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Review

On the mechanical performance of glass-fibre-reinforced thermosetting-resin pipes: A review

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ABSTRACT

A comprehensive review is conducted on the performed investigations in the field of mechanical behaviour of glass-fibre reinforced thermosetting-resin (GFRP) pipes. Classified into six categories of stress/strain analysis, failure evaluation, environmental issues, viscoelastic behaviour and creep analysis, fatigue analysis and impact analysis, the main streamline of the performed and on-going studies in current years have been outlined. The recent trend and challenges in conducted researches are highlighted and discussed. Performing a gap analysis, new perspectives which are still required to be developed more deeply for their industrial applications or have not been addressed in literature are nominated.

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1. Introduction

The unique and outstanding properties of polymeric composite materials consisting of higher mechanical, including stiffness and strength specific properties, low weight, anti-corrosion, higher natural frequencies and extended lifetime against fatigue phenomenon have rendered them as a competitive candidate for the wide range of engineering applications. Furthermore, the development of new manufacturing methods associated with polymeric composites has often resulted in more cost-effective and value-added production lines. Polymeric composites, as the most important category of composites, not only are employed in high-tech industrial applications like aerospace and military sectors, but also penetrated into the low-tech industry like sanitary wares. The market of polymeric composites is spanning the widespread spectrum of industrial sectors consisting of railroad, road, air and sea transportation, military, aerospace, municipality, energy production and transmission, civil and infra-structure, oil and petroleum, sports and leisure.

One of the biggest consumer sectors of composites is the construction field including civil, infra-structure, oil and gas industries [1]. Avoiding heavy repair and maintenance costs arisen due to corrosion in chemically reactive environment, the demand for

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Glass-Fibre Reinforced Polymer (GFRP) pipes and tanks in the industries of advanced and developing countries are booming. Similar to the other high-tech industries which are originated from military sectors, development of composite pipes was also inspired from the technological overflow of the high pressure vessels.

The key feature of GFRP pipes, making them the main competitor of traditional steel, asbestos and concrete pipes suffering from chemical corrosion phenomenon, can be originated from their inherently high corrosion resistance characteristic. This is resulted in smooth internal surface over the long period of operation time and lower head loss [2]. Moreover, GFRP pipes offer high specific strength, light weight and relatively low elastic modulus. While the former presents more durable pipes, the two others present pipes more resistant against vibrations and internal shocks [3]. Moreover, transportation, installation, connection and repair procedures of GFRP pipes are much easier than other traditional ones. Improved strength properties and extended lifetime of GFRP pipes against fatigue phenomenon have been promoted their applications in different service, irrigation and potable water transmission systems, municipal and industrials waste water systems, water-intake of cooling towers, fire extinguish systems and process flow lines of factories [1].

Categorised into three main groups of Glass-fibre Reinforced Polyester, Vinyl ester or Epoxy (GRP, GRV and GRE) pipes, the performed investigations on glass-fibre reinforced thermosetting-resin piping systems in the past decades are reviewed and discussed.

The organisation of the paper is outline as: first, production methods of GFRP pipes on the industrial scale are briefly explained; second, the configurations of GFRP pipe wall construction are elaborated. Design constrains of GFRP pipes dictated by international rules and regulations are summarised afterwards. Then, different conducted studies on the GFRP pipes are categorised and reviewed to draw an overall trend of the current studies. Subsequently, a gap analysis is performed to highlight the topics for the future studies which are necessary to be explored in the development procedure of GFRP pipes. Finally, concluding remarks are presented.

2. Production process

GFRP pipes for commodity application are, generally speaking, produced either using centrifugal casting (CC) or filament winding (FW) process.

GFRP pipes produced by CC process are made of chopped glass fibres, polyester resin and fillers. In CC process, chopped fibres, resin and other additives are mixed and fed at the determined quantity to the feeder arm moving back and forth inside the rotating mould [4]. The mould is initially rotated at relatively low speed. Once feeding of all raw materials is complete, the rotation speed of mandrel is increased providing sufficient centrifugal forces to compress fed materials against the mould wall. Therefore, raw materials are condensed and any trapped air is vented. In this method, the pipe wall is constructed from the outside inwards. Finally, the pipe is heated to cure and the mould is kept rotating during the curing process ensuring uniform wall thickness over the entire length. Schematic illustration of CC process is depicted in Fig. 1.

As an alternative to the aforementioned chopped reinforcement CC method, a preformed glass reinforcement sleeve is placed inside the mandrel and then resin and filler are fed into the mould [2]. This process is known as preformed reinforcement sleeve method [2].

FW process is the most broadly used method for fabricating GRP, GRV and GRE pipes. This process exists in two different forms commercially referred to as discontinuous or reciprocal and continuous FW process [2].

In reciprocal method, fibre bundles are firstly impregnated in resin bath and then wetted fibres are applied onto a rotating mandrel via a travelling trolley which drives back and forth along the length of mandrel. Adjusting translational speed of the trolley and the rotational speed of the mandrel, different winding angles can be achieved. Fixed length of pipes is produced in this method and after production of each piece of pipe, the mandrel is replaced with new one for the next piece. Hence it is commercially also called discontinuous FW process. Schematic representation of discontinuous filament winding method accompanied with industrial equipment is shown in Fig. 2.

As it is appeared in Fig. 2, in this process just fibre glass roving is used and no chopped fibre is incorporated in the pipe wall construction. Thus employed raw materials are continuous glass fibre, thermo-set resin and aggregate fillers, when applicable.

After producing each piece of pipe, the whole pipe and mandrel is transferred to the curing station. The produced pipe is heated using infra-red lamps while it keeps rotating. After accomplishment of curing process, the mandrel is extracted from the pipe at another station. Curing and mandrel extraction stations are presented in Fig. 3.

In continuous FW method [2], mandrel is shaped by advancing steel band supported by beams. Therefore, a reforming mandrel moves in a spiral path toward the end of machine. Continuous fibres, chopped fibres, resin and aggregate fillers are applied to the mandrel from overhead. After curing and whenever the desired length is reached, a synchronised saw unit cuts the pipe. In this process, pipes are produced continuously and the production process stops only to replenish or change material components. Thus, the process is commercially referred to as continuous FW method. Schematic presentation of reforming mandrel and continuous FE machinery at industrial scale are shown in Fig. 4. Unlike the discontinuous FW process where separate stations are required for manufacturing and curing pipes, all production stages are accomplished in single machinery in continuous FW process.

3. GFRP pipe wall construction

All GFRP pipes consist of three layers as liner, structural and external layers regardless of employed production process. The liner which is in direct contact with conveyed fluid provides very smooth internal surface, particularly in filament wound pipes. This thin layer which plays the role of barrier layer protects other layers against direct exposure to the internal fluid. The liner is composed

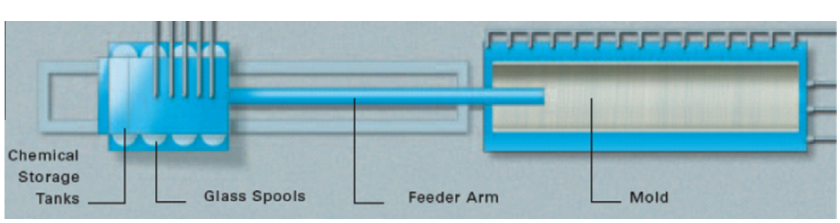

Fig. 1. Schematic illustration of centrifugal casting process.