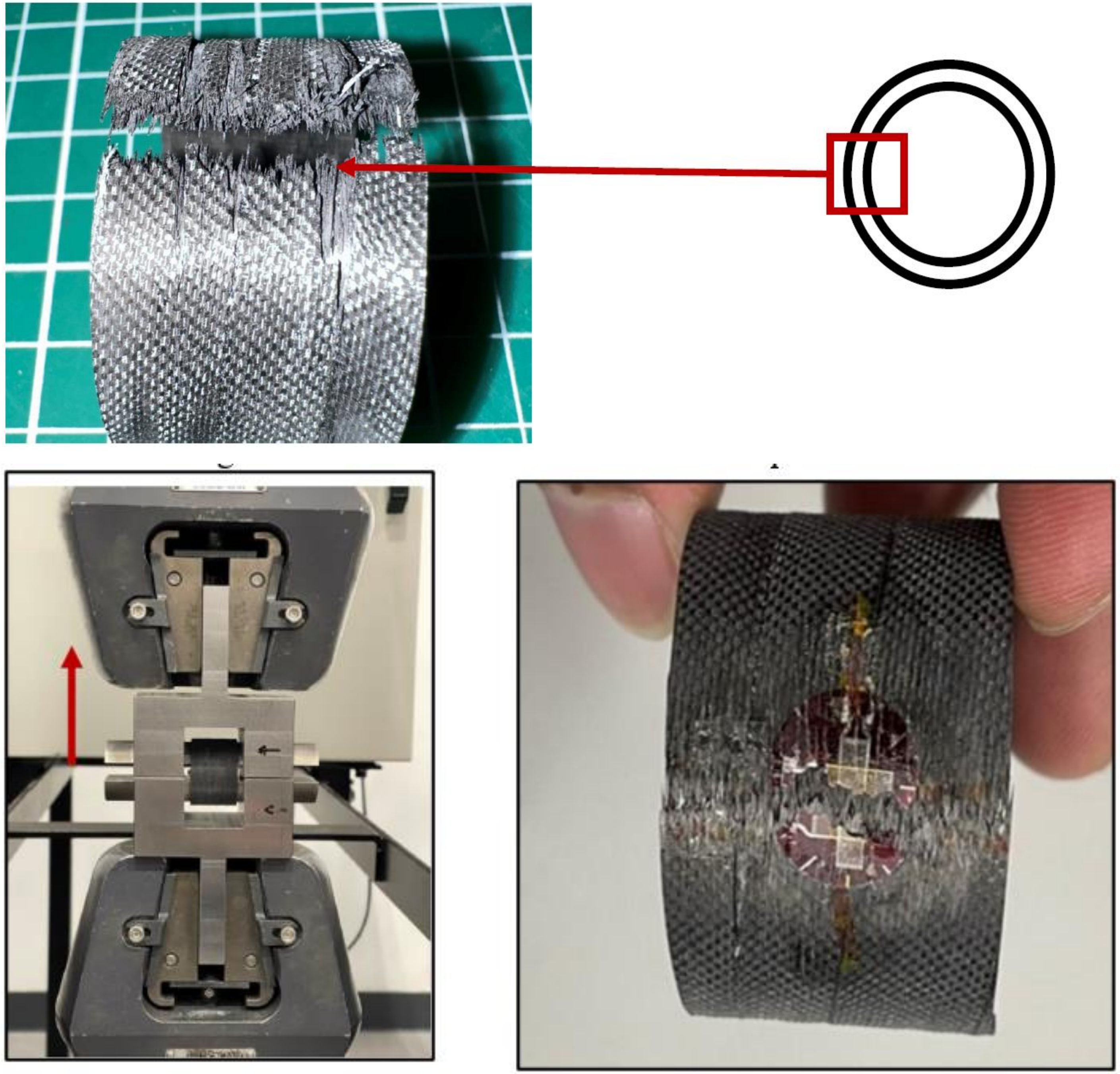


SEM images amine-functionalized graphene at 40,000x.

Methodology



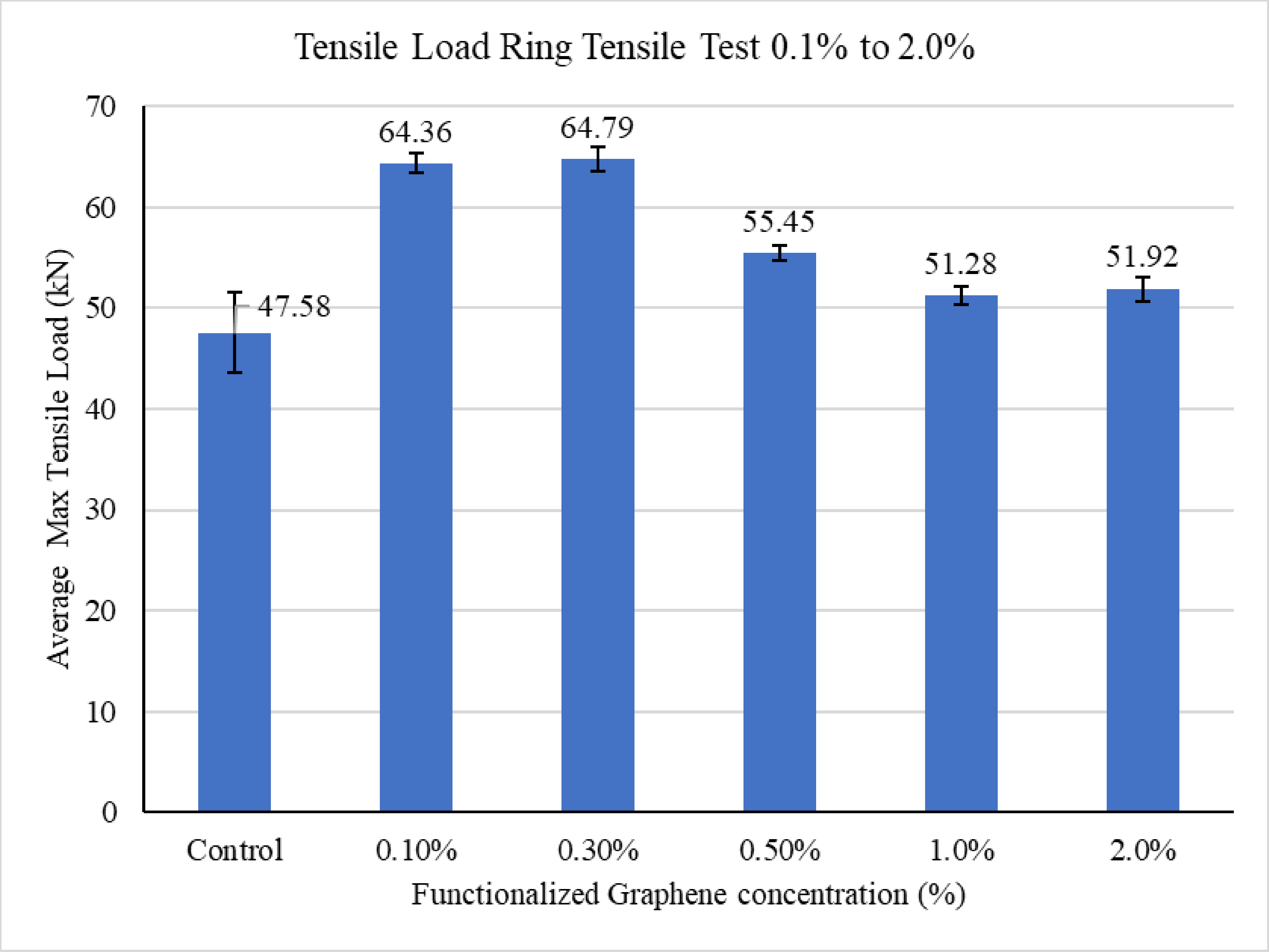
Result – Testing Observation



- In the fabrication, it was observed that thickness of the composite under similar fabrication technique linearly increased with the percentage of graphene added in the resin.
- The test is repeated five times each for control, 0.1%, 0.3%, 0.5%, 1% and 2% graphene concentration samples.
- The failure cross-section area occurred at the 3 o’clock and 9 o’clock position relative to the axial load direction.

Results – Load vs % Graphene

- The findings indicate graphene concentration of 0.1 wt% to 0.3 wt% relative to the resin weight in the composite gives the best performance improvement.
- Tensile performance is seen in 0.1% to 0.3% graphene concentration by 35% compared to unmodified composite sample.
- However, increasing the additive content does not necessarily increase the materials ability to withstand more load



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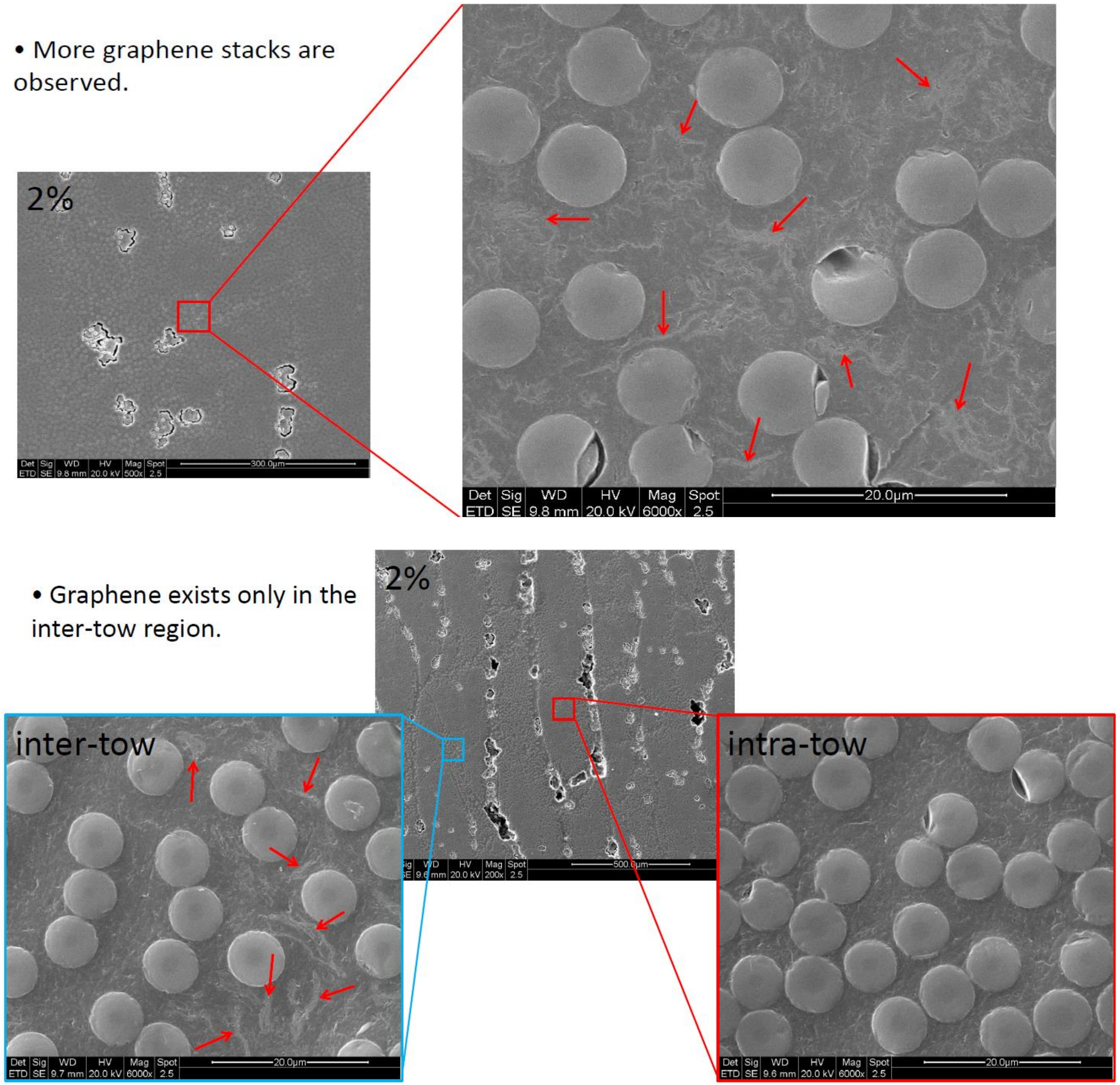
Results - SEM Images

- Graphene material is distributed in the inter-tow region rather than intra-tow.
- Inline coating technique externally applies the resin to cover the filament surface prior to winding process rather than in between the filament.
- Further modification for improving graphene intra-tow penetration is the next step towards uniform distribution in both inter-tows and intra tows area.



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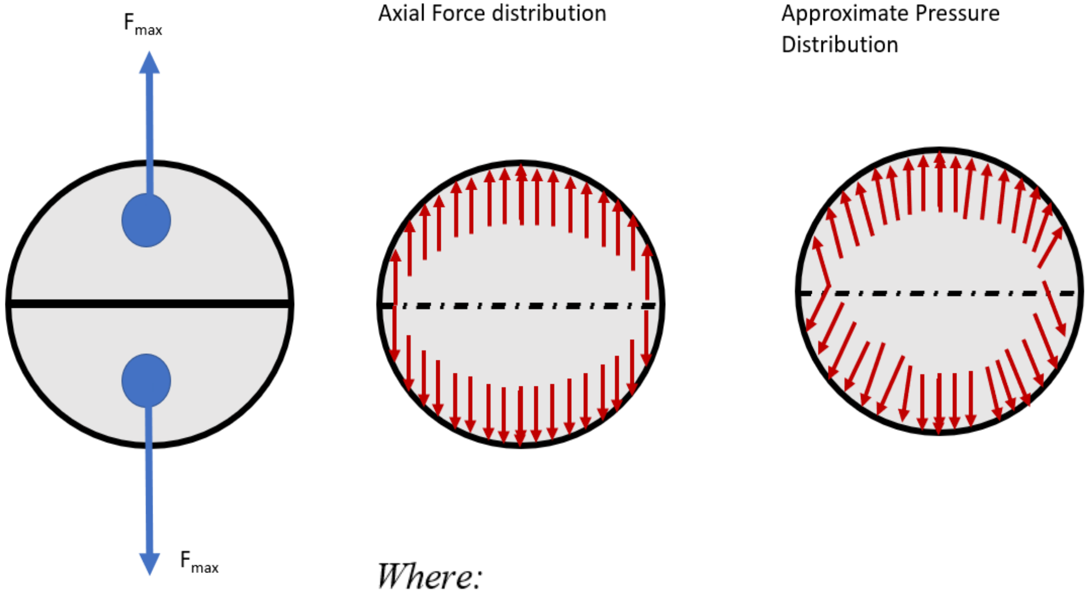
Analysis – Burst Pressure

- The findings indicate graphene concentration of 0.1 wt% to 0.3 wt% relative to the resin weight in the composite
- The vessel can achieve 35% more burst capacity at 0.3% graphene concentration.
- Tensile stresses are created in hoop structures to withstand the bursting action caused by pressure.
- Analysis of the axial loading as a surrogate burst test indicates addition of graphene additives in matrix of composite system will potentially enable higher burst capacity with similar geometric dimensions.



$$P = \frac{F_{max}}{2lr}$$

Where:

t= thickness, mm
l = width, mm
r = radius, mm
P = burst pressure
Fmax= Tensile load at failure, kN
σ_{hoop} *= hoop stress, MPa*

% Graphene	Max Tensile Load (kN)	Burst Pressure (bar)
Control	47.58	601
0.1%	64.36	812
0.3%	64.79	818
0.5%	55.45	700
1.0%	51.28	647
2.0%	51.92	655

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Discussion

- The calculated burst pressure shows a direct correlation between tensile strength and burst capacity.
- The cost of adding graphene additives needs to be less than the cost of virgin carbon fiber composite system that is being reduced.
- Implementation of Graphene in pressure vessel applications requires
    - Uniform intra-tow, and inter-tow graphene distribution inside the matrix composite.
    - Suitable type of graphene
    - Suitable percentage concentration amount throughout the system
    - The right technique to distribute graphene additive in the fabrication technique.

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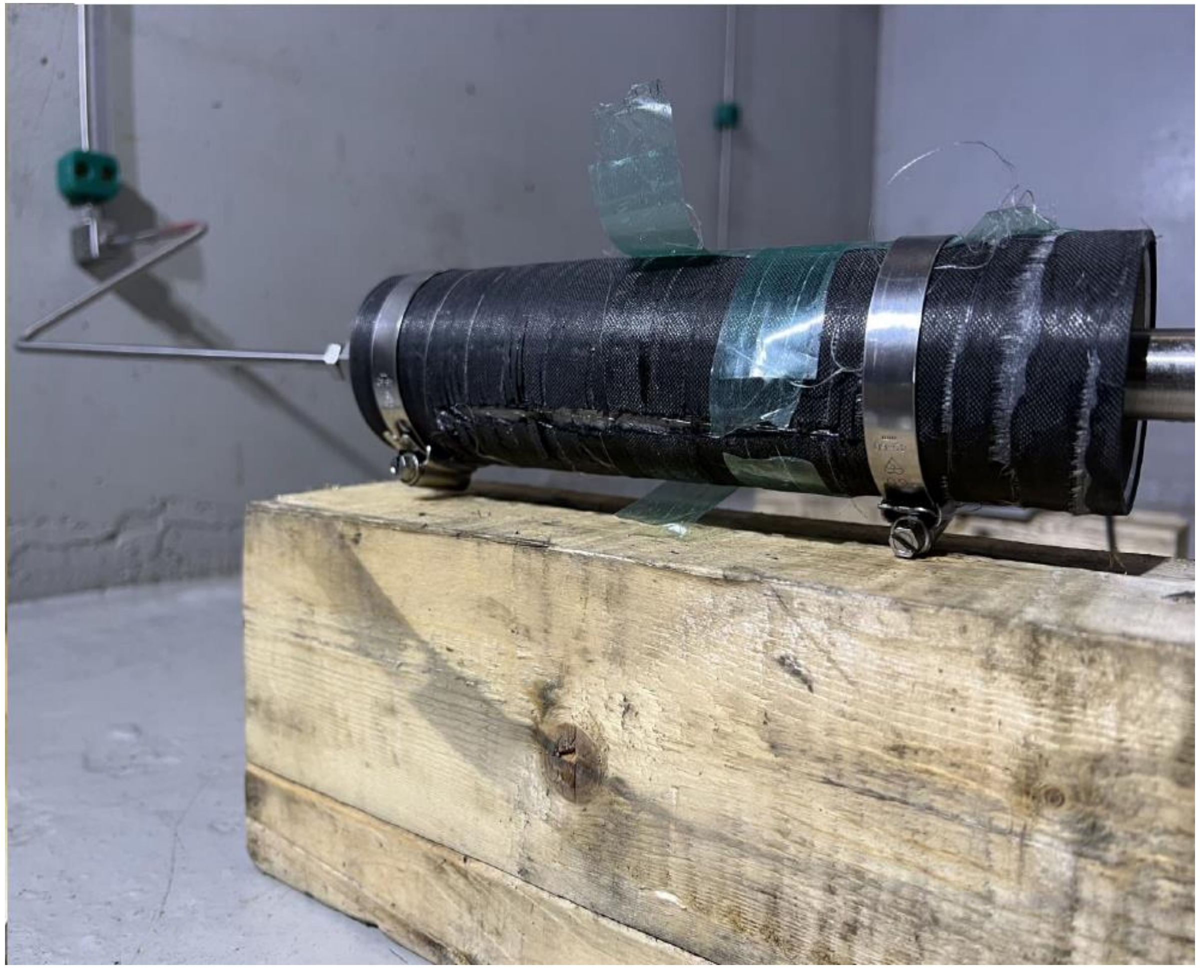
Application of graphene additives in composite pressure vessels presents a favorable solution to reduce the cost, feedstock materials and carbon emissions of carbon fiber composites pressure vessels production.

- Ultimately, potential material reduction can only be confirmed with additional testing such as impact response, cyclic gas test, and full-scale burst test on graphene-added hydrogen storage pressure vessel.
- By utilizing graphene from sustainable sources, carbon can be stored in the form of graphene in composite structures.
- Adding graphene to the composite matrix enhances the material's capacity to sustain further strain prior to breaking.



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