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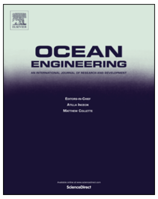

Review

A review on design, manufacture and mechanics of composite risers

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ABSTRACT

Exploration of deeper oceans for oil and gas requires increasingly lightweight solutions. A key enabler in this aspect is the use of fiber-reinforced composite materials to replace metals in risers. However, design synthesis and analyses of composite risers are more challenging than for conventional metals due to the complex behavior and damage mechanisms which composite materials exhibit. Composite risers are predicted to be a high-impact technology that will be mainstream in the medium term but there is still relatively little literature pertaining directly to the behavior of these materials under the complex loading scenarios arising from their use in deep water structures. Therefore there is a need to perform a review and assessment of the available technologies and methodologies in the literature to gain a good understanding of their predictive capabilities, efficiency and drawbacks. This article provides a comprehensive review of published research on manufacture, experimental investigations and numerical analyses of composite risers in deepwater conditions determining the gaps and key challenges for the future to increase their application.

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1. Introduction

Fiber reinforced polymer composites are increasingly being used in the marine and offshore industries. This is especially the case for pipelines/risers, stress joints and fluid handling since composites offer many important advantages over metals due to their high specific strength and stiffness, good durability, low thermal conductivity and good corrosion resistance (Meniconi et al., 2001; Salama et al., 2002; Smith and Leveque, 2005; Suresh et al., 2004; Tamarelle and Sparks, 1987). The current trend for the offshore industry is towards deeper applications; there were 44 fields over 500 m depth in 2000 and 200 in 2007 (Quest Offshore, 2011). The production of oil from deep waters is expected to increase from 2.5 million barrels per day in 2004 to 8.25 million barrels in 2015 (Lloyd's Register, 2013).

During this production process the oil must be transported from the well-bore at the seabed to the connecting rig on the surface and this is generally performed through tubes called risers. These risers are long and relatively thin, with predicted depths of 4 km and typical diameters of 100–300 mm (Tarnopol'skii et al., 1999). Risers are also used for drilling which transfer mud to the surface or for production which transport hydrocarbons, control fluids or gas. Depending on the operating depth range, different riser configurations are used. Fig. 1 schematically shows different riser/platform configurations together with a range of operating depths. For some riser applications, such as the Tension Leg platform, a problem is that the required top tension escalates considerably with increasing length of the risers.

A number of studies have demonstrated the potential for fiber reinforced polymer (FRP) composites in deep-water risers at water depths more than 1500 m (Tarnopol'skii et al., 1999; Beyle et al., 1997). According to Tarnopol'skii et al. (1999), thermoplastic composite risers (TPCR) offer good solutions to current limited technologies in Top Tensioned Risers (TTRs) and Steel Catenary Risers (SCRs). Both the metal TTRs and SCRs are generally not able to support their own weights at water depths higher than 1500 m and the costs for these buoyancy and compensation systems may further increase with water depth. Ochoa and Salama (2005) acknowledged the potential application of composite risers to extend this capability to a depth of 3000 m with Tarnopol'skii et al. (1999) showing a calculation for steel and composite riser design showing that conventional steel risers would be 90,000 t compared to a similar composite riser which would be approximately 20,000 t. Ward et al. (2007) compared the performance of steel and CFRP composite production risers operating in the Gulf of Mexico. The risers have an approximate length of 1800 m, an outer diameter of 0.3 m and a wall thickness of 0.25 m. The top tension required for the composite riser was reported by Ward et al. (2007) 2.7 times less than for the steel using load cases of normal shut-in with 1-year winter storm and 100-year hurricane. Furthermore, the size of the tensioner joint and tapered stress joint needed at the top and bottom of the composite riser system are considerably smaller than the all steel system. Ward et al. (2007) also reported risk analyses, in terms of the failure modes and hazard, of the steel and composite risers. It was shown that composite risers offer better resistance against many failure modes over steel including burst, collapse, axial yielding of liner, leakage and crack through the liner and the composite tube. However, there are some issues with composites in deep water conditions. Tan et al. (2015) concluded that composite risers are more vulnerable to vortex-induced-vibrations (VIV) than steel configurations and therefore fatigue damage for the composite yielded 25.5% higher root mean square (RMS) strains. It is suggested that some of these effects could be negated by increasing the fiber-winding angle increasing the load bearing properties and raising eigenfrequencies, mitigating the VIV. These affects are increased by the degradation of the material properties due to water. Rege and Lakkad (1983) showed the effects of salt water on glass and carbon fiber materials where the results show that there is a reduction in strength related to the percentage of weight gained, the flexural strength is more severely degraded than other properties. The strength values decrease is related to temperature where an increase leads to greater deterioration, which could be problematic for deeper reservoirs. Siriruk and Penumadu (2014) studied the effect of sea condition on cyclic fatigue showing that there was a degradation in fatigue, compared to testing of dry laminates in air, of 30% for wet laminate tested in air which compared to 71% for dry laminates immersed in water and 84% for wet laminates immersed in water. This shows a dramatic reduction in the fatigue life of the composite. The results obtained for water confined samples with exposed edges, may overstate the case for marine structures since in many cases only one face will be exposed to sea water and these results show that dry laminated with one side immersed lost 42% of their cyclic life and wet one side immersed lost 47%. Kaboudian et al. (2014) looked at the distribution of tension along a composite riser showing that this was relatively constant and that therefore failures will be more scattered than for steel. They found that the addition of buoys along the riser causes kinks in the tension distribution and advised that long continuous buoys should be added along the bottom-half of the riser, instead of shorter buoys with gaps. The longer buoys reduce high bending strains at the buoy edges and longer modules are also better at reducing the effects of VIV. Chen et al. (2013) performed a further study into the effects of VIV in composite risers and showed that the high stiffness of the liner reduces the overall performance of the riser as the high strength of the composite can not be fully utilized. The composite risers require lower top-tension and less or even no buoyancy leads to a significant reduction in the weight hanging from the platform deck, this is economically beneficial which increase with increasing length. Tan et al. (2015) performed an analysis of coupled fluid-structure simulations against full scale experiments of 1500 m steel and composite risers. The results show a close correlation and goes on to compare aluminium, steel and titanium liners showing this is the weakest link for composite riser design. The titanium liner riser yielded 20% lower RMS strains than the aluminum liner riser and 10% lower RMS stress than the steel liner riser concluding that titanium alloys are a better choice than steel due to their density, wear and corrosion resistance.

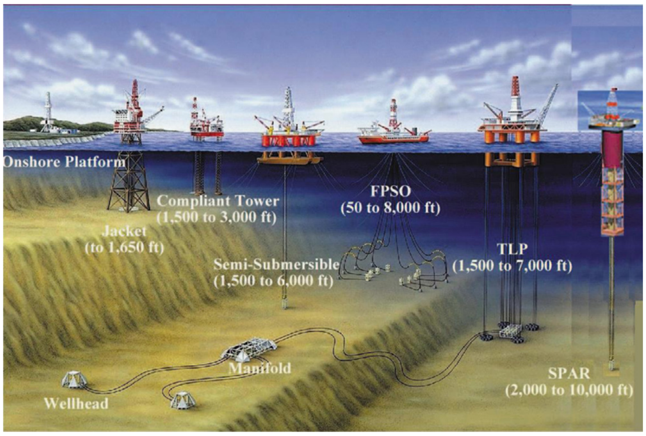

Fig. 1. Different types of Platforms and Risers, Huang (Huang, 2012).

Composite risers can be classified into two main types: bonded where there is binding between the riser's layers, and un-bonded where riser's components are able to move relative to each other, shown in Fig. 2. Bonded risers often include a core fiber-reinforced angle ply laminate sandwiched between a metallic/elastomeric

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