BRAIDED COMPOSITE PIPES INCORPORATED WITH GRAPHENE NANOPLATELETS

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ABSTRACT

Carbon fibre reinforced polymer (CFRP) composites are promising materials for offshore oil and gas industry applications, owing to their high corrosion resistance, specific strength and stiffness. Graphene nanoplatelets have been demonstrated to improve gas barrier properties in CFRP composites and thus CFRP-graphene hybrid composite pipes could provide an alternative to lined pipes. In this work, a method combining braiding, spray coating and vacuum-assisted resin infusion was developed to fabricate the hybrid composite pipes. CFRP pipes spray coated with different GNP loadings (0, 0.1 wt. %, 0.5 wt. % and 1 wt. %) were prepared and cut into rings. Afterwards, compressive tests on both axial and radial directions were performed. As a result, for the axial direction, both compressive strength and modulus remained unchanged within error. For the radial direction, the elastic modulus increased at first followed by a continuous decrease with the inflection point at 0.1 wt. %. This is because properties in the axial direction of the composite pipes mainly depend on the reinforcing carbon fibres; when it comes to the radial direction, it is typically governed by a combination of the fibres, the matrix, and their corresponding interfacial interactions.

1 INTRODUCTION

In recent decades, the offshore oil and gas production has moved sharply away from shallow water reserves towards 'deep water' production [1]. However, current steel tether design is unable to work deeper than 1500 m without a large-size platform that counterbalances high axial tension mechanics. In this case, substituting materials with light weight are in demand to provide essential savings [2]. Consequently, for the 'deep water' (up to 1500 m) and 'ultra-deep water' (3000 m) offshore exploration and production, non-metallic and lightweight composite materials are needed urgently for easier transport and installation [3]. Carbon fibre reinforced polymer (CFRP) composites are promising materials owing to their high corrosion resistance, specific strength and stiffness, which have been widely used in aerospace and automotive fields. However, CFRP have poor gas barrier performance meaning that a liner has to be inserted. Graphene nanoplatelets (GNPs) have been demonstrated to improve gas barrier properties in CFRP composites [4] and thus CFRP-graphene hybrid composite pipes could provide an alternative to lined pipes.

In this work, four layers of carbon fibres were braided to form the pipes, with different loadings of GNP spray coated onto interfaces, followed with vacuum assisted resin infusion to fabricate the CFRP-GNP hybrid composite pipes. After cured, the pipes were cut into rings for compressive tests on both axial and radial directions, to investigate the effect of GNP addition on mechanical properties of CFRP pipes.

2 EXPERIMENTAL

2.1 Materials

Graphene nanoplatelets (GNPs) from XG sciences (Grade M15) were used as the fillers in this work, which have an average particle diameter of ~ 6.6 µm [5], thickness of 6–8 nm (~ 20 layers of graphene) and density (ρg) of 2.2 g cm−3. Toray (Japan) T700 12K carbon fibres were used for braiding. Araldite epoxy resin and Aradur hardener from Huntsman (USA) were used as the low viscosity epoxy resin and hardener. Acetone was supplied by Fisher Scientific (UK).

2.2 Pipe fabrication

The 2D tubular carbon fibric sleeves were braided onto a 50.8 mm-diameter steel mandrel by using a 48-carrier maypole type braiding machine (Cobra Braiding Machinery Ltd) [Prasad1-3], with the braiding angle at ±71°, as shown in Figure 1a. After the first layer of sleeves braided, the whole mandrel was moved from the machine to a fume hood for various loadings (0, 0.1, 0.5 and 1 wt. % of the carbon fibre) of GNP spray coating [J5-6], afterwards, moved back to the machine for the second layer sleeves braiding, repeated until the fourth layer sleeves braided. The whole assembly was then infused with epoxy resin by vacuum assisted resin infusion (VARI), as shown in Figure 1b, and cured at 80 ℃ for 2 hours followed by 140 ℃ for 8 hours. After cured and demoulded, composite tubes were cut into rings with the height at ~13 mm for compressive testing, as shown in Figure 1c.

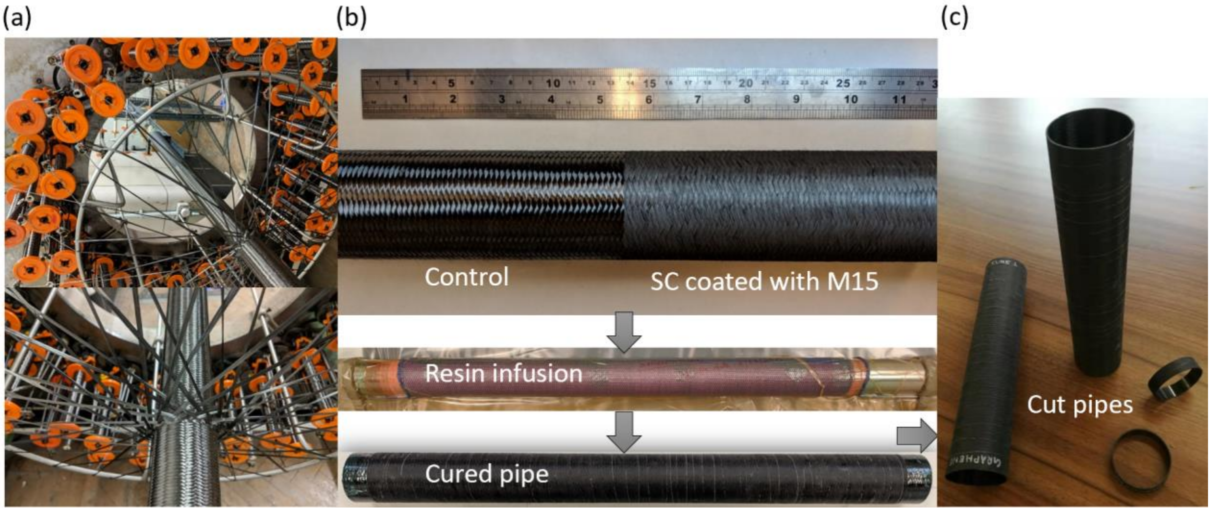

Figure 1: Images of the (a) carbon fibre braiding procedure; (b) composite pipe fabricated by vacuum assisted resin infusion (VARI); (c) cured pipes and cut rings.

2.3 Compressive testing

Compressive tests on both axial and radial directions were carried out based on the ASTM D695 and ASTM D2412 standards [1-2] respectively, with three specimens tested for each GNP loading. Regarding the axial compressive tests:

$$\sigma = \frac{F}{A} \quad (1)$$

where σ is the compressive stress, F is the load and A is the cross-sectional area of the specimen.

While for the radial direction tests, pipe stiffness (PS) and elastic modulus (E) can be obtained based on the ASTM D2412:

$$PS = F_u/\Delta y \quad (2)$$

$$PS_c = C * F_u/\Delta y \quad (3)$$

$$C = (1 + \Delta y/2d)^3 \quad (4)$$
$$SF = EI = 0.149r^3PS \quad (5)$$
$$I = t^3/12 \quad (6)$$

where PS is the pipe stiffness (MPa), F_u is the force per unit length (kN/m), Δy is the vertical ring deflection (mm), C is the correction factor, d is the initial inside diameter (mm). SF is the stiffness factor, E is the Elastic modulus of the pipe wall (GPa), I is the centroidal moment of inertia of the pipe wall cross section per unit length of the pipe, r is the mean radius (mm), t is the pipe wall thickness (mm).

3 RESULTS AND DISCUSSION

3.1 Morphology

Braided carbon fibres spray coated with different GNP loadings (0, 0.1, 0.5 and 1 wt. % of the carbon fibre) were characterized by SEM, as shown in Figure 2. The dimension of GNPs varies from 1 μm to 27 μm, with an average particle diameter of ~ 6.6 μm [5], and distributed on the surfaces and interfaces of carbon fibres.

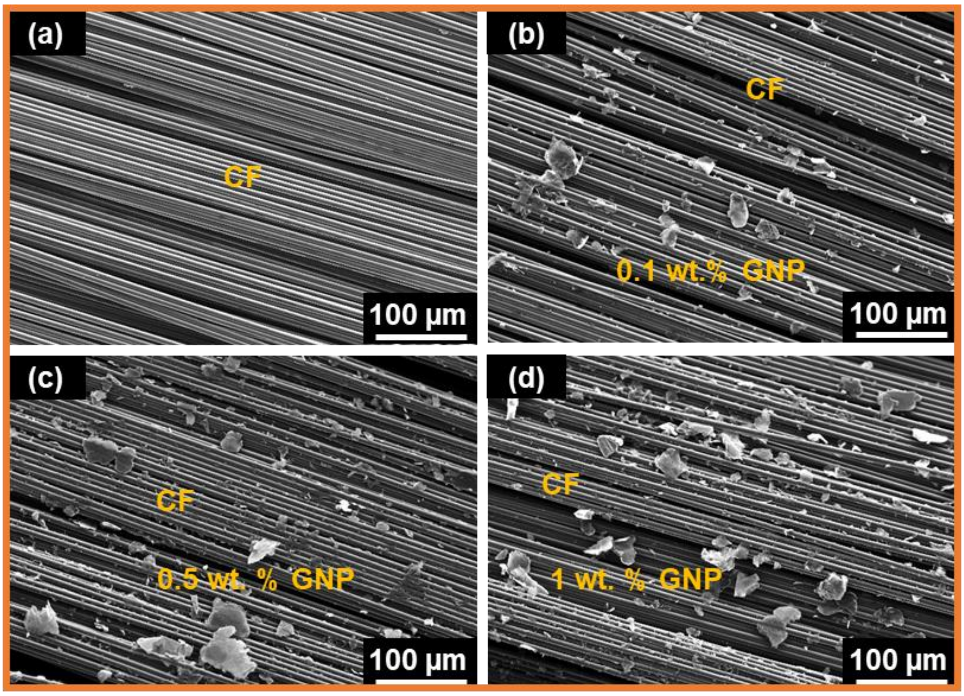

Figure 2: (a-d) SEM images of carbon fibres spray coated with 0, 0.1 wt. %, 0.5 wt. % and 1 wt. % GNPs.

3.2 Axial compressive properties

The axial compressive stress-strain curves, at both transverse (90°) and longitudinal (0°) directions, are summarized in Figure 3. Corresponding axial compressive strength and modulus of the composite rings with different GNP loadings are shown in Figure 4. For both the axial compressive strength and modulus, composite rings with different GNP loadings resulted with comparable values considering the error bars, namely the GNP addition has bare effect on them, as the axial properties of the composite pipes are dominated by the carbon fibres.

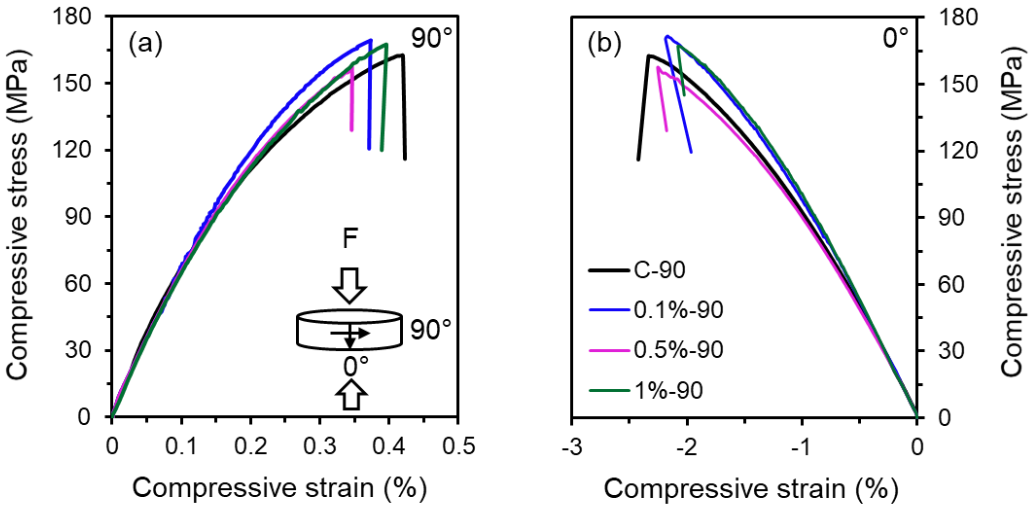

Figure 3: Stress-strain curves of the CFRP composite rings with different GNP loadings under axial compression, at both (a) transverse (90°) and (b) longitudinal (0°) directions.

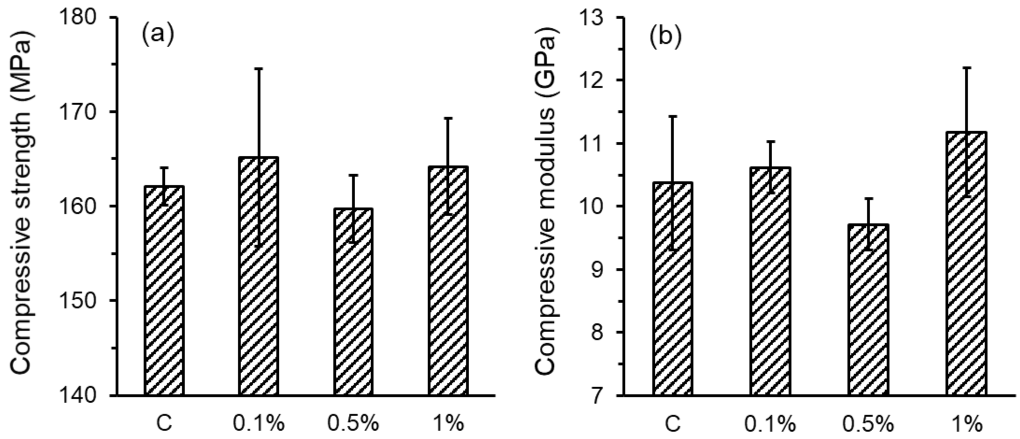

Figure 4: Axial compressive (a) strength and (b) modulus of the composite rings with different GNP loadings.

3.3 Radial compressive properties

The radial compressive load-displacement curves and force per unit length-deflection curves of the CFRP composite rings with different GNP loadings are illustrated in Figure 5, with the corrected pipe stiffness and elastic modulus of the rings summarized in Figure 6. Compared with the axial properties, composite rings with 0.1 wt. % GNPs spray coated onto carbon fibres achieved 5.8% and 1.7% improvement in pipe stiffness and elastic modulus respectively, indicating the GNPs could be used to strengthen the matrix and interface. While higher loadings, 0.5 wt. % and 1 wt. %, led to decreased pipe stiffness and elastic modulus. This could be caused by the insufficient load transfer between as received GNP fillers and matrix or carbon fibres, as a result, GNPs led to stress concentration and reduced mechanical performance.

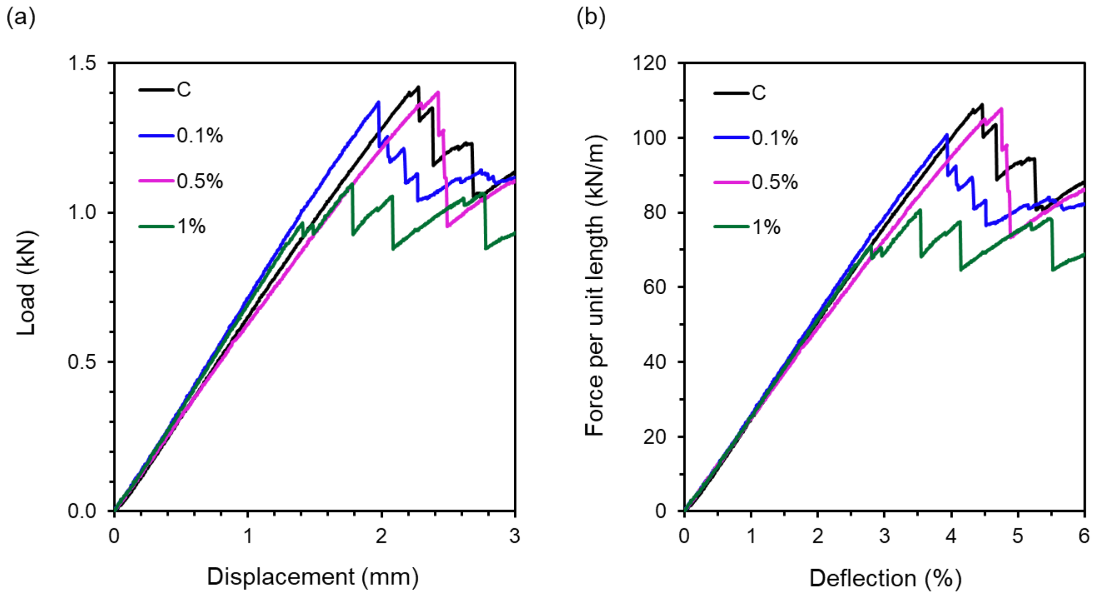

Figure 5: (a) Load-displacement curves and (b) force per unit length-deflection curves of the CFRP composite rings with different GNP loadings under radial compression.

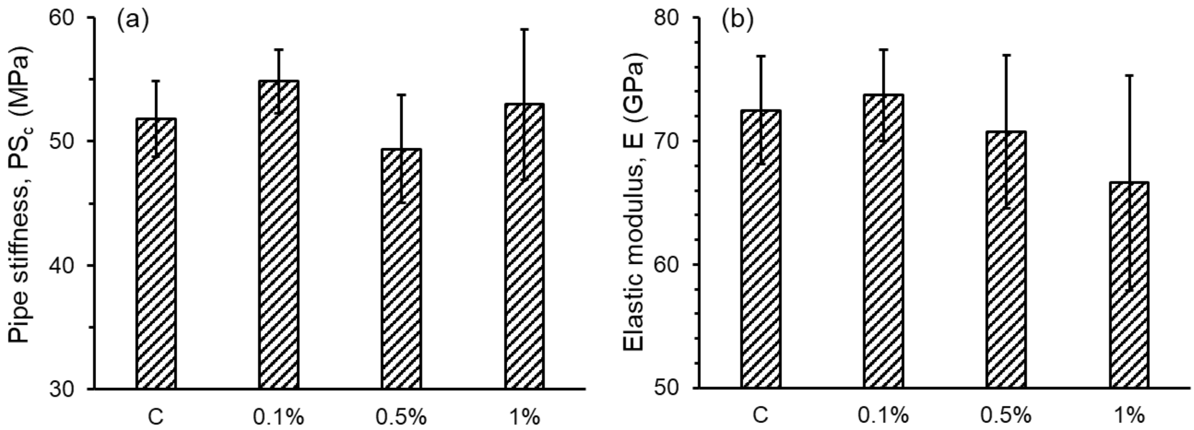

Figure 6: (a) Corrected pipe stiffness (PSc) and (b) elastic modulus (E) of the composite rings under radial compression, considering both 2.5% deflection and failure point conditions.

4 CONCLUSIONS

In general, the axial compressive behaviour of the GNP/CFRP hybrid composite rings is similar to tensile properties of panel samples as we reported before, that GNPs have no obvious effect on them, as both of them are dominated by the carbon fibres. While radial compressive properties of rings and flexural properties of panels got improved at lower GNP loadings, then decreased with the loading further increasing, as they are affected by both carbon fibres, GNPs, epoxy resin and their interfacial properties.

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