Tunnel Lining System

White Paper

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Executive Summary

The tunnel lining is a critical component of any tunnel boring machine (TBM), as it ensures the structural stability of the excavated tunnel behind the machine. Conventional tunneling approaches rely on precast concrete segments or prefabricated pipes, which impose significant constraints on tunneling speed, logistics, and achievable tunnel geometries, especially in microtunneling applications.

This paper presents a novel tunnel lining concept based on the in-situ extrusion of a thermoplastic polymer directly within the TBM. Instead of transporting prefabricated lining elements, the liner material is delivered in granular form via a pneumatic transport system and processed using an integrated extrusion unit. The molten polymer is continuously shaped inside a mold to form the tunnel lining and subsequently cooled to achieve the required structural integrity.

The developed system is derived from established industrial pipe extrusion processes but introduces a new implementation tailored to the constraints of microtunneling. By decoupling tunnel construction from rigid prefabricated elements, the concept enables increased geometric flexibility, simplified logistics, and the potential for continuous tunnel construction.

Figure 1: Swissloop Tunneling's Prototype TBM

Technical System Design

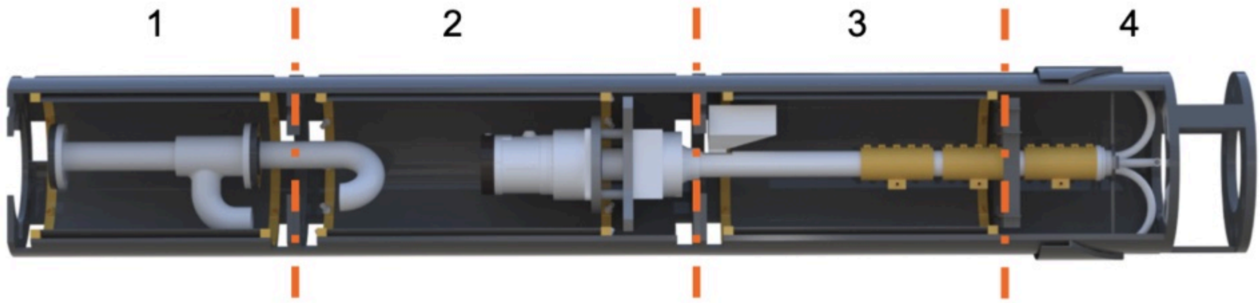

Figure 2: Swissloop Tunnelings Tunnel Lining System (cross-sectional view)

Structural Design of the Lining System

The tunnel lining system is designed as a modular, four-part structure consisting of the following sections:

1. **Storage Section** – An empty section that can be used to store various components that do not fit elsewhere in the machine. In the case of Swissloop Tunneling, this section is used to house the Venturi pump, which is responsible for material excavation.
2. **Motor Section** – Contains the hydraulic motor and gearbox that power the screw extruder.
3. **Extruder Section** – Houses the spiral extruder.
4. **Mold Section** – Contains the mold that forms the polymer pipe as well as the connection pipes.

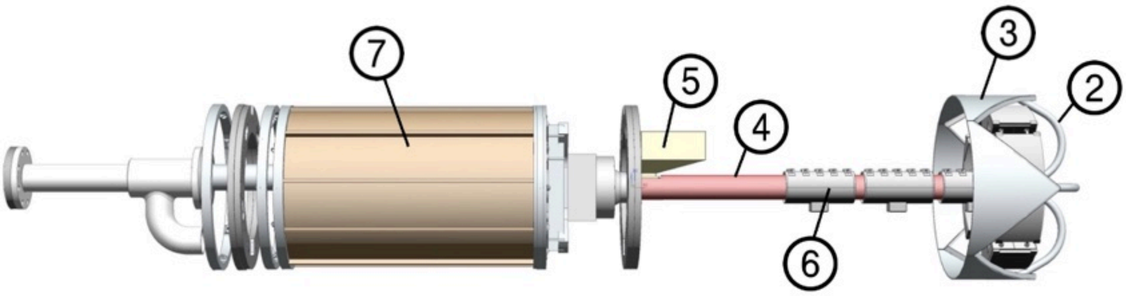

Figure 3: Swissloop Tunnelings Tunnel Lining System (cutaway view)

2. **Connection Pipes** – Transport the polymer from the extruder to the mold.
3. **Mold** – Guides the polymer flow until a pipe is formed from four polymer streams.
4. **Spiral Extruder** – Melts and compresses polymer granules to form a liquid polymer stream.
5. **Hopper** – Stores a small amount of polymer granules to ensure that the polymer feed into the extruder is continuous.
6. **Extruder Heating Elements** – Provide additional heat to melt the polymer. The mold and the connection pipes are also heated.
7. **Double-Walled Water Cooling** – Cools the polymer using a double-walled structure. This double-wall construction is shown in Figure 3 for the motor section, but is also implemented in the storage section and the extruder section.

To improve accessibility for maintenance, the upper section of the tunnel lining system can be dismantled in segments using removable panels. The extruder, motor, and storage sections are furthermore covered with stainless steel panels of varying thickness to compensate for polymer pipe shrinkage along the cooling sections and to reduce friction between the polymer and the tunnel lining system.

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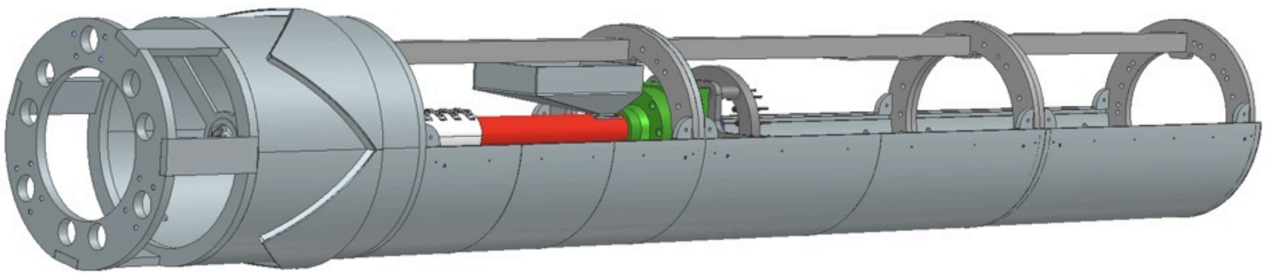

Figure 4: Swissloop Tunnelings Tunnel Lining System (Panels removed)

Functionality of the Lining System

The polymer is supplied in granular form and enters the machine through a hose that is pressurized by a pneumatic system. The pneumatic system operates in cycles in which, through a combination of several valves, a precise quantity of polymer granules is conveyed into the machine and temporarily stored in the hopper. This design allows the polymer feed to be accurately controlled and easily adjusted in case more or less granulate is required, for example when the machine speed is increased or reduced.

From the hopper, the granules are fed into the screw extruder, which is responsible for melting the polymer granules and generating sufficient pressure to force the molten polymer through the four connection pipes to the mold. The screw is divided into three sections: a feeding section that conveys the polymer into the extruder, a compression section in which the polymer is melted, and a pumping section where the required head pressure is built up.

In the tunnel lining system, the extruder is the main source of heat. About 70% of the heat used to melt the polymer is generated by the hydraulic motor through friction and shear forces between the polymer granulates. The rest is provided by three different types of heating elements, which are designed to keep the polymer at the required operating temperature. This is necessary to get the polymer to its optimal extrusion temperature.

From the extruder head, the molten polymer is split into four heated connection pipes that transport the polymer from the center of the machine to the mold, where it is formed into the pipe.

After leaving the mold, the extruded polymer slides along the machine and is cooled by a water-cooling system consisting of a double-wall construction for each section of the lining system. At the end of the storage section, the polymer is cooled to a temperature at which it can withstand the mechanical forces acting on the material.

Heat not transferred into the polymer is conducted into the machine structure. To prevent excessive thermal loading of adjacent components, additional air cooling is integrated into the tunnel lining subsystem.

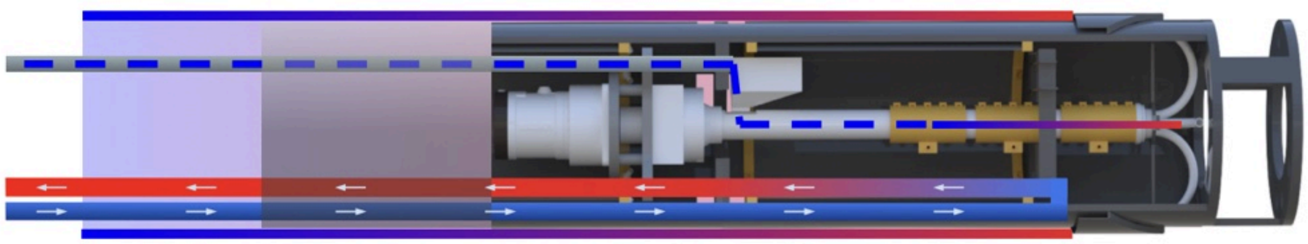

Figure 5: Swissloop Tunnelings Tunnel Lining System (Fluid flows)

Material Selection and Properties

The tunnel lining material must satisfy both mechanical and thermal requirements. Structurally, the system must withstand radial loads induced by the surrounding soil pressure and, in the case of Swissloop Tunneling, also radial and axial loads resulting from propulsion, as the machine operates in a similar manner to a classical gripper TBM. Thermally, the material must be compatible with a continuous extrusion process and exhibit stable behavior during cooling.

A polypropylene-based material was selected due to its favorable combination of mechanical strength, thermal conductivity, and low shrinkage. These properties allow the liner to maintain dimensional stability while reaching the required structural strength after extrusion and cooling.

Concept Evaluation

Conceptual Advantages and System Implications

The presented tunnel lining concept represents a fundamental shift from conventional tunnel construction approaches based on prefabricated structural elements. By producing the tunnel lining continuously through in-situ polymer extrusion, the lining process is decoupled from rigid geometrical constraints and discrete installation steps.

One of the primary conceptual advantages of this approach is the elimination of prefabricated lining elements. Transport, handling, and alignment of rigid segments or pipes are replaced by a continuous material flow, significantly simplifying logistics and reducing system interruptions. This enables a more continuous tunneling process and opens new degrees of freedom in tunnel geometry and system layout.

The modular design of the lining system further enhances maintainability and operational flexibility. Accessibility to internal components is improved without compromising structural integrity, supporting efficient installation, inspection, and servicing throughout the machine's lifecycle.

System-Level Flexibility and Scalability

The continuous extrusion-based lining concept introduces a high degree of scalability across tunnel diameters and application scenarios. Since the liner is not constrained by the dimensions of prefabricated elements, scaling is primarily governed by extrusion capacity, cooling performance, and material behavior rather than manufacturing or transport limitations.

From a system perspective, this enables adaptation to:

- varying tunnel diameters,
- non-standard tunnel cross-sections, and
- application-specific structural requirements.

The concept is inherently compatible with modular machine architectures. Key subsystems such as extrusion, heating, and cooling can be scaled or adapted independently, allowing the lining concept to be transferred across different tunneling platforms with minimal changes to the underlying principle.

Operational Implications

By transitioning from discrete liner installation to continuous tunnel construction, the presented concept has significant implications for tunnel boring operations. The removal of segment installation steps reduces mechanical complexity and minimizes interruptions during tunneling.

Material logistics are simplified, as polymer granulate can be transported efficiently and stored compactly compared to bulky prefabricated elements. This can be particularly advantageous in constrained environments or long-distance tunneling scenarios.

Thermal management emerges as a key operational parameter within this concept. The rate at which the extruded polymer can be cooled to reach structural integrity directly influences the achievable tunneling speed. As such, cooling performance becomes a system-level design driver rather than a secondary consideration.

Conceptual Limitations and Boundary Conditions

While the extrusion-based tunnel lining concept offers significant advantages, it is subject to inherent boundary conditions. The achievable structural performance is closely linked to the selected polymer material and its thermal and mechanical properties. Consequently, material selection plays a central role in defining the operational envelope of the system.

Cooling capacity represents another fundamental limitation. Due to the low thermal conductivity of polymers, sufficient cooling length and heat dissipation capability are required to ensure structural integrity before the liner is subjected to full mechanical loading.

Additionally, the concept assumes stable and predictable extrusion conditions. Variations in material properties, environmental temperatures, or process stability may influence liner quality and must be managed at the system level.

Conclusion

This White Paper presented a novel tunnel lining concept based on continuous in-situ extrusion of thermoplastic material. By rethinking the role of the tunnel lining as an actively manufactured system component, the approach addresses key limitations of conventional lining methods in terms of geometry, logistics, and process continuity.

The concept emphasizes system-level integration, scalability, and operational flexibility rather than detailed implementation, providing a foundation for future research, development, and industrial application. As tunneling requirements continue to evolve, extrusion-based tunnel lining represents a promising direction for next-generation underground construction technologies.

Figure 6: Extruded Polymer Pipes