Experimental Setup for Thermal and Cyclic Axial Loading of District Heating Pipes

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Abstract

In Europe, pre-insulated district heating (DH) pipes are typically evaluated for quality control in accordance with EN 253; however, the standard does not include testing under simultaneous thermal and axial cyclic loads. The present work advances beyond the standard by introducing a test setup that superimposes thermal loads and cyclic axial shear stresses on pre-insulated DH pipes, thereby reflecting more realistic stress conditions in DH pipes. The configuration extends the EN 253 methodology by integrating welded connections for heat-carrier circulation, a pendulum-bearing for controlled cyclic axial loading, and a pipe casing fixation system. A structured multi-stage test procedure—comprising thermal conditioning, cyclic axial loading, and quasi-static axial shear testing—was developed, incorporating precise temperature control and 3D-digital image correlation for displacement tracking. The contribution of this work lies in the conceptual design, rationale, and realisation of a flexible thermo-mechanical test configuration that remains compatible with existing standards while enabling testing beyond their current scope. The proposed setup provides a methodological foundation for future investigations into ageing mechanisms, adhesion performance, and load interaction effects in pre-insulated DH pipes under realistic operational conditions. As the experimental campaign is still ongoing, this paper presents the test methodology and setup, while final test results will be reported elsewhere.

Introduction

Most DH pipes consist of a high-density polyethylene (HDPE) casing, an insulating layer of rigid polyurethane (PUR) foam, and a steel service pipe for transporting the heat carrier (Pelda, 2024). One purpose of this design is that the bond between the three components guarantees the pipes' mechanical performance. Another criterion of this design is an acceptable thermal performance. During operation, DH pipes undergo temperature changes due to variations in customer demands, seasonal heat losses, and operational loads according to weather conditions. These changes lead to mechanical and thermal loads on the pipes. Temperature fluctuations lead to variable thermal expansion of the steel service pipe, which induces an axial shear stress due to restraint by the surrounding soil. Throughout its service life, the composite must withstand the resulting shear stresses to fulfil its load-bearing function, especially in the gliding zones where axial forces vary due to soil friction. The service life of pre-insulated DH pipe systems with PUR insulation is typically at least 30 years when normative specifications (EN 253 and EN 13941) are complied with. However, a strong bond between the service pipe and insulation is required to ensure the functionality of DH pipes. Total loss of the bond, which some operators define as the end of service life, can result in serious damage to connections and bends. While EN 253 provides a robust framework for evaluating the factory-made quality of pre-insulated DH pipes, the standard is limited to quasi-static testing at 23°C and 140°C. Procedures for assessing simultaneous thermal and cyclic axial loading are not included. As a result, the interaction effects that occur under operating conditions, such as dynamic temperature changes, cyclic axial stress, and material fatigue, remain largely unaddressed. To address these gaps, the present study introduces an experimental setup specifically designed to reproduce the combined thermo-mechanical loads acting on pre-insulated DH pipes.

Methodology

The methodological approach of this work was designed to develop a test setup capable of superimposing controlled thermal and cyclic axial loads on pre-insulated DH pipes. The methodology consists of three

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core components: (i) a review of existing testing approaches, (ii) the derivation of functional and boundary requirements for a new setup, and (iii) the conceptual and technical development of the proposed thermo-mechanical test configuration. Particular attention was given to studies involving thermal ageing, axial shear testing, cyclic loading, or combined thermo-mechanical influences. Relevant standards (e.g., EN 253 and EN 13941-1), experimental reports, and research projects were analysed to extract design parameters. In addition, data presented graphically in the literature were digitised and converted into numerical form to support the evaluation and comparison of test conditions. The present contribution focuses on the conception, rationale, and realisation of the test setup. The methodology presented here establishes the foundation for subsequent work, in which validated thermo-mechanical results and ageing-related performance assessments will be reported.

Existing Test Setups

The industry standard for testing factory-made pre-insulated DH pipe systems is the EN 253. However, in recent years, various tests which deviate from the standard have been conducted to investigate the material behaviour of pre-insulated DH pipes beyond the standard.

For instance, between 2007 and 2011, within the research project by Thieme et al. (2011), experiments to analyse the effect of cyclic axial stress on the residual strength and service life of new and thermally aged (150 °C / 5,000 h) pre-insulated DN 50 DH pipes were conducted. Therefore, they split their experiments into two. First, they performed Wöhler tests under different load horizons until failure to create S-N curves (Wöhler curves). Second, they repeated the experiments, but defined a limited number of load cycles not resulting in failure, following axial shear strength tests according to EN 253 to determine the residual axial shear strength of the pipes. Their goal was to statistically show the probability of survival and to ultimately estimate the service life based on linear damage accumulation. The test setup included a test rig with a servo-hydraulic test cylinder, a force transducer, and a single-channel controller. The tests were performed in a force-controlled manner with a sinusoidal force curve at varying oscillation frequencies between 0.005 Hz and 0.8 Hz and constant amplitudes, and no travel recording. The experiments were performed at room temperature, with a stress ratio (R)[1] of 0.1. Depending on the experiment, the number of applied cycles varied. For the Wöhler test, until failure, 25 to 100,000 cycles could be observed. For the Wöhler tests without failure, an axial shear stress of 0.04 MPa was applied, and a target cycle count of 10,000 was set, which, according to the authors, corresponds to at least 30 years of operation under daily load cycles. Furthermore, the influence of specimen length on the shear stress distribution in the pipe was analysed using the finite element method (FEM). They concluded that, as test specimen length decreases, a more uniform shear stress distribution is achieved, and they recommended a specimen length of 100 mm. Nevertheless, they tested specimens ranging from 50 mm to 200 mm in length, which aligns with findings of Weidlich et al. (2018) regarding specimen length. Based on the findings, Thieme et al. (2011) concluded that, as the oscillation frequency decreases, the oscillation resistance also decreases. They hypothesised that this could be caused by increasing cyclic creep effects at low oscillation frequencies. Since load cycles in DH pipes occur at very low frequencies, they subsequently planned to extrapolate the frequency range of load cycles to operating conditions to estimate the residual strength and failure. However, due to project-specific restrictions, it was not possible to proceed.

Thereafter, within the research project by Schleyer et al. (2016), a similar servo-hydraulic test setup inside a temperature-controlled chamber was used to conduct static and cyclic axial shear stress tests to analyse the effects of mechanical and thermal loads on new and thermally conditioned (140 °C /2,000 h, and 170 °C / 2,000 h) 150 mm-long pre-insulated DH DN 50/140 pipes with PUR. Following the methodology from Thieme et al. (2011), Schleyer et al. (2016) also performed Wöhler tests under different load horizons until failure to create S-N curves. Subsequently, they repeated the Wöhler tests with a limited number of load cycles, not resulting in failure. Following axial shear strength tests according to EN 253, to determine the residual axial shear strength of the pipes. The differences in their approach were: a different preconditioning of the pipe specimens, a temperature of the pipe specimen of 30 °C during testing, applying two

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[1] The stress ratio (R) is described by the ratio of the minimmum to the maximum occuring axial shear stress during cyclic loading (Götz and Eulitz (2022)).

different stress ratios of R = -1 and R = 0.1, as well as a test frequency of 0.5 Hz for all tests. The target cycle count for the non-destructive cyclic tests was set to 10,000, while the axial shear stress amplitudes were individually set for each experiment and ranged from 0.04 MPa to 0.06 MPa. They observed that the axial shear strength increased after cyclic loading. They concluded that, based on current knowledge, it remains controversial to what extent the cyclic axial loads applied here could increase the axial shear strength of thermally and oxidatively pre-aged pre-insulated DH pipes. Furthermore, they stated that cyclic axial loading, in compliance with limit loading conditions according to current standards and guidelines for pipe static network dimensioning, is less significant than thermal-oxidative ageing.

Moreover, in 2020, within the research project by Hay et al. (2020), experiments using a modified version of the test setup introduced by Schleyer et al. (2016) were conducted to investigate the fatigue behaviour of thermally conditioned pre-insulated DN 60/125 DH pipes with PUR foam insulation under superimposed cyclic axial stress and thermal loading. Therefore, they performed Wöhler tests on thermally preconditioned pipes at 120 °C, 140 °C, and 160 °C until failure occurred. For testing, 150 mm long cut-out pipe specimens were heated using an electric heating element to 90 °C and 120 °C in a nitrogen-flushed chamber to prevent thermo-oxidative ageing processes during the experiments. The temperature inside the chamber was set to 30 °C. In addition to applying a cyclic axial shear stress, they also compressed the PUR foam by 1 % to simulate earth load. The test frequency was set to 1 Hz for all tests, while the applied axial shear stress was individually set for each experiment, ranging from 0.04 MPa to 0.12 MPa. Due to time constraints, they limited the target cycle count of the Wöhler tests to 1,000,000. Based on their findings, they concluded that PUR foam reacts elastically and can therefore be described using a simple spring model to determine the modulus of elasticity. However, as the conditioning temperature increased, the elasticity decreased until, at 160 °C, no elastic behaviour could be observed, or only slight behaviour. They also concluded that the decrease in axial shear strength caused by thermal ageing due to preconditioning of the pipes leads to a higher load level for the same stress amplitude.

Similarly, in their study, Doyle & Weidlich (2021) evaluated the effect of cyclic axial shear stress superimposed with thermal load on the residual shear strength, shear modulus, toughness and failure behaviour of PUR foam in pre-insulated DH pipes, compared with unaged reference samples. The study focused particularly on the initiation and propagation of cracks in the foam. Therefore, they developed a rig with a heatable chamber that could simultaneously test five 200 mm-long DN 20/90 pipes. Electronic control of the mechanical cycling rig was coupled with a thermocouple placed in the middle of the specimen. This ensured that the maximum force was applied simultaneously with the maximum temperature. Three different cyclic loading trials were carried out. The first trial subjected the pipes to temperature-induced stress only with a temperature interval of 25 °C to 100 °C using a heating and cooling ramp of 30 min corresponding to a gradient of 150 K/h. The second trial represented a worst-case scenario in which thermal and axial loads are superimposed with a temperature interval from 25 °C to 100 °C and an axial shear stress interval from 0 MPa to 0.12 MPa over 250 cycles. The third trial represented a scenario under mild conditions in which thermal and axial loads are also superimposed with a temperature interval from 25 °C to 100 °C and an axial shear stress interval from 0 MPa to 0.04 MPa for 125 cycles. Following the trials, an axial shear strength test according to EN 253 was carried out. The researchers concluded that simultaneously applying axial shear stress and thermal loads reduces the foam's strength and increases its stiffness, and that this change is not caused by degradation of the foam's molecular structure.

Vega et al. (2021) aged and analysed DH pipes with PUR foam insulation at elevated temperatures by applying cyclic axial loads over two years, with a special focus on chemical degradation. They heated four DN 50/160 DH pipes, each 3.4 m long, to 130 and 140 °C using electricity, while a fifth one was kept at room temperature (23 ± 2 ◦C). Two of the heated pipes were additionally subjected to a cyclic axial shear stress at a rate of 2 mm/min until 20 kN was reached, which was associated by the researchers with an axial shear stress of 0.031 MPa. The piston was then locked in the loaded position for 28 minutes, after which it returned to the starting position, and no load was applied for a further 28 minutes. This cycle was repeated over 16,000 times in less than two years. The exact number of applied axial load cycles and the corresponding ageing time were reported in (Banushi et al., 2021). The axial shear strength was analysed using the so-called "Pipeopsy" method, a plug method described in (Jakubowicz et al., 2025). The researchers found that the adhesion strength of pipes exposed to both thermal and axial loads decreased faster than that of pipes exposed only to thermal ageing.

Takeaways from Existing Test Setups

A review of five existing experimental approaches for assessing thermo-mechanical behaviour in pre-insulated DH pipes reveals substantial variation in specimen orientation, thermal and cyclic axial loading strategies, and control modes. Overall, existing literature mainly targets the fatigue behaviour of pre-insulated DH pipes using two dominant strategies: (1) development of Wöhler curves, and (2) residual axial shear strength testing according to EN 253. Most studies conducted their experiments in vertical universal testing machines, using short specimens whose dimensions were aligned with EN 253 requirements. Only Vega et al. (2021) deviated from this by employing a horizontal test setup and considerably longer specimens of 3.4 m, aiming to better approximate real installation conditions. A consistent observation across the literature is that existing test setups orient their maximum applied axial shear stress levels toward established standards and common engineering practice, as shown in Figure 1: Overview of the max. applied axial shear stress vs. max applied temperature. An exception to this observation is Thieme et al. (2011) and Schleyer et al. (2016), who applied destructive axial shear stresses beyond common standards.

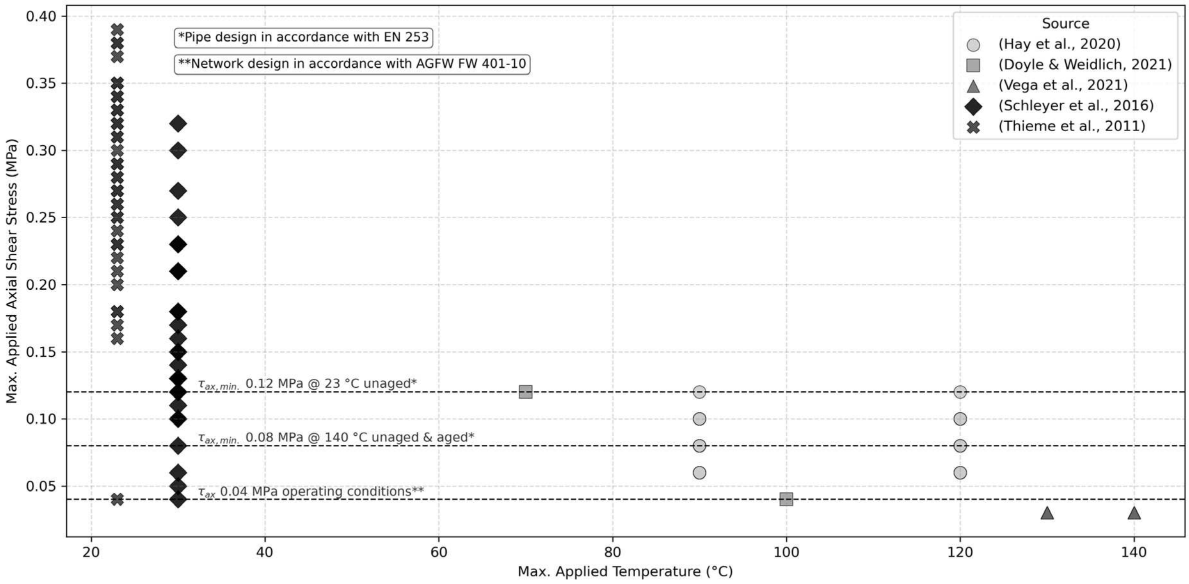


Figure 1: Overview of the max. applied axial shear stress vs. max applied temperature

In the literature, thermal loading is typically imposed by heating the steel service pipe and maintaining a constant temperature during mechanical cycling. An exception is Doyle & Weidlich (2021), who applied synchronised alternating thermal and mechanical loading. Furthermore, the max. applied temperatures, as seen in Figure 1: Overview of the max. applied axial shear stress vs. max applied temperature, fall within the range of typical operating temperatures of DH networks today (Heißler, 2020), except for Vega et al. (2021), who analyse peak temperatures for 3rd-generation DH networks. Another essential point from the literature is the number of applied cycles. Thieme et al. (2011) and Schleyer et al. (2016) limited the number of applied cycles to 10,000, corresponding to the expected number of load cycles over a 30-year service life (assuming a cycle per day), while also testing until failure without a fixed number of cycles. Likewise, Vega et al. (2021) derived their cycle count from the expected number of load cycles over a 30-year service life, whereas Doyle & Weidlich (2021) strictly followed EN 13941 for transmission pipelines. Hay et al. (2020) used 1,000,000 cycles as a termination criterion, reflecting a high-frequency fatigue approach. Figure 2: Overview of the number of cycles vs. max. applied temperature shows an overview of the applied number of cycles and the maximum applied temperature. It can be seen that the number of applied cycles falls within the range of an expected service life of 30 years, assuming one cycle per day.

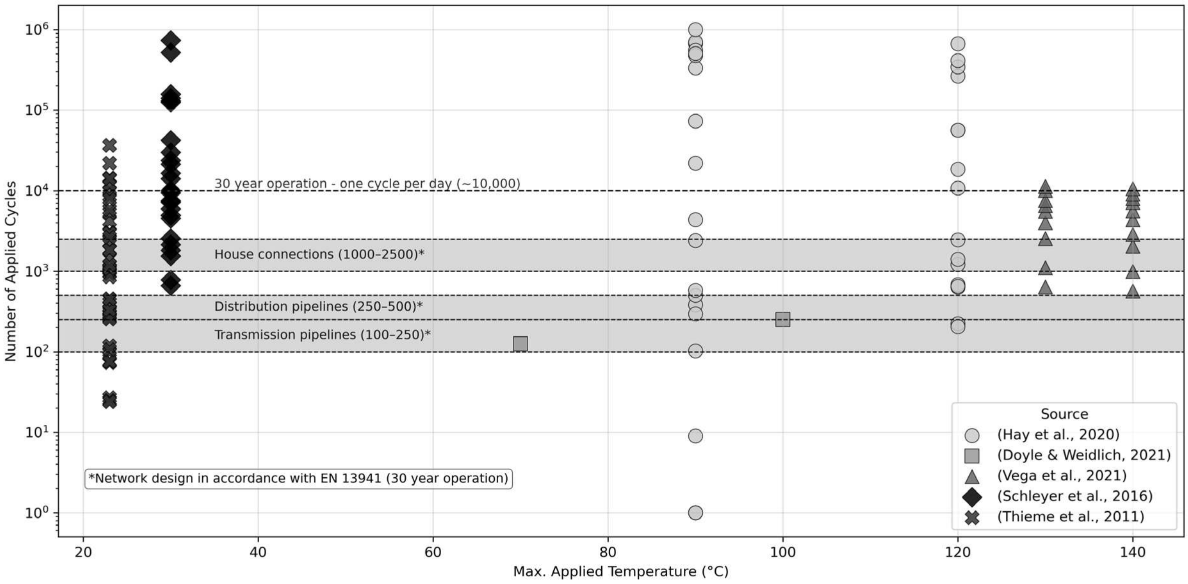


Figure 2: Overview of the number of cycles vs. max. applied temperature

Regarding load ratios, Schleyer et al. (2016) and Hay et al. (2020) adopted a stress ratio of R = –1, corresponding to fully reversed cyclic loading. On the other hand, Thieme et al. (2011) used a stress ratio of R = 0.1, Doyle & Weidlich (2021) and Vega et al. (2021) used a stress ratio of R = 0, corresponding to cold laying of DH pipes. Not only is the ratio between maximum and minimum applied shear stress of importance, but also the frequency at which the axial load is applied to the test object. Except for Doyle & Weidlich (2021) and Vega et al. (2021), most studies rely on high loading frequencies or short test durations followed by an extrapolation of the results into low-cycle-fatigue ranges commonly observed in DH systems. Which, on the other hand, do not capture long-term creep, relaxation, or other time-dependent deformation processes. A comparative overview of test frequencies and stress ratios is given in Table 1: Applied test frequencies and stress ratios.

Table 1: Applied test frequencies and stress ratios

Source	**Test Frequency [Hz]**	**Stress Ratio (R)**
(Doyle & Weidlich, 2021)	< 0.001*	0*
(Hay et al., 2020)	1	-1
(Schleyer et al., 2016)	0.5	-1, 0.1
(Thieme et al., 2011)	0.8, 0.2, 0.1, 0.05, 0.01, 0.005	0.1
(Vega et al., 2021)	0.00028*	0*
*not explicitly reported in the source		

Environmental control also differs significantly. Hay et al. (2020) conducted tests in a nitrogen-flushed chamber to suppress oxidation, while simultaneously simulating earth load by compressing the PUR foam by 1 % (stress-strain ratio) and preconditioning the pipes thermally at high temperatures. By contrast, most other studies were tested under an ambient laboratory atmosphere. Furthermore, nearly all non-destructive investigations performed axial shear strength tests after cyclic loading following EN 253 procedures, except Vega et al. (2021), who additionally applied the alternative “PipeOpsy” method. When an elevated thermal load was applied, it was universally applied to the steel service pipe to represent operational conditions. Schleyer et al. (2016) and Hay et al. (2020) are the only researchers who applied a constant temperature of 30 °C to simulate Earth’s temperature at the casing in operating conditions. It is worth mentioning that, besides Doyle & Weidlich (2021), no one has reported the applied temperature change rate to heat and cool the steel service pipe. Even though standards such as EN 253 require a temperature change rate of a maximum of 10 K/h. However, actual DH networks may experience much slower or higher variations depending on the operation strategy.

In brief, these takeaways raise fundamental questions about which approach to choose when dealing with fatigue and thermo-mechanical material behaviour of pre-insulated DH pipes. On one hand, high-cycle fatigue Wöhler tests following extrapolation into low-cycle-fatigue ranges applicable for DH systems or long-term low-cycle-fatigue testing simulating operation conditions following residual axial shear strength tests. Furthermore, the question of the representativeness of laboratory conditions arises: Which axial shear stresses, temperature levels, loading frequencies, and stress ratios appropriately reflect real network operation? These methodological uncertainties highlight the challenges in developing reproducible laboratory tests that balance realism, standard conformity, and practical feasibility. They also underscore why a consistent and transparent definition of boundary conditions is essential when designing new experimental setups for evaluating the thermo-mechanical behaviour of pre-insulated district heating pipes.

Implications for the Present Study and Conceptual Design of the Test Setup

The findings from the literature review directly informed the conceptual design of the thermo-mechanical testing approach developed in this study. A central requirement was that the test setup should be capable of superimposing thermal and cyclic axial mechanical loads, thereby replicating the combined loading conditions experienced by pre-insulated DH pipes in operation. To reflect the full spectrum of real network conditions, the setup should allow testing across the entire range of temperature loads commonly encountered in DH systems, ideally including the capability to couple peak temperature with peak axial load, since this combination best represents critical in-situ operating scenarios. The temperature range should theoretically cover all five generations of district heating and cooling systems with the corresponding temperature change rates. Given the diversity of thermo-mechanical loading patterns in DH networks, the setup should further enable both high-cycle fatigue and low-cycle fatigue testing. This includes accommodating different stress ratios relevant for DH operation. For example, a stress ratio of $R = 0.1$ reflects the typical installation under cold-laying conditions where a minimum thermal load is always present once the network is in operation. Alternatively, once steady-state operation is reached, seasonal or operational temperature fluctuations could be represented by a stress ratio of $R = 0$, provided the maximum axial shear stress is adjusted accordingly. To ensure methodological continuity with existing industry practice and to maintain comparability with established data, the design of the test setup should be oriented closely towards EN 253. The setup should therefore not only follow the principles of EN 253 but also remain capable of performing tests according to the standard when required. In addition, the number of mechanical load cycles should be aligned with the network design criteria defined in EN 13941-1, balancing realistic assumptions on load frequency with the practical limitations imposed by laboratory equipment and available testing time. Ideally, an advanced test configuration would also incorporate the ability to suppress thermo-oxidative processes during elevated-temperature testing (e.g., by nitrogen flushing) and to simulate earth loads based on statistically relevant soil cover depths. While these additional features represent desirable extensions for future system development, the present study prioritised feasibility within the constraints of the available universal testing machine and laboratory infrastructure. Overall, the conceptual design aimed to create a test setup that is realistic enough to capture the essential thermo-mechanical interactions occurring in real DH pipes, standard-aligned enough to ensure comparability with established testing practice, and flexible enough to explore new loading scenarios beyond the scope of existing standards.

Test Setup

The experimental setup was derived from the requirements of EN 253 and extended to enable combined thermal loading and cyclic axial loading in the form of axial shear stresses. Three modifications were implemented to adapt the standard configuration to the intended application:

- welded connections for the circulation of the heat carrier fluid,
- a pendulum bearing assembly enabling controlled application of tensile and compressive axial forces to the steel service pipe, and
- a clamping device for fixing the test specimen in the axial direction.

The test setup according to EN 253 is shown in Figure 3 a). The modified test setup is illustrated in Figure 3 b). Figure 3 c) gives an image of the test setup. For all tests, tensile and compressive axial forces can be applied to the steel medium pipe via a hydraulic universal testing machine. The axial force F_{ax} , which needs to be specified for the universal testing machine to achieve the defined axial shear stress level, can be calculated as follows

$$F_{ax} = \tau_{ax} * L * D_s * \pi \qquad (1)$$

Where

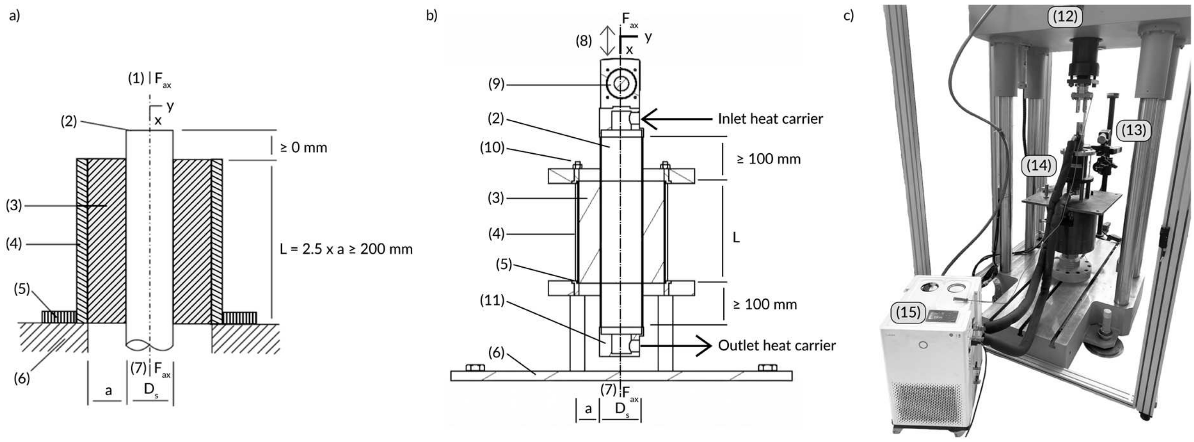
τ_{ax} = the axial shear strength, in MPa;

F_{ax} = the axial force including the weight of the steel medium pipe, in N;

L = the length of the PE jacket, in mm;

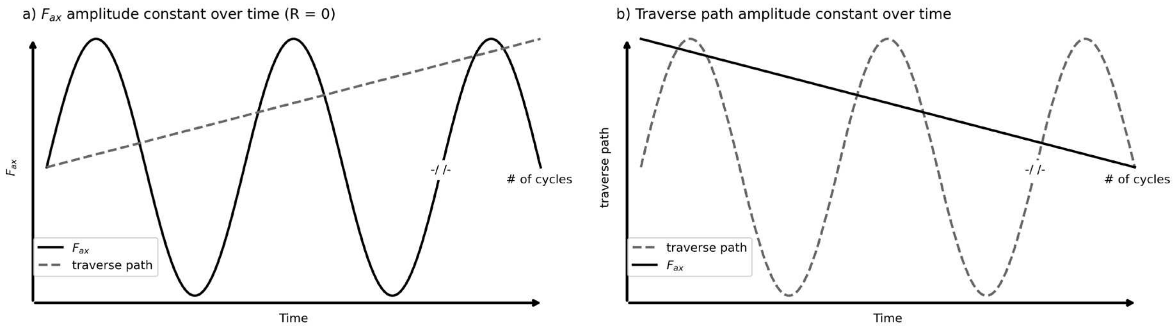
D_s = the outer diameter of the steel medium pipe, in mm.

To transmit tensile and compressive forces, the pendulum bearing, which is welded to the test specimen, is connected to the universal testing machine via a metal pin. The force is measured using a 20 kN force transducer with an accuracy class 0.5. The clamping device, which cages the specimen, consists of two mounting rings connected by steel rods, which are fitted to the upper and lower ends of the test specimen and prevent longitudinal movement of the pipe casing, thereby generating an axial shear stress along the service pipe and the insulating foam. Furthermore, the universal testing machine can be operated either in distance-time-controlled mode or in force-time-controlled mode, resulting in two fundamentally different loading scenarios. Figure 4: Hypothesised a) Fax constant over time and resulting traverse path vs. b) traverse path constant over time and resulting Fax illustrates these two possible control strategies and their expected outcomes. In scenario A, a constant axial force is applied over time. It is hypothesised that, due to material creep and temperature-induced softening, this setting will result in an increasing traverse displacement to maintain the target axial load. In contrast, scenario B applies a constant traverse displacement over time, which typically leads to a decreasing axial force as the material relaxes.



a) Test setup according to EN 253, b) Test setup, c) Image of the test setup, Legend - (1): applied axial force, (2): steel service pipe, (3): thermal insulation foam, (4): pipe casing, (5): mounting ring, (6): base plate of the testing machine, (7): alternative applied axial force, (8): applied cyclic axial force, (9): pendulum bearing, (10): anchoring of the test object, (11): welded attachment for the heat carrier, (12): universal testing machine, (13): 3D digital image correlation, (14): test object, (15): process thermostat – Figure not to scale

Figure 3: Test setup in comparison to the setup according to EN 253


a) F_{ax} amplitude constant over time (R = 0)

b) Traverse path amplitude constant over time

Figure 4: Hypothesised a) Fax constant over time and resulting traverse path vs. b) traverse path constant over time and resulting Fax

The displacement is recorded using three-dimensional digital image correlation (3D-DIC). For this purpose, the GOM ARAMIS 6M stereo camera system with a resolution of 2,752 × 2,200 pixels was used. Images are captured at 5 Hz during static and cyclic tests. Reference point markers are used to record and track the 3D coordinates during the tests. Continuous digital data acquisition includes force, relative displacement, and temperature. Where relative displacement describes the displacement of the steel medium pipe in relation to the casing. During testing, temperature control is provided by a Lauda INTEGRAL IN 150 XT process thermostat using thermal oil. With a working range of –45 °C to 220 °C and a temperature stability of ±0.05 K, the device ensures a stable test temperature during all temperature test phases. The test objects should be manufactured from factory-made district heating pipes and cut out at right angles to the pipe axis. According to EN 253, the test specimen shall be a length of pipe assembly where the length of the casing is equal to 2,5 times the thickness of the thermal insulation, but not less than 200 mm. For that reason, to allow welding, both ends of the pipe must be stripped back a minimum of 100 mm to expose the steel service pipe. Furthermore, the coaxiality tolerance according to EN 253 must be maintained for all test specimens. Following a successful inspection of the test specimens, welding work can be carried out to fit the inlets and outlets for the heat carrier and the pendulum bearing.

The test programme for low-cycle fatigue testing comprises four consecutive stages to ensure well-defined thermal and axial loading conditions.

1. Axial shear test: Before low-cycle-fatigue testing, a reference value according to EN 253 is established.
2. Heating phase: Each specimen is heated to the target test temperature and held isothermally for one hour to ensure a uniform temperature distribution throughout the pipe.
3. Cyclic axial loading: While maintaining the target temperature, a defined number of axial loads is applied to the steel medium pipe.
4. Axial shear test: After completion of cyclic loading without failure, a quasi-static axial shear test is performed under the target temperature with a crosshead speed of 5 mm/min until failure of the composite occurs. A lower shear strength would then indicate fatigue compared to the monotonic-loaded specimen.

On the other hand, the test programme for high-cycle-fatigue testing consists of three consecutive stages to ensure defined thermal and axial loading conditions.

1. Axial shear test: Before low-cycle-fatigue testing, a reference value according to EN 253 is established.
2. Heating phase: Each specimen is heated to the target test temperature and held isothermally for one hour to ensure a uniform temperature distribution throughout the pipe.
3. Cyclic axial loading: While maintaining the target temperature, a high number of axial loads is applied to the steel medium pipe until failure of the bond is observed.

Discussion and Conclusion

The test setup presented opens the way for a wider investigation into the thermo-mechanical behaviour of pre-insulated DH pipes. The work aimed to design a test methodology that enables superimposed thermal and cyclic axial loading of short-length pre-insulated DH pipe specimens beyond the scope of existing standards. The review of existing test setups revealed large variations in thermal loads, cycle counts, stress ratios, and frequencies. Many approaches involve high-frequency fatigue tests with subsequent extrapolation into the low-cycle regime, which may not adequately reflect long-term operational behaviour. This highlights the methodological challenge of defining laboratory test conditions that appropriately represent in-situ behaviour over decades. The present setup, therefore, offers a flexible platform that can support both high-cycle and low-cycle testing under controlled and adjustable thermal conditions. Temperature control proved to be a critical aspect of the test concept. Although the setup allows testing up to 220°C, it does not currently include a nitrogen-flushed chamber. As a result, thermo-oxidative ageing at elevated temperatures cannot be fully suppressed and may influence long-term material behaviour. Future extensions of the setup could integrate nitrogen purging or controlled atmospheric conditions to distinguish between thermal and thermo-oxidative effects. Likewise, simulating earth loads by applying defined pre-compression of the insulation remains a potential extension for cases where soil-pipe interaction is of interest. Despite these limitations, the test setup closely aligns with EN 253 requirements wherever feasible and remains compatible with EN 13941-1-based load cycle considerations. It also enables testing at representative stress ratios for cold-laid pipes and steady-state temperature variations. In its present form, the configuration allows systematic exploration of the roles of temperature level, axial shear stress amplitude, and cycle frequency in the degradation behaviour of pre-insulated DH pipes. In summary, the newly developed test setup expands the methodological toolkit for evaluating pre-insulated DH pipes under more realistic thermo-mechanical loads. It enables controlled application of axial cyclic loads, elevated temperatures, and EN 253-compliant test procedures within a single configuration. This makes it suitable for investigating ageing mechanisms, adhesion performance, and load interaction effects under conditions that more closely resemble real network operation than existing standards allow. As the full experimental programme is still ongoing, future work will apply the setup to further quantify the combined effects of thermal ageing and cyclic axial loading and to develop improved indicators for long-term performance and service life prediction of pre-insulated DH pipe systems.

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