TFSB as Bedding Material in District Heating Pipe Construction–Scientifically Proven Long-Term Experience

Bernd Wagner, Stefan Hay, Thomas Neidhart, Florian Spirkl, Michael Ried, Louis Zrenner, Ingo Weidlich, Eugen Gabriel, and Timo Banning

Abstract Following the explanation of the increasing importance of alternative backfill materials like TFSB, TFSB and their status in terms of science and technology are depicted. Selected results of the research project FW-ZFSV 4.0 are presented: computer-aided static calculation, in situ long term loading of district heating pipes in TFSB and sand, quality assurance and resource conservation. The conclusions provide an overall assessment of the use of TFSB in district heating pipe construction.

Keywords District heating networks · TFSB · ZFSV · Design · Planning · Static calculation

1 Initial Situation

District heating competes with other heat supply solutions. Increasing technical and economic competitiveness is of major importance.

The civil engineering work for the dominant buried preinsulated bonded district heating pipes (DH pipes) can account for 55% or more of the total construction costs [1, 2]. Cost reductions, especially for excavation, backfilling and compaction offer a lever for reducing investment costs when expanding or building district heating

B. Wagner (✉) · S. Hay
AGFW, Frankfurt am Main, Germany
e-mail: b.wagner@agfw.org

T. Neidhart · F. Spirkl · M. Ried · L. Zrenner
OTH Regensburg, Regensburg, Germany

I. Weidlich
HafenCity Universität Hamburg, Hamburg, Germany

E. Gabriel · T. Banning
GEF Ingenieur AG, Leimen, Germany

D. Vanhoudt (ed.), *Proceedings of the 19th International Symposium on District Heating and Cooling*, Lecture Notes in Networks and Systems 1700,
https://doi.org/10.1007/978-3-032-09844-3_10

networks. Increasing requirements of the circular economy and decreasing availability of sand are exacerbating the situation. (Keyword: Ersatzbaustoffverordnung (Substitute Building Materials Ordinance) in Germany) [3].

Alternative backfill materials are therefore becoming increasingly important [4].

2 Temporary Flowable, Self-compacting Backfill Materials

Temporary Flowable, Self-compacting Backfill Materials (TFSB) as an alternative backfill material consist of base material (soil/excavated material and/or soil building material), water and additives (hydraulic and/or layered silicate). They are free flowing after mixing and are installed without any compaction. Stiffening, solidification and hardening cause the transition to solid TFSB, which are increasingly mechanically resilient over time. Further details can be found in [5], for example.

3 TFSB in District Heating

From many years of use in sewer construction, it was and is generally known that TFSB offer potential in terms of construction technology, cost reduction, reduction of the impact of construction measures on the surrounding area and environment and conservation of resources.

Since 2009, TFSB have therefore been investigated specifically for use in district heating pipe construction in research projects. Potential savings of 3.5–16% compared to current construction technology were shown. The axial bedding mechanism was researched and clarified. Calculation approaches for displacements and forces were developed. Technical questions regarding suitability and specific requirements in the district heating sector were clarified [6, 7].

TFSB have been included in 2019 in the AGFW regulations, which is the German established code of practice for district heating and are approved for backfilling in the whole trench including the pipe area. Standards such as DIN EN 13941 District heating pipes: Design (Part 1) and Installation (Part 2) do not (yet) include TFSB.

Despite the advanced state of research and the high application potential, TFSB are mainly used for special requirements such as bottlenecks and pipe crossings. Exploration conducted in advance showed that mainly unanswered questions, a lack of solutions and uncertainties, primarily in planning and practice, hinder consideration and use as a regular alternative to conventional backfilling with sand.

4 The FW-ZFSV 4.0 Research Project

Therefore, the aim of the research project "District heating pipeline construction 4.0 with temporarily flowable self-compacting backfill materials for low and high operating temperatures" (FW-ZFSV 4.0) was to address and investigate these obstacles and provide answers to them. Specific starting points and goals were:

- Investigations into the long-term behavior of TFSB as a bedding material in district heating pipe construction, including the experimental Bypass pipe research measuring section (Bypass section) in scale 1:1 operated by AGFW in Frankfurt since 2015.
- Implementation of static calculation in planning tools.
- Answering open organizational and approval-related questions.

5 Selected Results: Static Calculation, In Situ Behavior

The project involved investigations into current issues relating to the use of the material, computer-aided static calculation, in situ long-term behavior, the use of recycled material as a base material and sustainability plus economic considerations. Selected results regarding computer-aided static calculations and in situ long-term behavior are presented in compact form below. The detailed presentation of all research results can be found in [3].

5.1 Practical Planning Tools: Computer-Aided Static Calculation

Comparative studies were carried out on simplified calculation models for initial sand bedding using several calculation programs with different solution methods.

Overall results showed that it is advantageous to calculate TFSB with beam-spring models instead of finite element models. The calculation is possible with conventional beam programs. The beam programs must be able to model the softening branch (decreasing friction) in the bedding spring that results from the underlying contact-working-resistance-line (see (Fig. 1 left). However, due to the numerous inputs in the model and for the springs, this is time-consuming, error-prone and impractical. Implementation using a specific calculation module in software explicitly designed for pipe statics is more suitable.

The implementation was therefore carried out by means of a specification sheet in software widely used in the district heating sector as bedding type TFSB (ZFSV in German) (Fig. 1 right) and will be available on the market.

Extensive comparative calculations based on the recalculation of the Bypass section confirmed the shorter length of the sliding zone and final displacements

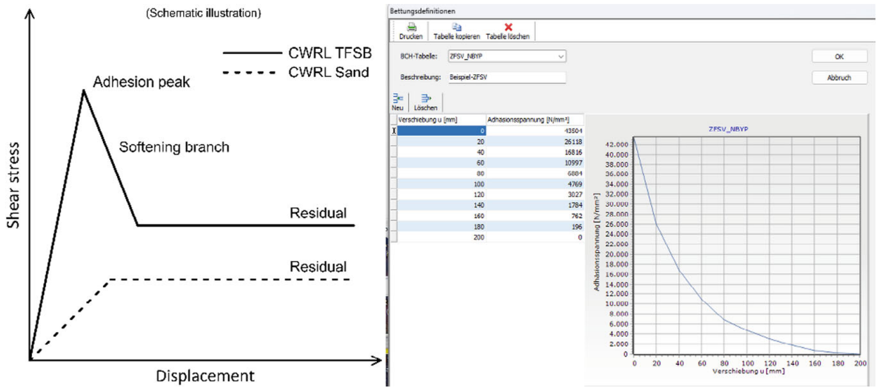

Fig. 1 CWRL: comparison of TFSB and sand (left) and implementation of bedding type TFSB in the software (right) (*Source* own illustration and screenshot)

already known from in situ displacement measurements when bedding DH pipes in TFSB compared to sand. Variation calculations showed that "softer" mixtures with a reduced adhesion peak should be aimed for in the future in the preparation of TFSB-recipes.

5.2 *In Situ Long-Term Loading of DH Pipes in TFSB Bedding and Sand Bedding*

Investigations were carried out on a large scale on the Bypass section in the Europaviertel district of Frankfurt am Main. The Bypass section was constructed and put into operation in 2015. Two parallel, approximately 1.6 m covered and approximately 50 m long DN 40/125 DH pipes were backfilled with TFSB respectively with sand. Under otherwise identical conditions the pipes were connected to a concrete fixed point on one side with the other end freely movable (Fig. 2). Details can be found in [7]. The Bypass section was operated by AGFW until July 2023 and then dismantled. Extensive investigations were carried out during the dismantling process.

Long-term temperature load and cyclical temperature load

The heating medium in the Bypass section has experienced temperatures of between 90 and 110 °C over several years - starting from an initial 14 °C—and has also been cooled down several times.

In the last four months of operation (Fig. 3), various cyclical temperature stresses between approximately 20–140 °C and 60–140 °C with longer holding phases at 140 °C took place. During the dismantling process, pipe sections were removed

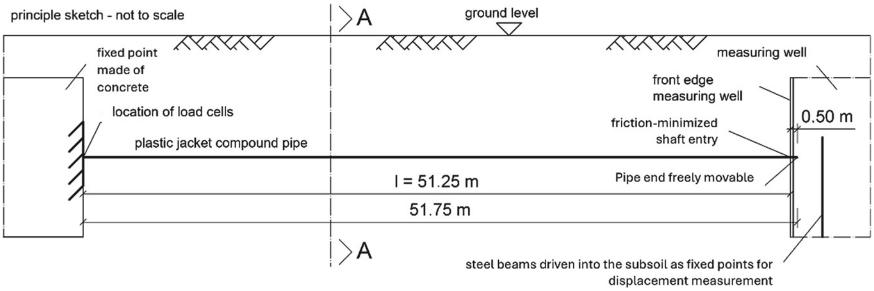

Fig. 2 Schematic longitudinal section of the Bypass section (*Source* [7], altered)

from the DH pipes for both bedding types and examined for compliance with the requirements of EN 253.

After 8 years of operation of the Bypass section results are:

- The thermal elongation impediment of the DH pipes in TFSB is greater than in sand.
- The larger thermal elongation impediment of the DH pipes bedded in the TFSB did not result in any damage to them.
- The DH pipes sections tested meet the requirements of EN 253: cell size, percentage of closed cells, water absorption at elevated temperature, foam density, compressive strength, axial shear strength.
- There are no differences due to the bedding material in the reduced bonding strength of the DH pipes caused by thermal stress.

In-situ investigation of the CWRL

In situ push-through tests of the DH pipes were carried out at several points along the Bypass section using a specifically designed, complex press construction (Fig. 4 left and middle). The tests were carried out for both bedding types under the overburden conditions of the Bypass section with an embedment length of the DH pipes of around 3 m. The aim was to determine and compare the CWRL in situ with the CWRL previously determined from Re-SIST shear tests (Fig. 4 right) in the laboratory in [7].

Figure 5 shows the CWRL for TFSB (in situ and Re-SIST) and for sand (in situ). The results in conjunction with Fig. 5 are:

- The forces and the displacements were measurable in situ; adhesion and friction can be distinguished.
- The known drop in shear stresses for TFSB takes place after the adhesion peak is exceeded.
- The in situ CWRL and the Re-SIST CWRL are similar.
- The Re-SIST test is suitable for small-scale suitability testing.
- Significantly smaller axial shear stresses occur in sand.

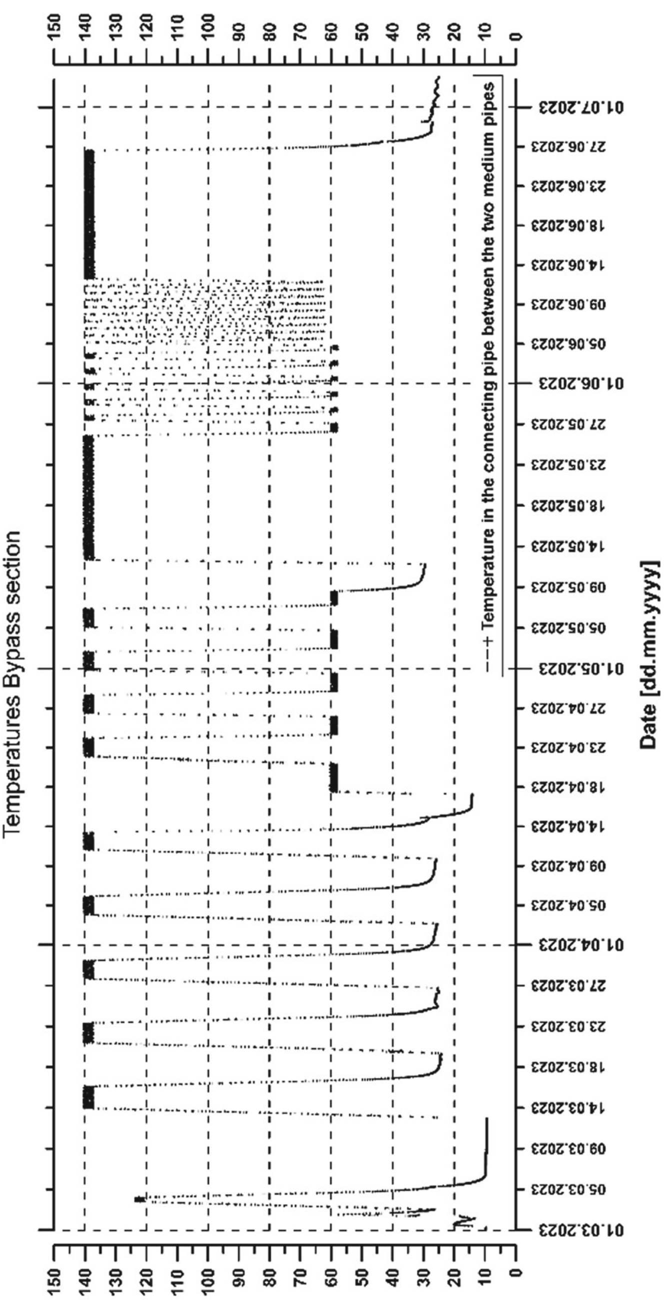

Fig. 3 Cyclical temperature load Bypass section March–June 2023 (*Source* own diagram)

Fig. 4 Press device for in situ push-through tests (left), pull and push coupling of the DH pipes with the press device (middle), Re-SIST shear test device for laboratory investigations (right) (*Source* own images)

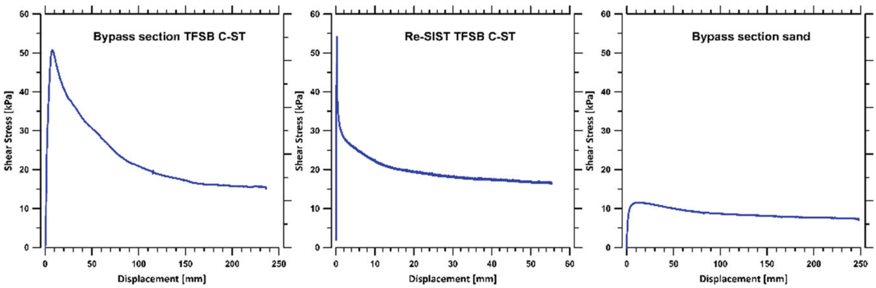

Fig. 5 CWRL TFSB in situ (left) and Re-SIST (middle) and sand in situ (right) (*Note* For display reasons, the x-axes are partly scaled differently.) (*Source* own diagram)

6 Quality Assurance and Resource Conservation

6.1 Quality Assurance

Compared to conventional pipe area backfilling with sand, the use of TFSB requires different and other quality assurance measures, which are, however, common.

When using TFSB, quality assurance must already be part of the design and planning phase. For the static design, it is necessary to decide on the characteristic CWRL value and the unconfined compressive strength regarding the re-excavation capacity. These are input values for the subsequent TFSB recipe design and suitability testing. Self-monitoring and external monitoring during the execution phase include tests to ensure that the installed material meets the specifications. The procedure and required tests are well known and standardized.

Regarding the district heating-specific quality assurance, the requirements elaborated in [7] remain mostly valid. Where necessary, they have been updated and supplementend with knowledge gained during the project in exchange with practitioners and within the research project.

It is planned to update and further anchor these measures and additional regulations on the use of TFSB in district heating in the AGFW regulations.

6.2 Resource Conservation

The greenhouse gas emissions (carbon footprint (CFP)) of sand and TFSB were compared using standard procedures and applying reasonable system boundaries.

A comparative evaluation of a real project was carried out in cooperation with a construction company. In addition, a simplified life cycle assessment was carried out.

Figure 6 left shows the results of the CFP evaluation. In Fig. 6 right the results of the simplified life cycle assessment are shown.

The assessment of the project yields that the use of TFSB as bedding material saves approximately 5% CFP (V1 versus V3). If the trench width is additionally optimized, this results in a saving of approximately 10% CFP (V1 versus V4). Additionally, one can clearly recognize in Fig. 6 right that for identical trench dimensions, the TFSB bedding only shows a higher water consumption than the sand bedding. Environmental indicators can be reduced by 30% in some cases, and by as much as 50% if the trench dimensions are optimized.

Even though the assessed project dealt with the bedding of a wastewater pipe, the authors consider the transferability of the results to other pipe systems, such as district heating pipes, to be justified.

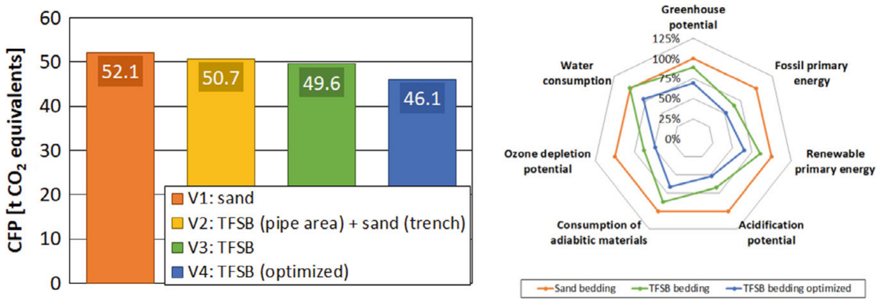

Fig. 6 Evaluated project—different construction variants: CFP for the pipe area and trench backfill (left) and simplified life cycle assessment (right) (*Source* own diagram)

7 Conclusions

In addition to the research results published to date, the results from the research project confirm that TFSB are very well suited as bedding material for district heating pipe construction and pave the way for their continued use in the future. The presented and overall results [3] of the research project yield that TFSB offer a great opportunity and a high optimization potential for expansion and construction of district heating networks. Particularly in view of the increasing demands of the circular economy, which will make the use of sand as a bedding material and the transport and disposal of excavated material even more difficult.

Acknowledgements The research project was approved and funded by the Federal Ministry for Economic Affairs and Climate Action (BMWK) under the funding code 03EN3022 via the project sponsor Jülich. The project partners are grateful for the funding, without which the implementation of the project with a 48-month term until end of July 2024 would not have been possible.

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