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Influence of technological and environmental factors on the behaviour of the reinforcement anchorage zone of prestressed concrete sleepers

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HIGHLIGHTS

- Forces acting in prestressed concrete elements during heat treatment and reinforcement release.
- Comparison of experimental and calculated results of prestress force after heat treatment.
- Investigation of environmental impacts on concrete structure of sleepers.
- Analysis of concrete microstructure of new and damaged prestressed concrete sleepers.

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ABSTRACT

The article analyses the influence of technological factors on variations in the stress and strain state during the production of prestressed concrete sleepers. The paper focuses on technological damage to the anchorage zone and its influence on concrete and the pretensioned reinforcement of the last prestressed concrete sleepers located by abutments. The article presents the calculation principles of stresses caused by thermal and humidity deformations, compares theoretical and experimental results and specifies the nature of damages. The paper deals with concrete structure and an interface between reinforcement and concrete of new and three years old prestressed concrete sleepers, explores the results of laboratory tests on deteriorating the ends of new prestressed concrete sleepers under freezing and thawing cycles, looks at changes in concrete structure and the interface between reinforcement and concrete at the ends and in the middle of prestressed concrete sleepers applying a scanning electron microscope (SEM) and energy-dispersive X-ray spectroscopy (EDS). Secondary ettringite formation (DEF) in concrete micro-cracks and at the interface between reinforcement and concrete and elemental composition of the formed crystals have been determined. Significant difference in concrete structure and new solid phases at the ends of used and new sleepers has been defined. Concrete structure in the middle of the three years old railway sleeper has remained almost unchanged. The obtained results show that technological factors are affecting the deterioration nature of the ends of prestressed concrete sleepers.

1. Introduction

Prestressed concrete structures are the ones of the most effective structures used for the buildings of various purposes and complexity. Prior to exploitation, prestressed concrete structures are affected by various technological factors appearing during production. The micro-cracking of concrete structure, initial stresses and strains in reinforcement and concrete appearing during the production of prestressed concrete structures are more dangerous comparing with ordinary reinforced concrete structures.

Concrete cracking at the reinforcement anchorage zone and damage to bond between reinforcement and concrete are induced by stress variations in pretensioned reinforcement during the production of prestressed concrete structures [1–4]. The conducted research [5] shows that bond between reinforcement and concrete depends on many technological factors: concrete composition and strength during reinforcement release, curing conditions, element maintenance after concrete design strength is reached, the type of reinforcement, and the methods of release. Other research [6,7] shows that variations in technological stresses in concrete and reinforcement are different and causes initial damage to concrete structure during production processes. Micro-cracks, open pores, capillary, bond damage between reinforcement and concrete during reinforcement release and other damages enable aggressive substances from the environment penetrate into concrete. Different chemical processes taking place in the micro-cracks and pores of concrete are induced by these damages. New solid phases

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occurring in concrete micro-cracks and other imperfections cause additional stresses and can damage concrete structure [8–13].

The prestressed concrete elements of transport structures are affected by the greatest variety of effects. Extremely complicated environmental conditions influence prestressed concrete railway sleepers in service. Eight main reasons causing a failure in different types of the sleepers made from different materials are provided in a comprehensive analysis [14] of deteriorating prestressed concrete sleepers. Technological factors are one of the reasons, nevertheless, no more detailed research has been done. However, a number of studies on the behaviour of prestressed concrete sleepers under mechanical loads [15–20] and environmental conditions have been carried out and included a change in temperature [20], humidity and sulphate attack (delayed formation of ettringite) [12,22,23]. The behaviour and durability of the sleepers are affected by soil and ballast [24,25].

The performed research [10,21,22], shows that concrete corrosion and deterioration of prestressed concrete sleepers in service are highly dependent on the porosity of concrete structure and micro-cracks induced during production. Concrete structure and permeability have a significant impact on durability [26], bond between reinforcement and concrete, frost resistance and chemical (sulphate, alkaline) corrosion. An oxide layer can form on the surface of reinforcement before the production of reinforced concrete elements and it is dependant on the environmental conditions [27]. Therefore, oxide layer results a more hydrophilic surface and can enhance bond properties between reinforcement and concrete [28,29].

Different sources [15,22,23] show that the most common part of the damage and deterioration of prestressed concrete sleepers used in the natural environment are observed at their ends (reinforcement anchorage zone) (Fig. 1). This can be caused by the impact of water and frost [21], alkaline corrosion [23], sulphate corrosion [10,12,22] or concrete micro-cracking [9].

However, little research on the influence of technological factors on concrete porosity as well as on the appearance and development of micro-cracks during the entire period of production and service has been done. This work presents investigation of technological damages and their influence on construction behaviour during service. A qualitative influence of variations in the initial stress and strain state and bond between reinforcement and concrete on the behaviour of the reinforcement anchorage zone and construction quality has been analyzed.

2. Analysis of technological stresses and deformations of concrete and reinforcement

2.1. Influence of temperature on variations in stresses during production

An important point is ensuring the sufficient quality of technological processes during the production of prestressed concrete elements. However, this can be very hard to implement, because many complicated physical and chemical processes are happening between various materials and components in prestressed concrete elements. Technological damage to prestressed concrete elements is unavoidable because of different characteristics of materials and production processes. Reinforcement anchorage is the most important zone of prestressed concrete elements. Shear and normal stresses can cause the micro-cracking of concrete at the interface between concrete aggregate and cement paste, and reinforcement and concrete during heat curing of prestressed concrete elements.

Our analysis [6,30] and other authors examination [7,31] on technology for producing the prestressed concrete structure have revealed that the main production processes cause stress variation in reinforcement and concrete. In case of prestressing reinforcement to abutments, bond is forming between reinforcement and concrete at the beginning of concrete hardening. Bond strength depends on concrete composition, hardening conditions, maintenance after curing and the method of reinforcement release. The biggest change in stress is noticed in the part of reinforcement outside concrete at the end of the casting bed. When concrete is heated during production, shear stresses appear at the reinforcement and concrete interface due to difference in temperature. At this stage, stresses in reinforcement reduce due to reinforcement elongation. Compression force appears in concrete, because heated concrete expands and these deformations are restrained by bond between reinforcement and concrete. After hardening, during cooling, concrete shrinks and stresses in concrete decrease, but increase in reinforcement outside concrete due to different thermal and shrinkage deformations. Reinforcement is pulled out of concrete at the end of the last element and shear stresses appear at the interface between reinforcement and concrete. Reinforcement draws into concrete during release.

Fig. 2 describes technological effects at separate stages of production. The analysis of changing initial prestressing force P_0 shows that forces, in part of reinforcement outside concrete, cause stresses in the reinforcement anchorage zone and change its direction and value. Therefore, bond between reinforcement and concrete is more damaged at the end of the last element.

The first stages of prestressed concrete production include prestressing reinforcement to abutments (Fig. 2a), pouring concrete (Fig. 2b) and starting heat treatment. At these stages, opposite direction force F_1 (Fig. 2c) appears due to thermal deformations of reinforcement before bond between reinforcement and concrete appears. This force depends only on difference in temperature between abutments and the element. Then the total thermal deformation:

$$\Delta_{1(\Delta T)} = \alpha_p \cdot \Delta T_p (l_T - l_c) + \alpha_p \cdot \Delta T_c \cdot l_c, \quad (1)$$

where l_c is total length of prestressed concrete elements in casting bed; l_T heated part of casting bed; α_p thermal expansion coefficient

Fig. 1. End cracking of prestressed concrete sleepers.