ANALYSIS OF A THAUMASITE ATTACK IN A RAILWAY TUNNEL

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ABSTRACT

Concrete linings failed before the acceptance of a railway tunnel in a north mountain area of China. A series of experiments were done to analyze the cause of this case. Thaumasite, ettringite, gypsum and calcite were found in the deteriorated concrete linings. The composition of on-situ soil and water samples were also analyzed. Though the sulfate concentration soil behind the linings are not very high, the underground water bring plenty of sulfate after its upsteam flow through a gypsum stratum. It is the external sulfate that induce the deterioration in a low temperature environment which is suitable for thaumasite formation.

KEYWORDS

Concrete lining, damage, thaumasite, external sulphate.

INTRODUCTION

High speed railway construction is booming in China. In mountain area of North China, building tunnel is an economic and effective way for railway engineering. Due to the complicated geological environments, the deterioration of concrete linings in some existing tunnel were reported these years, most of them related to the linkage of groundwater (Huang Bo *et al*.2010). But the failure for a new tunnel due to concrete problems is very rare.

In this paper, a case of an unfinished tunnel lining failure was analyzed. Located in Shanxi province, the construction of the tunnel began in October 2010. The depth of the tunnel is about 300 meters and the temperature in the tunnel always keep at 8-15℃.

In September 2014, some severe deterioration was found in the initial shot-crete lining just before the acceptance of the tunnel. Even the second plain concrete lining was damaged by the expansion, shown in Fig.1

Based on the in-situ test and lab analysis, the cause of the failure was discussed here.

Figure 1 Profile of the tunnel, extruded 2nd lining and surrounding rock water collection

EXPERIMENTAL

Materials

From the primary investigation, it can be deduced that the expansive reaction is the main factor. In order to know what happened to the concrete lining, water, soil, and corrosion products samples were taken from the tunnel site, shown in Fig.2. Since the waterproofing was broken by the expansion, plenty of surrounding water was found in the tunnel. The sediment in drainpipes was also taken to lab.

The grade of shot-crete and 2nd lining is C25 and C30 respectively. Cores were drilled from the shot-crete and second lining to test the compressive strength. The results show that the strength satisfy the design demanding. So the experimental was focused on chemistry analysis.

Figure 2 Deteriorated concrete behind the waterproofing board and a white substance on surface

Experimental

The concentration of SO_4^{2-}, HCO_3^-, Cl^-, Ca^{2+}, Mg^{2+} and pH value etc. of water samples was measured according to a Chinese standard “Code of water quality analysis for water conservancy and hydropower development”.

X-ray fluorescence (XRF) and X-ray diffraction (XRD) was carried out to analyse the mineral composition and element distribution (S, Ca etc.) of soil, sediment and concrete samples. Then Scanning electron microscope (SEM) and Energy dispersion spectrum (EDS) was used to investigate the morphology of the corrosion products.

Following steps were used to test the SO_4^{2-} concentration in corroded concrete samples:

-Picking out coarse aggregates from the sample, only mortar was left.

-Grounding the mortar and pass the thieve of 80 μ m.

-Mix the powder passed 80 μ m with 1：1 hydrochloride acid, boiling for about 60 minutes to get solution.

-Measure the SO_4^{2-} concentration by ion chromatography.

-Converting the above value to a concentration of mortar mass.

RESULTS AND DISCUSSION

Adjacent rock water and soil

The results of water analysis are shown in Table 1. It can be seen that the SO42- concentration peak appears in No.5, sample of the adjacent rock water of upstream. According to the geological investigation report, it is the very location where the underground gypsum stratum exist. Following the move of the groundwater, the upstream contacting with the gypsum will have a higher SO_4^{2-} concentration than that of the downstream.

Table 1 ion concentration and mineralization of adjacent rock water or surface water

(mg/L)	Nubmer and sampling location					
	1 DK319+342	2 DK319+334	3 DK319+350	4 DK317+822	5 DK314+120	6 DK312+500
	Tunnel right wall	Tunnel left wall	Tunnel right wall	drainpipe	adjacent rock upstream	surface water

PH	7.94	7.68	7.47	7.86	7.12	7.62
Free CO_2	7.98	7.98	15.96	7.98	23.94	15.96
K^++Na^+	11.5	14.95	1.38	50.83	11.04	31.74
NH_4^+	0	0	0.21	0.08	0.71	0
Ca^{2+}	90.15	95.3	141.66	141.66	618.14	181.58
Mg^{2+}	35.93	31.24	32.8	32.8	148.39	33.58
Cl^-	9.76	9.76	12.2	34.15	29.27	17.07
SO_4^{2-}	**290.03**	**262.26**	**231.41**	**373.34**	**1650.71**	**376.42**
HCO_3^-	99.19	136.39	285.18	198.39	508.37	297.58
tds	536.56	549.9	704.84	821.25	2966.63	937.97
HCO_3^- (mmol/L)	1.63	2.24	4.67	3.25	8.33	4.88

For the surrounding soil of the deteriorated tunnel, the SO42- concentration is not so high, all below 0.5% (mass).

Sediment in drainpipe

Different minerals was found in the sediment in drainpipes including thaumasite, ettringite and gypsum, as shown in Fig. 3, which are products of slufate attack. In normal leakage water, calcite always can be found. XRD and EDS also prove that.

Fig.3 SEM photograph of typical crystal found in sediment

Concrete

XRD, SEM and EDS analysis identified an ettringite/thaumasite mixed crystal as being the main reaction product in the deleterious concrete, similar to the cases reported by Baoguo Ma *et al*（2006）, Crammond *et al* (2003) and H. Justnes *et al* (2006).

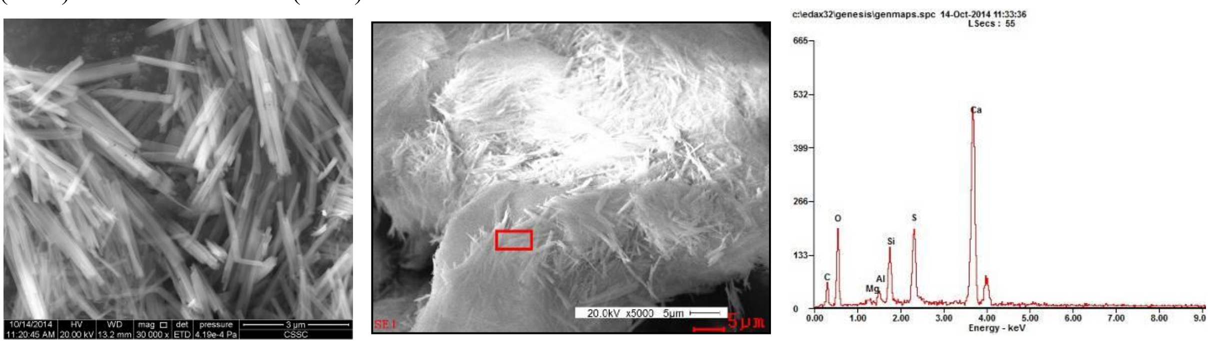

Figure 4 Thaumasite found in deterorated shot-crete

CONCLUSIONS

The main cause of the deterioration of the tunnel lining is the external sulphate attack, resulting strength degradation by thaumasite and expansion by ettringite. Design code of mountain tunnel should be improved to enhance the prevention of deleterious thaumasite formation in the future.

ACKNOWLEDGEMENTS

The financial help of the Tianjin Science and Technology Support Plan (Project No. 13ZCZDSF01600) is gratefully acknowledged.

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