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Review

The durability of shotcrete in cold region tunnel: A review

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HIGHLIGHTS

- The research status of shotcrete in tunnels in cold regions is combed and summarized.
- The influencing factors of shotcrete in tunnels in cold regions are summarized.
- The development direction of shotcrete in tunnels in cold regions is forecasted.

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ABSTRACT

Frost damage is a common problem for tunnels in cold regions. To improve the durability of the shotcrete in cold areas this paper reviews recent research findings, summarizes the common damage and frost heaving process of shotcrete in cold areas, and includes the microstructure changes of shotcrete caused by the freeze-thaw cycles, the main influencing factors of frost durability, the four stages of the frost damage of shotcrete, and primary methods used to improve the frost durability of shotcrete. Suggestions for further research on the frost resistance of shotcrete were provided.

Contents

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1. Introduction

Shotcrete is flexible, convenient, does not require the laying of templates, and helps to resist deformation in poor geological conditions or a collapse [1–5], and it is a popular material in tunnel engineering [6–10]. In tunnel engineering, shotcrete is usually sprayed onto the surface of the surrounding rock to prevent oxidation and the deterioration of the surrounding rock [11–14]. Meanwhile it prevents the surrounding rock from softening. Shotcrete is widely used for enhancing the stability of the lining structure within the tunnel surrounding rock [15–19].

When the tunnel gradually extends to cold areas, the internal temperature could be greater than the outside temperature of a tunnel, and the wind speed inside a tunnel is lower than the outside. Those result in the cold region tunnel concrete becoming prone to damage, including lining leakage, hanging ice, or other frost damages [20–23]. As the temperature changes, the shotcrete is directly exposed to outdoor airflow or is in a shallow covering range. When this occurs, the shotcrete will be affected by the cold air temperature. The pore water in shotcrete will freeze and melt under the changes in temperature, which will result in micro damage, frost heaving, fragmentation, and instability within the materials [24–26]. The temperature change results in hidden dangers within the tunnel operation, as well as weakening of the tunnel in winter. This causes a huge waste of resources and economic losses [27–29]. According to the theory of damage mechanics, the final instability of shotcrete is chiefly influenced by the formation of cracks during freeze-thaw cycles [30–35]. The freeze-thaw damage is the main factor that affects the durability of shotcrete structures in cold regions [36–39]. This paper summarizes shotcrete of tunnel disasters, explores the impact factors related to spray frost durability of concrete, explores the microstructural damage of shotcrete, and proposes methods to improve the frost durability of shotcrete.

2. Frost heaving process of shotcrete in cold region

2.1. Frost heaving process of shotcrete in cold region

The frost heaving process of shotcrete in cold region is summarized as follows:

(1) When temperatures drop below 0 °C, the excess water in the shotcrete begins to freeze resulting the volume's expanding.
(2) The shotcrete begins to freeze from the outside. After freezing, the ice closes the surface hole of shotcrete. It then begins to press the partially unfrozen water into the interior along the capillary channel.
(3) As the excess water within the shotcrete freezes, the ice volume increases along with the pressure of the unfrozen water. When the internal water pressure increases to the tensile strength of shotcrete, the pores become cracked and new cracks are formed.
(4) The pressure forces the water to flow into the cracks. As the freeze continues, the water pressure continues to increase. When the water pressure reaches a threshold, the cracks expand, new cracks are formed, and the shotcrete structure is damaged.

2.2. Frost damage of shotcrete in cold region tunnel

The tunnels in the cold regions also suffer from icing, side wall frost heaving, and other damages caused by the freeze-thaw cycles [40,41], as shown in Fig. 1.

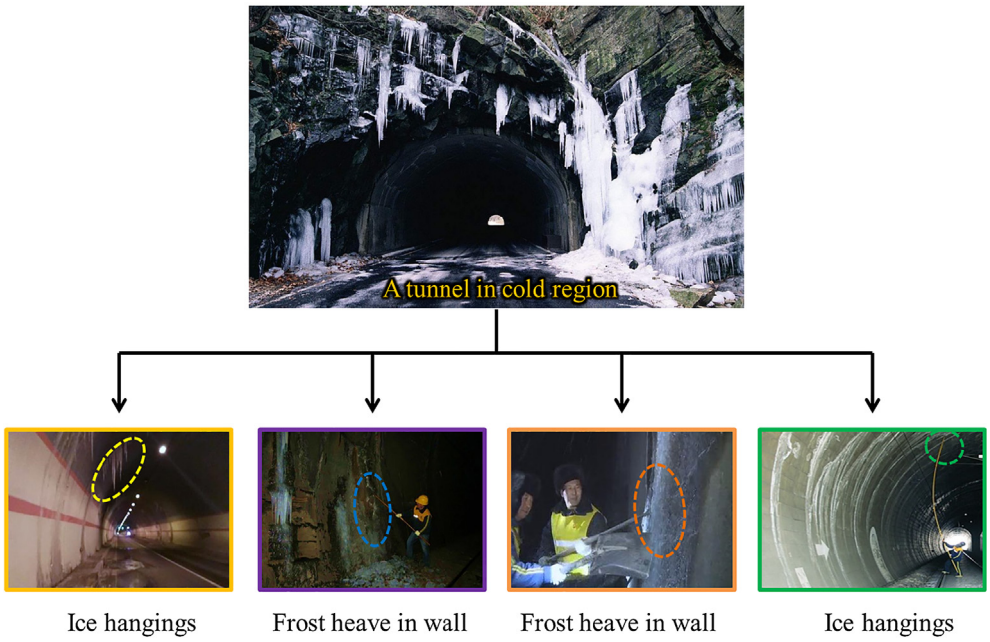

Fig. 1. Frost damages of concrete in cold regions.