*The 2013 World Congress on*
***Advances in Structural Engineering and Mechanics (ASEM13)***
*Jeju, Korea, September 8-12, 2013*

# Fracture behavior of prototype steel-GRP (hybrid) riser under internal fluid pressure

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## ABSTRACT

This study describes the fracture behavior of prototype steel-glass reinforced plastic (S-GRP) riser under internal fluid pressure. Subsea marine riser comprising of hybrid metal composite materials has recently drawn keen industrial attention. In comparison to metallic riser, this kind of composite riser have already proven to be cost effective comparing the specific strength. The hybrid riser structure used in the study consists of a steel liner and composite layer. The composite layers have been manufactured from symmetric layers of four harness satin weave configuration. The prototype specimens were prepared according to DNV-RP-F202. A static burst test is carried out to determine the critical burst pressure of the hybrid riser. The failure mode of the fractured specimen is investigated and analyzed using scanning electron microscopy (SEM). The improved burst pressure results show that, hybrid riser developed in this study is indeed a feasible alternative over the conventional metallic riser.

## 1. INTRODUCTION

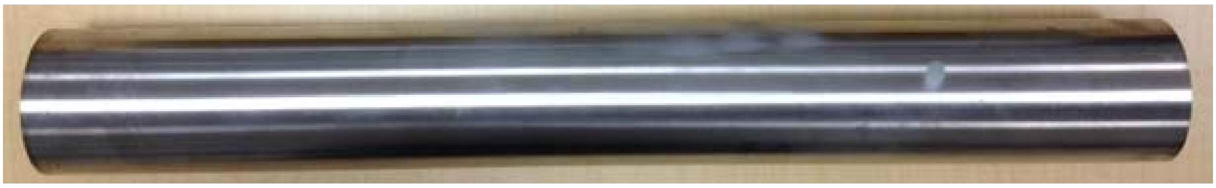
Oil explorations from shallow coastal environment have decreased sharply in recent years. Due to this, oil production from deep waters (3,000m and above) have increased prominently. Even in deep waters, the tension leg platforms widely used provides the economic feasibility for drilling and production. When the drilling proceeds into deep water, the steel riser becomes challenging to accommodate due to its weight. This attracted serious research attention to develop composite based risers for drilling and production. There is a growing interest to move from steel riser to composite riser due to the numerous potential benefits. One of the most significant advantage is that composite material have higher strength to weight ratio compared to metallic materials and can be exploited advantageously to replace metallic riser for deep water applications. Another potential advantages is that the bursting pressure of a composite pipe with adequate thickness exceeds that of a steel pipe.

A number of codes and standards govern the design of marine riser or pipe, so the conformity with recommended practice & standards is required to design standard pipe with suitable safety factor for specific field use. According to our knowledge, only DNV (Det Norske Veritas) has developed a dedicated recommended practice for composite (fiber reinforced plastics) risers . Most of the codes follow similar guidelines

for practice.  There is a significant amount of literature available on burst test on steel riser and composite pipe(Takayanagi, Xia et al. 2002, Ramirez, Engelhardt et al. 2006, Gemi, Tarakçioğlu et al. 2009, Mertiny, Juss et al. 2009, Bai, Xu et al. 2011, Li, Chen et al. 2011). Various approaches adopted by researchers in order to achieve best performance of end fittings during test are available in literature (Chang 2003, Wakayama, Kobayashi et al. 2003, Mertiny, Juss et al. 2009, Onder, Sayman et al. 2009, Ramirez, Ziehl et al. 2009, Vereshaka, Karash et al. 2012). A similar background literature and well-established design practices are not available for hybrid risers. Therefore, there is a need to investigate, evaluate and analyze the hybrid composite riser failure modes.
Due to feasibility and cost limitation concerns, the experiment is conducted with reduced scale of pipe structures. The pipes for internal pressure testing were fabricated and an in-house facility has been developed for burst testing.

## 2. EXPERIMENTS

This section describes about the materials used for fabricating the hybrid composite riser. The in-house developed test setup and procedure to conduct experiments of burst is also discussed.



(a) Virgin sample of stainless steel pipe

(b) Stainless steel pipe after sand blasting

Fig. 1 Stainless steel pipe used for testing

### *2.1 Material and manufacturing methods*

The hybrid riser construction includes a 304 stainless steel pipe as shown in Fig. 1a as an inner liner. These pipes are of 650 mm in length and have 76.23 mm external diameter with 1.5 mm wall thickness. A woven glass fiber reinforced plastic (GFRP) prepreg supplied by J .D. LINCOLN, INC., is used as the bonded external layer of the hybrid metal composite riser. This prepreg consists of T300 and 2K filament count tow glass fibers with Bisphenol A/epichlorohydrin epoxy (resin content 40%). The outer surface of steel pipe was sand blasted as shown in Fig. 1b, to improve the adhesive behavior. The hand lay-up technique was used to manufacture the composite pipe with layer thickness of 1.5 and 3 mm respectively over the steel liner. The wall thickness of the steel and composite pipe used for testing is shown in Table 1. These samples were cured in furnace at a temperature of 120 °C up to 4 hour, to achieve maximum strength of the hybrid riser.

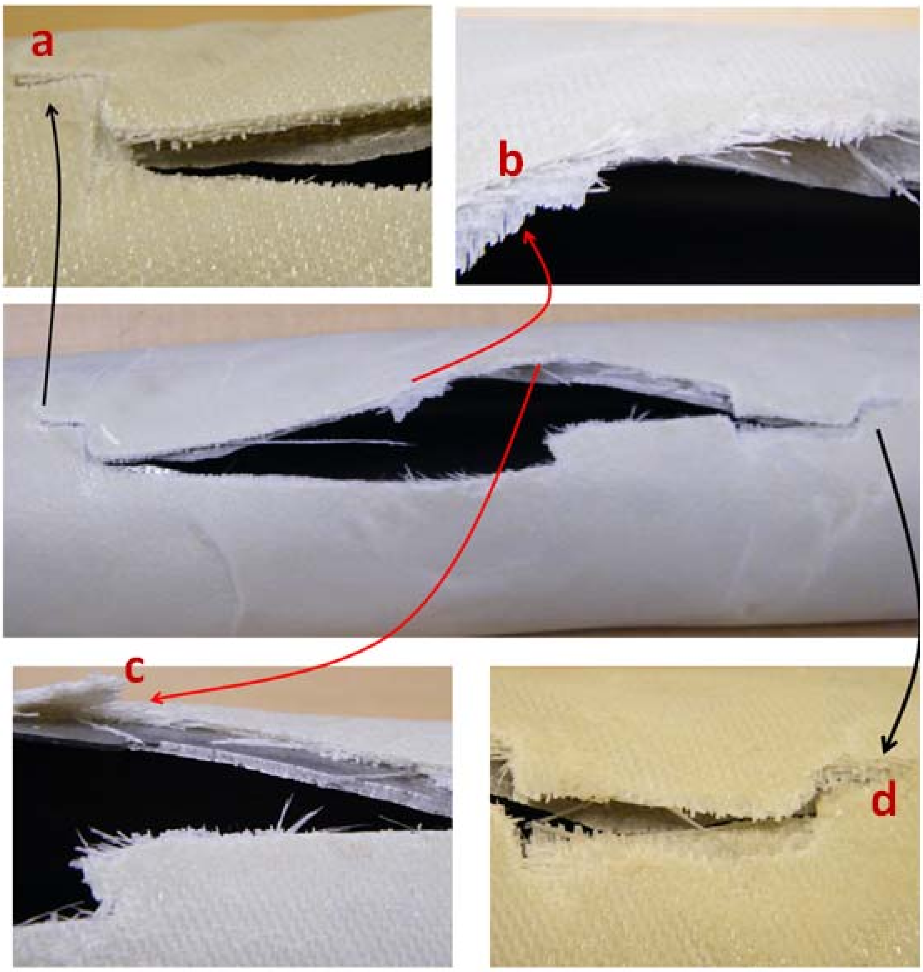


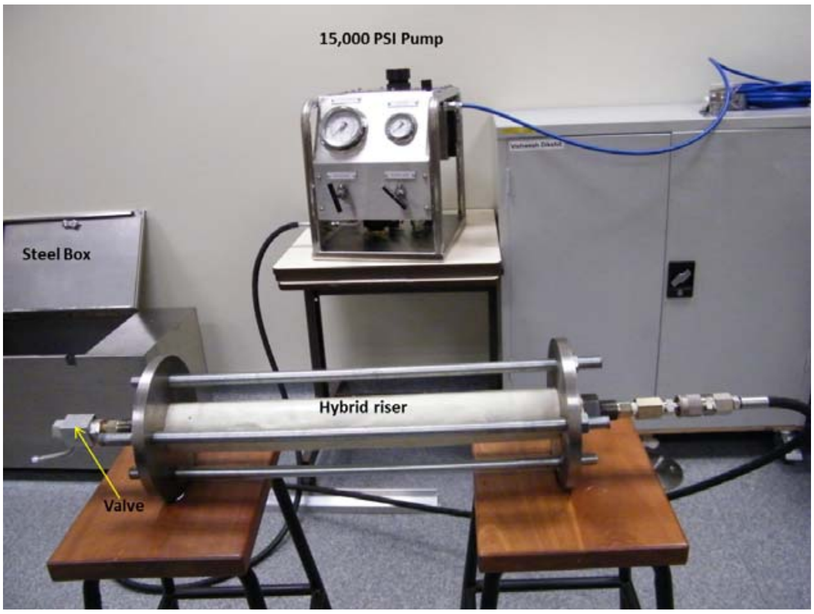

Fig. 1 Photographs of fractured hybrid composite pipe after burst

Table 1: Dimensions of the test samples

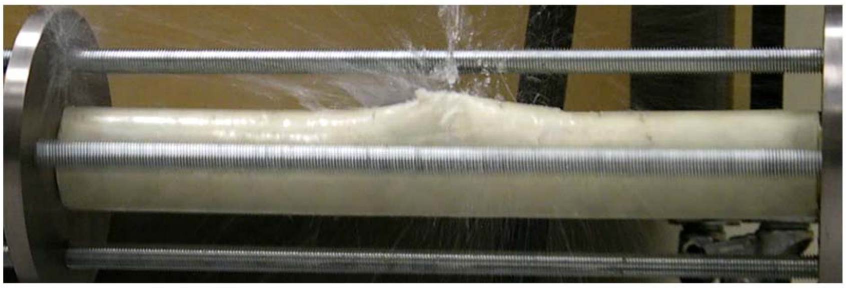
| Steel wall thickness(mm) | Composite wall thickness (mm) | Number of specimen |
|---|---|---|
| 1.5 | 0 | 3 |
| 1.5 | 1.5 | 3 |
| 1.5 | 3 | 3 |

## 3. Test setup and procedure

The test rig to conduct burst experiments is shown in Fig. 2a. The in-house developed set-up consists of an air driven hydraulic pump to apply internal pressure. The pump is connected to the pressure valve by hose and fittings, which are rated at 15,000 PSI (~1034 bar). The specimens were kept inside a strong steel box during testing. The tests were conducted according to ASTM 1599 standard and burst pressure of the riser was evaluated. The actual burst of a hybrid composite pipe, pressurized internally at a rate of 300 psi/min is shown in Fig. 2b. The burst tests were conducted in both steel and hybrid composite pipes.




(a) Test set up assembly



(b) Actual burst of hybrid composite pipe

Fig. 2 In-house testing facility for conducting burst tests

## 4. RESULTS AND DISCUSSION

The burst tests of steel and hybrid composite pipes were successfully conducted using the in-house developed test facility. Three specimens of each steel and composite pipe were experimented. The failure patterns of the pipe after bursting exhibited good repeatability. The fractured composite pipe after burst is shown in Fig. 3. The macroscopic damage is closely observed in four regions which are marked as *a, b, c and d.* The damage of steel pipe is not discussed rigorously as it is well documented in the literature.

It is noticed from Fig. 3 that, the pipe bulges around the circumference when a high internal pressure is applied and contracts in length before bursting. The fracture due to burst is observed at the mid length of the pipe. This kind of failure was commonly observed in both the steel and composite pipes. The following causes of failure as the pipe is initially pressurized until burst is explained. A closer examination of the marked regions reveals interesting observations. The fracture surface reveals that, during bursting the crack propagates and causes a major delamination at the steel composite interface. Until burst, the composite layer resist effectively when subjected to higher internal pressure than virgin steel pipes. When the internal pressure reaches critical value, the steel liner shows a bulging effect due to which, the composite also undergoes progressive damage phenomena such as fiber breakage, matrix cracking and fiber pull-out. Finally, hybrid pipe bursts with sudden drop in internal pressure. The average burst pressure results of the steel and hybrid composite pipes are shown in Table 2.

Table 2 : Test results of burst

| Pipes | Average burst pressure (PSI) |
|---|---|
| Steel | 5,583 |
| Hybrid riser 1 | 6,816 |
| Hybrid riser 2 | 8,557 |

The results show that hybrid risers with 1.5 and 3 mm composite layer thickness has approximately ~22 and 53% higher resistance to burst compared to virgin steel tubular structure. It is also observed that, burst strength of the hybrid pipe structure increases with wall thickness of the composite layer.

The micrographs of the fractured pipe surface are shown in Fig. 4. This is conducted to reaffirm the observations from the macroscopic failure patterns. Interlaminar region and cross sectional view of fractured composite layer is examined.

From Figs. 4a and b, fiber breakage, fiber pull-out and fiber bridging is observed. Similarly tow breakage and matrix cracking is seen from Figs. 4c, d and e. Further analyzing, fiber deboning with matrix cracking is also noticed from Fig. 4f. Thus, the fractured micrographs confirm the macroscopic damage failure modes.

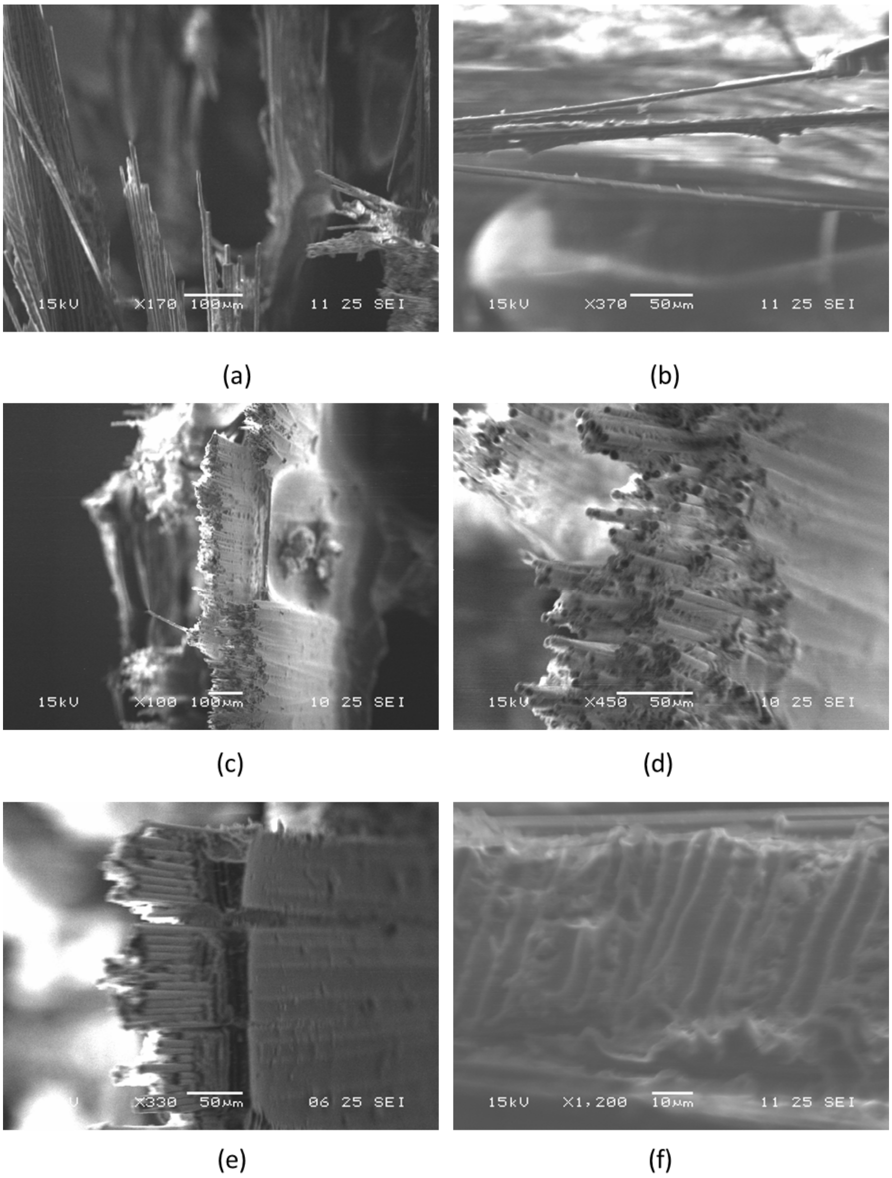



Fig. 4 Scanning electron micrographs of the fractured pipe to examine modes of failure.

## 5. CONCLUSION

In this study, the burst tests of steel and hybrid composite pipes were successfully conducted with an in-house developed facility. The conclusions from this study are: The pressure resisting capacity of the hybrid composite riser is higher than that of steel. Moreover in the hybrid structure, as the thickness of the composite layer increases, the pressure resistance also increases. The fracture behavior examined shows interesting observations of minute bulging, matrix cracking and microscopic damage at the interlaminar region whereas fiber pull-out, fiber and matrix failure is seen during crack propagation. The lightweight prototype hybrid composite riser developed in this study reveals adequate improvement in resisting burst pressure and shows promise that, a full-scale hybrid riser is indeed feasible for deepwater applications.

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