An evaluation of the defect quantification and damage characterization of glass fibre/HDPE thermoplastic composite pipe for oil and gas applications

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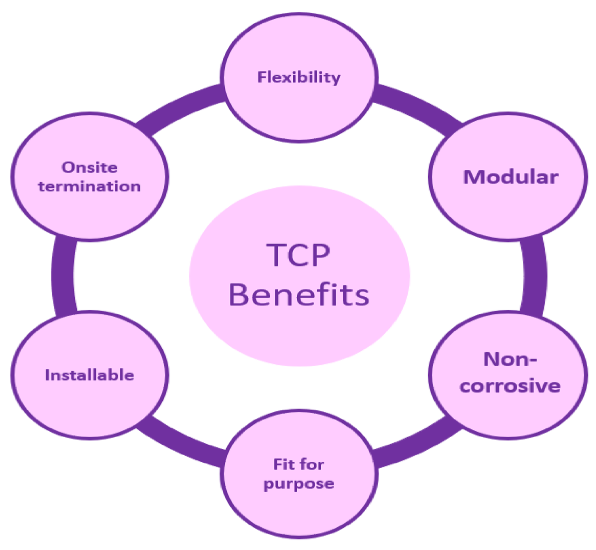
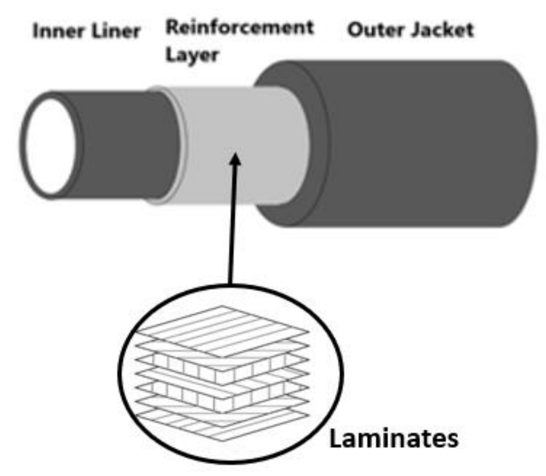
Motivation

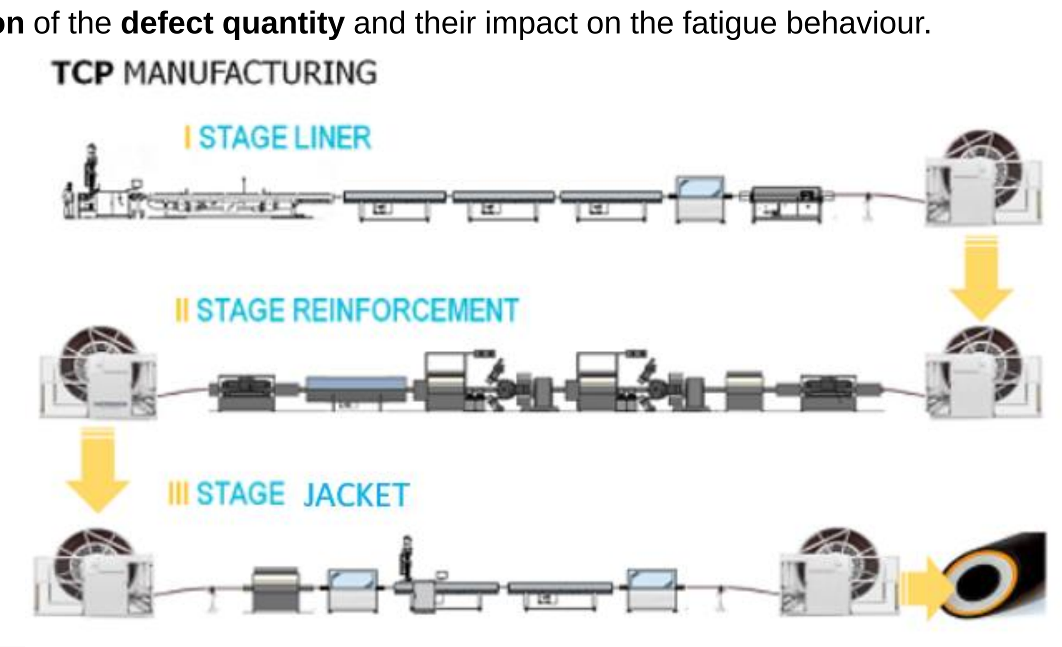
- **Composite pipes** are increasingly used as an alternative to conventional metal-based pipes.
- Flexible pipes which **thermoplastic composite pipes (TCP)** belong have proven to have beneficial features.
- TCP is 3 3-layered pipe comprised of the liner, reinforced and coated layer which are melt fusion bonded.
- Understanding their **fatigue behavior** is at an infancy stage and despite the progress made, the development of **defects** during the **manufacturing** process remains a critical problem.
- The presence of these **induced defects** has the potential of propagating to **initiate failure** of the TCP during in-service operations.

Research gap and Aim

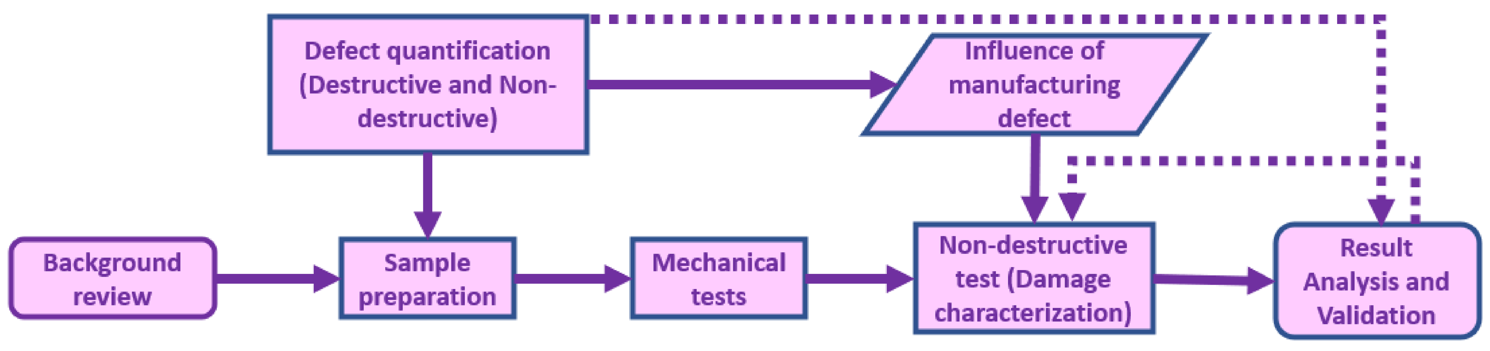
- The challenge is that several **environmental conditions** during their service life can affect TCP, which can be tied back to the **induced defects** from the **manufacturing process**.
- There is a lack of research directed towards the determination of TCP **material behaviour** during testing or applied loading.
- The aim of this research is to experimentally investigate the TCP's fatigue behaviour and establish their failure mode through **damage characterization**.
- Also, the **determination** of the **defect quantity** and their impact on the fatigue behaviour.







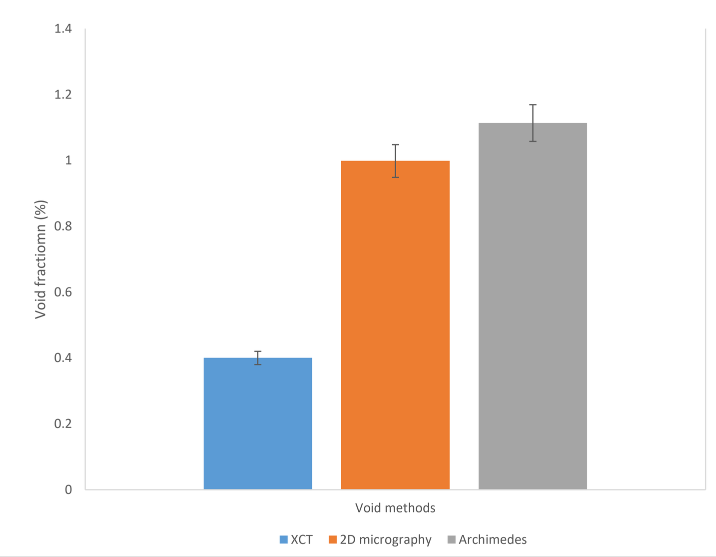
Methodology



- The pipe is a **multi-layer** glass fibre-reinforced polyethene structure with varying proportions designed for **specific applications**.
- **Flexural** and **compression test** is conducted in accordance with standards to generate failure.
- Samples are subjected to both destructive (**SEM** and **immersion** test) and non-destructive testing (**XCT**) techniques for quantifying the identified manufacturing defects.
- Also, NDT (XCT and **UT**) was used for damage characterization. The XCT provides microstructural information while the UT give the scans of the tested samples.
- The **end properties** and behaviour are validated from the obtained results and at **pristine** conditions for establishing **consistency**.

Result

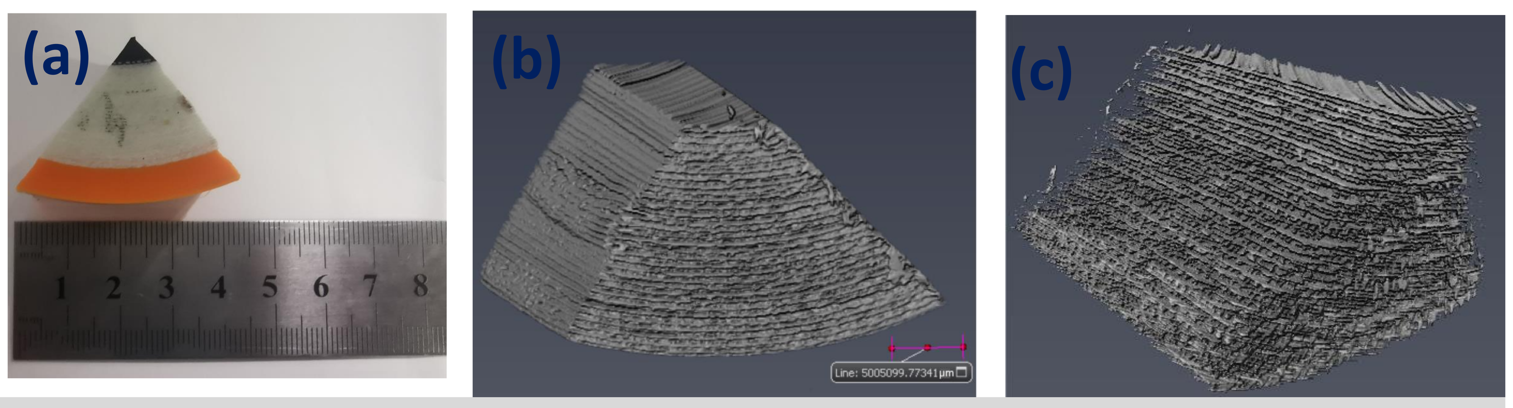
2D void quantification from SEM illustrating (a) micrograph (500x) (b) Post thresholding (c) Void identification through ImageJ tool



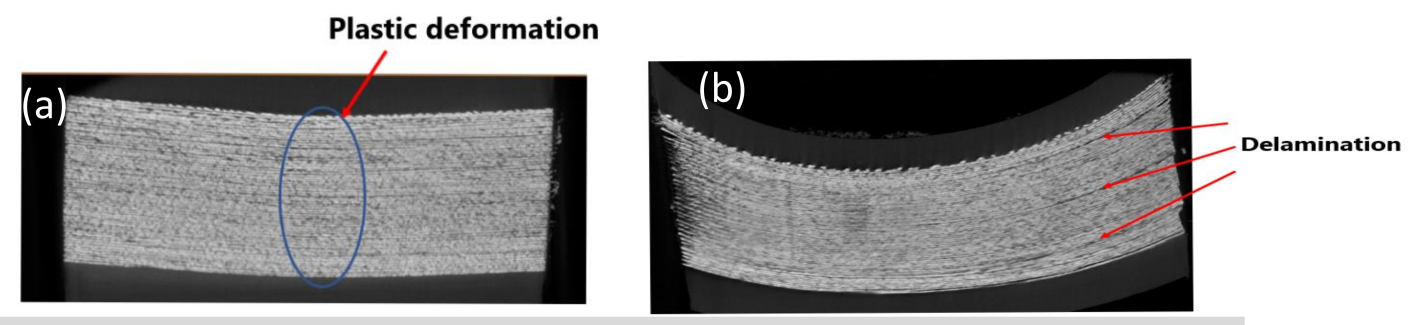
Void fraction in Vol-%: comparison of pristine XCT, micrography and Archimedes-test analysis

Manufacturing defect quantification (voids)

- The void ranged from **0.4** to **1.113%**. Based on the traditional engineering application threshold, the void content threshold was set at the range of **1** to **2 %**. The results of the calculated voids from the 3 methodologies indicated that there is **good concurrence**.
- However, there are **some contrasts** for both methodologies in terms of the values. This is because **fusion bonding** can change the **fibre area weight** and **matrix density** of the material because of the **compaction** and **heat**.
- As the **void volume** grows, they become more **elongated**, but all methods revealed that most of these elongated voids **constitute** a **minority** of the total void fraction.



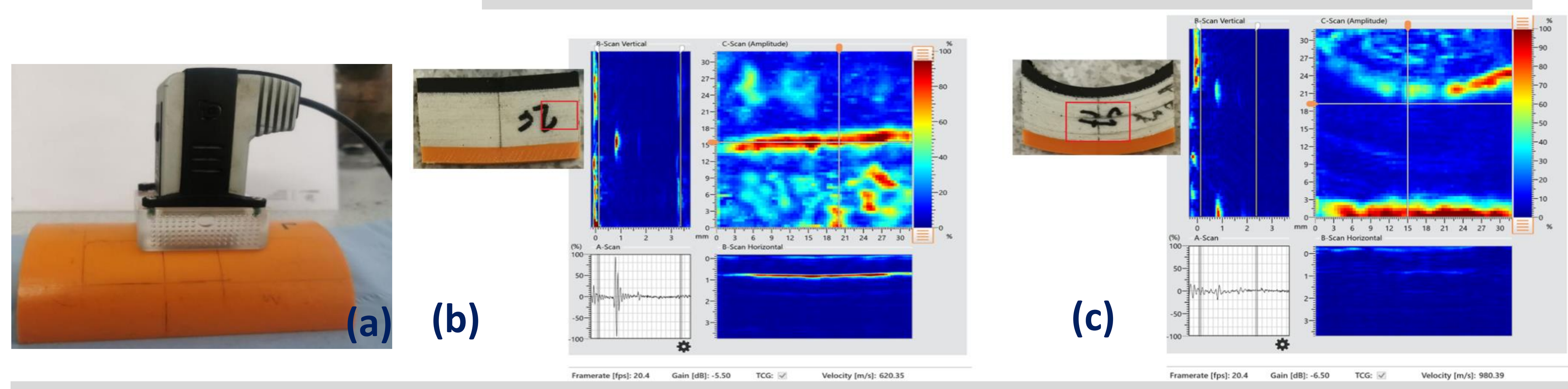
XCT reconstruction of the 3D dataset for the pristine sample highlighting (a) Sample of interest (pristine) (b) Reconstructed XCT dataset (c) Post pore subtraction



The 2D XCT image slice of the (a) flexural sample (b) Compression sample

Damage characterization analysis

- 2D XCT slice of the flexural TCP sample indicating **plastic deformation** with strain increase.
- This deformation occurs at the midline in the **radial axis** and through the slice it can be deduced that the reinforced layer absorbed the flexural load.
- The 2D XCT slice of the compressed TCP sample highlights the XCT scan of **delamination** (red).
- The severity of the delamination at this scale is minor and infers that manufacturing defects such as **fibre misalignment** did not influence the failure.
- The scan results reveal the possibility of **through-thickness matrix cracking** from the plastic deformation.
- **Challenges** faced for the UT inspection of glass fibre reinforced polymer pipes due to the property varying material phase which tend to absorb, scatter, and diverge the sound beams.
- Although this issue is prevalent in composites, it is worse for glass fibre in comparison to carbon fibre because of the **large fibre diameters**, **high density,** and generally **high porosity level**.



The ultrasound scan procedure displaying (a) The UT scan set up, (b) Flexural frontal plane, (c) Compression frontal plane

Conclusion

- The XCT analysis provides a more precise and reliable method for characterizing voids present in fibre-reinforced polymer composite structures. However, this should be individually considered as the combination of the other methods can proffer further insights.
- The key failure mode is matrix cracking in the reinforced layer plies that encourages delamination which is indicative of the low density of the polymer matrix in this layer due to the ease of the matrix cracking from loading.
- XCT and Ultrasonic inspection examined the damages in the mechanically tested samples and exposed the presence of internal matrix cracks from the flexural samples.

Desired impact

The desired goal is for the development of smart and reliable methods for monitoring the TCP manufacturing process to foster a sustainable and efficient process.

Publications

Okolie, O., Latto, J., Faisal, N., Jamieson, H., Mukherji, A. and Njuguna, J., 2022. Manufacturing defects in thermoplastic composite pipes and their effect on the in-situ performance of thermoplastic composite pipes in oil and gas applications. *Applied composite materials*.

Okolie, O., Latto, J., Faisal, N., Jamieson, H., Mukherji, A. and Njuguna, J., 2023. Advances in structural analysis and process monitoring of thermoplastic composite pipes. *Heliyon*.

Acknowledgement

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