The Material Qualification of PA12 Carbon Fibre for TCP application

A full picture on background, approach, methods and outcome according to DNV – ST – F119

Preamble

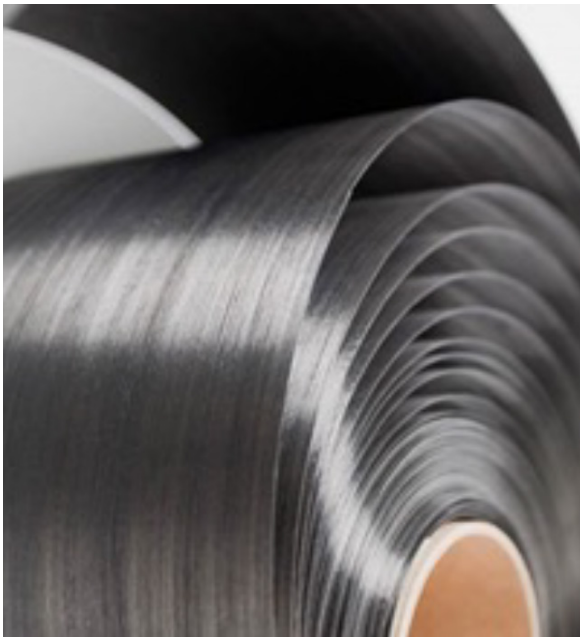
Following the successful certification of the composite static performance of VESTAPE® PA12-CF published earlier in 2020, the finalisation of the full generic qualification certification is addressed in this paper with the full picture on background, approach, methods, and outcome.

The full material certification consists of four individual certifications:

- liner and cover
- composite static
- composite dynamic fatigue
- composite long term stress rupture

Introduction

VESTAPE® PA12-CF composite tape was developed to address the industry need for a cost effective and corrosion-free solution in challenging offshore pipe applications. VESTAMID® NRG PA12 grades have a long and successful track record in flexible pipe for a variety of offshore applications, ranging from hydrocarbon service to water and gas injection. Several thousand kilometers of PA12 as pressure sheath component have been installed over the last decades, and they continue to perform as intended without failure. Reinforcing the reliable PA12 polymer with continuous carbon fibres to form the semi-finished product of VESTAPE® PA12-CF, the tape allows the material to serve not only as a barrier for the transported fluid, but also as a structural and load-bearing element.



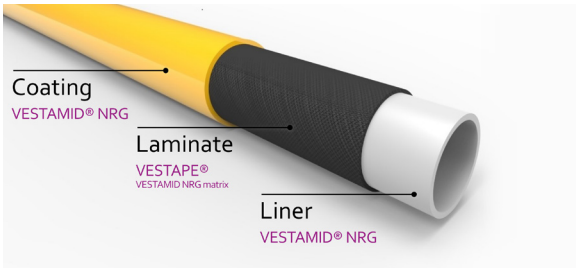
VESTAPE® PA12-CF unidirectional composite tape.

Being deployed in Thermoplastic Composite Pipe (TCP), a fully bonded monolithic flexible pipe, it enables a fully non-metallic pipe solution for the most demanding applications for a very wide envelope of conditions. TCP consists of three corrosion insensitive polymeric parts: first an inner liner pipe onto which, in a second step, the thermoplastic composite reinforcement tape is melt fused to the desired number of layers, and finally an outer extruded cover as protection against external damage. The three parts form a fully bonded reinforced single-material pipe. The pipe is then completed with end fittings to provide connection points. Together in our partnership between Strohm and Evonik, the vision of a cost-effective carbon fibre-based TCP product has been realised.

For that joint development activity, the DNV-ST-F119 TCP standard has been utilised to its full capacity. This novel approach, developed by Det Norske Veritas (DNV) and all relevant industry partners, is trailblazing in its knowledge-based characterisation requirements.

TCP as a fully non-metallic solution does not suffer from any corrosion known for metals and is largely insensitive to any corrosive media.
In addition, the use of carbon fibres makes it exceptionally resistant to any fatigue-based failure, marking it a perfect choice for any dynamic applications, from jumpers to risers. The almost non-regressive characteristic of its long-term stress rupture behavior allows for very efficient design without the need of overcompensation.

The very stiff nature of carbon fibres paired with the load transfer capability of VESTAPE® PA12-CF as matrix also enables its use in deep sea environments at operating pressures up to 700 bar and temperatures up to 80°C.



Details of the PA12-CF Thermoplastic Composite Pipe structure.

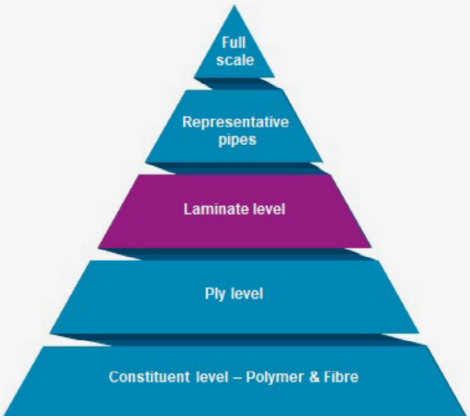
"With increasing interest from the industry in TCP technology, we are delighted to see the successful qualification of carbon fiber based tapes from Evonik, and the award of DNV Statement of Conformity to DNV-ST-F119. TCP is certainly a technology we will hear more about in future."

Geir Egil Eie, Head of Department for Technology and Testing at DNV.

Methods

DNV-ST-F119 test standard is an approach to characterise, design, and qualify thermoplastic composite pipes for offshore applications. It is establishing a relation between the functional requirements of a pipe and the performance characteristics of the materials it is made of. This establishes the F119 standard as a knowledge-based approach where an in depth understanding of the material is sought to demonstrate the lifetime performance of a product operating in a challenging chemical, thermal and mechanical environment. This philosophy is fundamentally different to more typical offshore qualification standards where a long piece of pipe is made and tested against a pass and fail criteria for all service conditions, adding very little to the actual understanding of the material.

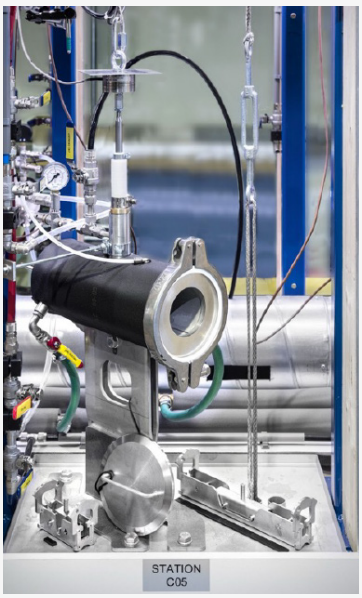
At the material level, proven aerospace test methods are used and adapted for composites to measure the mechanical behavior of the material across all possible failure mechanisms. Characterisation and the determination of material constants permit the use of state-of-the art simulation to evaluate the performance



Testing pyramid from constituent materials to the TCP system as shown in DNV-ST-F119.

of the product across all possible loads seen by the pipe through its multiple life phases. Such an approach enables the use of a digital twin with continuous lifetime performance assessment.
To ensure the validity of simulations, tests on full-scale pipes up to failure are performed and compared against calculations. Predicting both, performance, and failure modes, the tests are required to validate the methodology and the material models established from measured properties.

A test frame containing multiple parallel test stations for long-term testing in environment (courtesy of NLR).

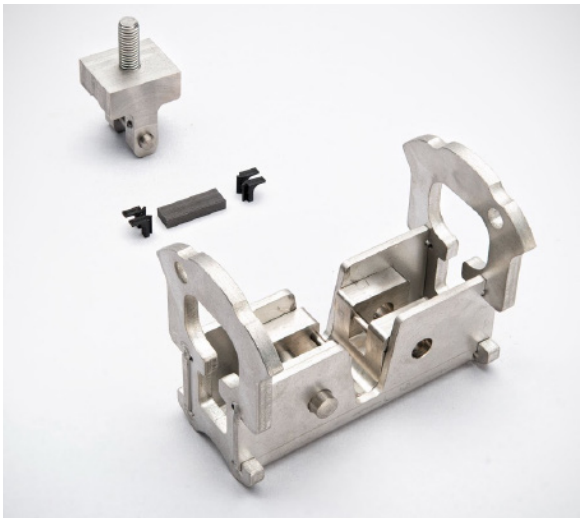


A test station showing the test container open and ready to be loaded with a test specimen (courtesy of NLR).

Execution

An extensive and thorough testing program needed to be designed and ratified to be suitable to the F119 approach. This suitability is to be understood for all media and temperature exposures and all material states like newly produced, reversibly softened by media, irreversibly aged by aggressive chemicals and worst-case combination thereof. The scope was further increased after considering all failure modes that can occur in a TCP structure for static, dynamic, and long-term stress rupture failure. Multiplied by the highest number of repetitions for each test to allow for the highest safety class and therefore the most efficient pipe design, the lead times for the most consuming long-term tests would have accumulated for more than 50 years of consecutive testing. Parallel testing capacities for performing high load mechanical tests for composites in specific test media at elevated temperatures were not available to a sufficient extent worldwide at that time.

Therefore, a new capacity was designed and built. Advanced data acquisition and evaluation methods to capture realistic material behavior were developed at the Dutch Aerospace Institute (NLR). Working with this well-established composite testing institute enabled the partnership to conduct the tests in parallel and reduce the lead time from several decades to five years. All implemented methods and equipment have been verified by DNV through a third party and after several rounds of improvement found suitable to provide representative data.



Detail of the test fixture used in the test station for a long-term short beam shear test (courtesy of NLR).

Results

The material qualification of VESTAPE® PA12-CF for energy applications resulted in establishing a new reference for material testing and characterisation. VESTAPE® PA12-CF's properties were established systematically across all composite failure mechanisms for static, dynamic, and long-term loads.

As described, new protocols, methods and test setups have been developed to enable the measurements of these properties and to achieve test durations measured in years. Delivering accurate methods is a critical element of meeting a standard requiring measurement over these durations and conditions.

The regression curves provided an unprecedented level of data for a single thermoplastic reinforced material. Classical assumptions regarding the long-term behavior of this class of material were verified to ensure an accurate determination of design curves.

The use of this critical data for the most challenging applications is illustrated through the following selection of results.

Ultra-deep-water applications require a continuous resistance against collapse forces for a safe and reliable operation. Certified, long-term compression regressions show almost a non-regressive behaviour and ensure a high collapse resistance during the entire service life of the pipe. The large number of data points provides a high level of certainty and allows efficient designs for even the highest safety classes. Finally, the remarkable proximity of the different regression curves obtained in different environments further highlights the intrinsic stability of VESTAPE®PA12-CF.

> "Testing carbon reinforced, saturated PA12 specimens in-situ in NORSOK fluid at elevated temperatures was quite a challenge. We successfully designed and built dedicated fatigue and stress rupture set-ups to be able to meet the test specifications and the safety and health regulations."
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> *Rens Ubels, principal project engineer at NLR*

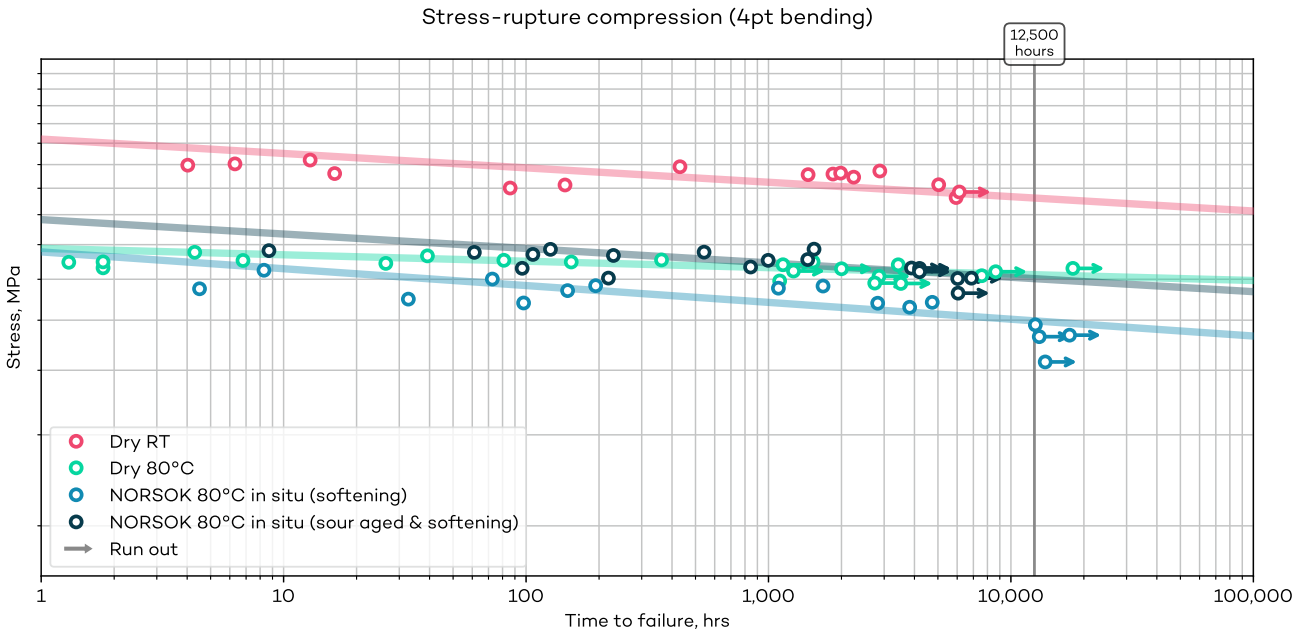

Figure. PA12-CF stress-rupture compression results for dry, softened (saturated) and aged & saturated condition at 23°C and 80°C beyond 12,500 hrs of continuous testing on a log-log scale.

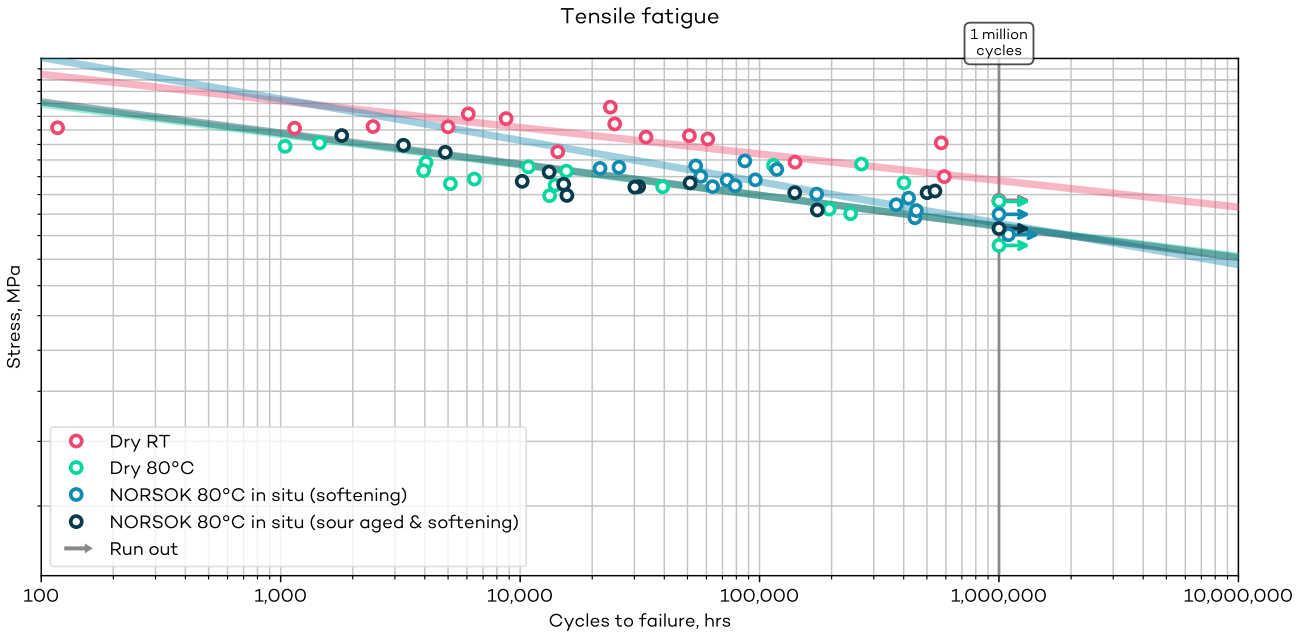

Figure. PA12-CF fatigue tensile results for dry, softened (saturated) and aged & saturated condition at 23°C and 80°C beyond 1 million cycles of continuous testing on a log-log scale.

Any riser application is dynamic in nature and requires high fatigue resistance to tensile stresses. VESTAPE®PA12-CF shines in this particular load scenario where the resistance of carbon fibres to large cyclic stresses is certified for all conditions. The data generated shows very little dependency to temperature demonstrating further the relevance of VESTAPE®PA12-CF for extreme load cases during decades of service.

The outcome of this work is the obtention of four certificates of conformity to capture the performance of the material and attest its fitness for oil and gas applications. The certificates cover all the failure mechanisms of the materials in the TCP across static, dynamic, and long-term load types.

Applications

Deepwater applications are extremely challenging due to the unique combination of pressure, temperature, and chemical environment. VESTAPE® PA12-CF delivers a high level of stable performance while being exposed to these specific chemical environments.

The dataset generated as part of the qualification allows to perform predictive engineering for virtually all the load cases seen by a deepwater dynamic system. Hundreds of load cases taking different combinations of load are typically calculated. The result is the determination of the performance of the product from its storage after manufacturing through its capacity to deliver up to 30 years after its installation.

The stability of VESTAPE® PA12-CF to a large variety of hydrocarbon compositions and gases makes this qualification relevant beyond the oil and gas industry. The energy transition needs material capable of transporting a variety of chemicals. This qualification targeted oil and gas applications. Due to the generic nature of the qualification, the demonstration can be made that the material is suitable and can easily be designed for other energy applications at elevated pressure and temperatures. The qualification data generated is also useful as a strong base for future applications not foreseen today.

"Invention of high performance thermoplastic composite tapes such as PA12 offers innovative alternative solutions for pipeline infrastructure, which can potentially have lower costs and environmental footprint. This is the case not only for traditional oil and gas industries, but also for pipeline infrastructure of the energy transition for the transportation and storage of carbon dioxide in carbon capture and storage as well as hydrogen."

Ramin Moslemian, principal consultant at DNV and lead for non-metallic technologies

The team in July 2021 at the end of the testing campaign. From left to right: Alexandre Paternoster (Strohm), Carsten Schuett (Evonik), Ruud Veul (NLR), Alexander Brack (Evonik), Hotze Jongstra (NLR), Marco Nawijn (NLR) and Rens Ubels (NLR).

Regulation

Composite materials are not the first choice for offshore applications. Their adoption took decades for the air transport industry. Strohm has been designing, manufacturing, testing, and selling thermoplastic composite pipes for over a decade. Having a clear and validated product certification process is a key step in the larger adoption of these products by the industry. The completion of the VESTAPE® PA12-CF qualification is a crucial step in validating the application of the F119 standard for the use of thermoplastic composites in the oil and gas industry and in the energy transportation sector.

Outlook

The completely non-metallic solution for load-bearing structures such as VESTAPE® PA12-CF tape shows great potential to meet any challenges that corrosive environments can bring. Being applicable to both static and dynamic mode for hydrocarbon, water, and gas services offers a great variety of suitable applications. With foresight to the emerging challenges that the commitment to carbon dioxide neutrality and the ongoing energy transition bring, the envelope can be increased even further. Hydrogen embrittlement is of no concern for this material class as well as carbon dioxide dense phase transportation. Subsequently the existing certification will be extended to capture those aspects as well by putting the material to the front in respective joint industry projects which aim at incorporating hydrogen and carbon capture and storage into the ST-F119 approach. In the long term, VESTAPE® PA12-CF will provide a solution that, with its virtually maintenance-free operation, offers significant advantages in combined CAPEX and OPEX models which cater to the general drive for sustainability in established and emerging applications.

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