RAILWAY TIES AFFECTED BY ALKALI-AGGREGATE REACTIONS

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ABSTRACT

A study was conducted on a railway tie showing longitudinal cracking between the rail seats and random cracking in the ends beyond the rail seat. Results show that reactive siliceous and dolomitic aggregates were used, and that deterioration of the concrete was primarily due to the combination of alkali-silica reaction and alkali-dolomite reaction.
Keywords: Alkali-aggregate reaction, deterioration, railway tie

INTRODUCTION

Railway ties manufactured at a plant in Henan province, China were showing random cracking in the ends beyond the rail seat and longitudinal cracking between the rail seats. Some of them were then broken up. These railway ties were produced during 1983-1984 and were put into service in late 1985 or early 1986. The on-line and spare (set beside) ties began to crack in 1987. The cracking continues to extend. A field survey carried out in 1990 shows that more than 90% railway ties were damaged. The railway ties laid in Northeast and North China were more seriously deteriorated than that placed in the central China. Railway ties used in the same places from other plants were in good condition.

The cracking of the spare ties shows that the deterioration was not caused by load. The railway ties cracked in a temperate climate of the central China. This seems to indicate that the damage was not primarily due to freezing and thawing. However, the low temperatures (lower than -10℃) in the winter of the Northeast and the North may aggravate the deterioration. It was suspected that the cracking was due to alkali-aggregate reactivity or sulfate attack.

BACKGROUND INFORMATION

The concrete railway ties had been made with ordinary Portland cement from Pingdingshan, Henan province. Alkali and SO_3 contents of the cement were 1.19% Na_2Oequiv. and 2.95-3.10%. C_3S, C_2S, C_3A and C_4AF were 49.73%, 23.61%, 7.40% and 13.88%, respectively. The fine aggregate was derived from rivers. Its fineness module was 2.2. The coarse aggregates were crushed calcitic dolostone, dolomitic limestone and metamorphic quartzite. They were in 5-20 mm. The contents of cement, sand, rock and water in 1 m^3 concrete were 510 kg, 523 kg, 1344 kg and 140kg, respectively. To obtain a good workability, 0.5-0.7% of a water reducing admixture was added. The admixture was a sodium salt of sulfonated naphthalene-formaldehyde condensate with about 25% of sodium sulfate. The ties were cured in about 80℃ steam for 10 hours.

EVALUATION OF ALKALI-REACTIVITY OF AGGREGATES

Coarse aggregates were collected from the cracked railway ties and the quarry. They were submitted to X-ray diffraction analysis, petrographic examination and evaluation of alkali-reactivity. The calcitic dolostone contained 70-80% rhombhedral dolomite in 2-20 μm, 5-10% calcite and 15-20% acid insoluble residue consisted of <10-60 μm quartz, kaolinite and illite etc. Dolomite crystals in some of the dolostone had been attacked. Fig. 1 shows the textures. The dolomitic limestone was composed of 10-20% 10-30 μm rhombhedral dolomite, 75-85% calcite and 2-5% impurities such as <10-50 μm quartz and microcline. Its microstructure is also shown in Fig. 1. Mineral in the metamorphic quartzite was strained quartz.

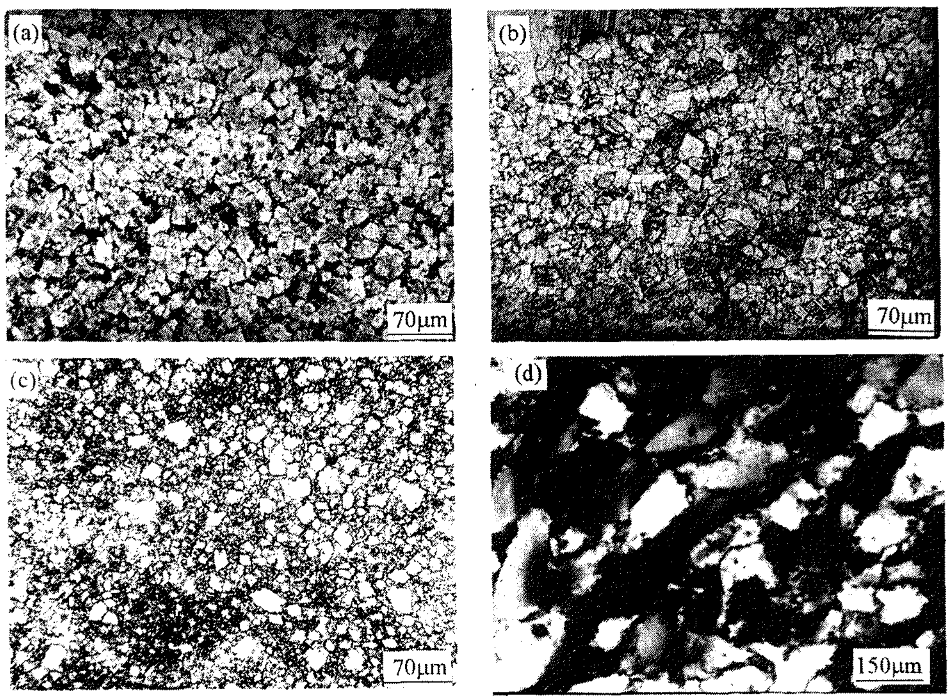

Fig. 1 The microstructures of the aggregates used. (a) Calcitic dolostone; (b) Calcitic dolostone with attacked dolomite; (c) Dolomitic limestone; (d) Metamorphic quartzite

Alkali-silica reactivity was tested with the Chinese autoclave method (CECS 48-93). Table 1 lists the results. The expansions caused by the calcitic dolostone (PCD) and the dolomitic limestone (PDL) are not in excess of the 0.1% limit. Thus, they seem nonreactive with respect to ASR. Some of quartz crystals in sample PCD were finegrained and could react with alkali solutions to form gel (14% of quartz was reacted when powder of PCD was soaked in a large amount of 1 mol/L KOH solution for 60 days). This reactivity may be responsible for the relatively large expansion. The metamorphic quartzite (PMQ) gives rise to a large expansion, thus is reactive.

Table 1 Expansion of micromortar bars for evaluating alkali-silica reactivity

Ratio of	Expansion (%)		
Cement to Aggregate	PCD	PDL	PMQ
10	0.053	0.038	0.097
5	0.091	0.056	0.160
2	0.090	0.038	0.234

The calcitic dolostone and dolomitic limestone were also subjected to rock prism and microconcrete bar tests to determine their alkali-dolomite reactivity. The rock prisms in 8mm × 8mm × 25-32mm were precured in 80℃ water for 2 days. After the prisms were cooled, their original lengths were measured. Then, they were immersed in 1 mol/L KOH solutions at 80℃ for 91 days and at room temperatures for another 570 days. The expansion of the prisms is demonstrated in Fig. 2. The calcitic dolostone (PCD) was very expansive. The dolomitic limestone appeared less expansive and the maximum expansion is 0.119%.

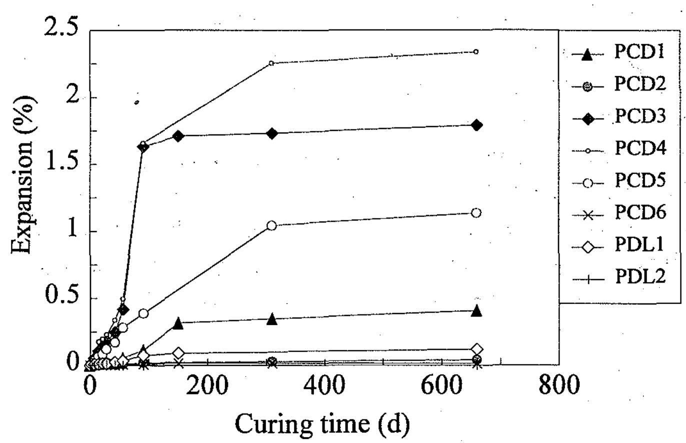

Fig. 2 Expansion of calcitic dolostone (PCD) and dolomitic limestone (PDL) prisms cured in 1 mol/L KOH solutions at 80℃ for first 91 days and at room temperatures for another 570 days

Fig. 3 shows the expansion of microconcrete bars (Tang et al. 1994) caused by the dolomitic limestone (PDL) and carbonate aggregates (PDM) derived from the ties. The alkali content of Portland cement used was boosted from 0.66% to 1.50% Na_2Oequiv. Aggregate was in 5-10mm. Cement/aggregate was 1. The demoulded specimens in 20mm × 20mm × 60mm were cured in 100 ℃ steam for 4 hours and then were autoclaved in 150 ℃ 10% KOH solutions. The expansions of PDL and PDM are

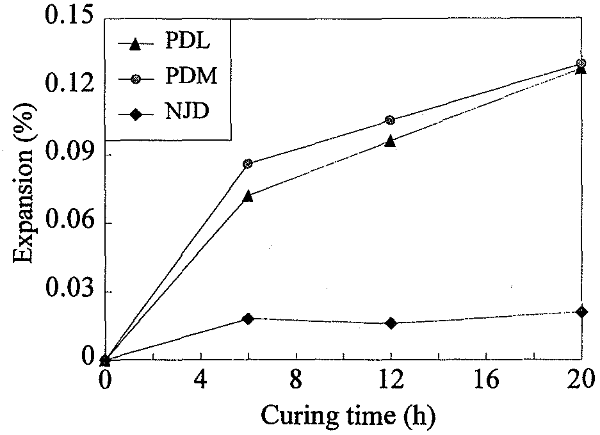

Fig. 3 Expansion of microconcrete bars with dolomitic limestone (PDL), carbonate aggregates (PDM) and nonreactive dolostone (NJD)

significantly larger than that of nonreactive Nanjing dolostone (NJD). Microscopic check reveals that the bars were cracked due to the expanding of the two aggregates. Therefore, the carbonate rocks are recognized as alkali-dolomite reactive.

PETROGRAPHIC EXAMINATION OF THE CRACKED CONCRETE

The 10cm × 10cm × 10cm concrete specimens placed outside the laboratory room of the plant cracked at age of 4-6 years. When cured in a moist container, alkali-silica gel was observed to squeeze out through the cracks. This indicates that the concrete was affected by alkali-silica reaction.

Observation on the polished and thin sections of cracked railway ties reveals that the quartzite has been eroded and cracks mainly originated from the coarse aggregates. Some cracks spread to mortars along the corners or boundaries of quartzite and carbonate rocks. A few of cracks extended from the dolomitic zones of the aggregates to mortars. Others were perpendicular to the boundaries of coarse aggregates. Fig. 4 illustrates the cracks in the concrete ties.

The fine aggregates were almost feldspar and crystalline quartz. A very small amount of particles composed of strained quartz and microcrystalline quartz were incorporated in sands. Some of these particles also cracked the mortars.

Ettringite phase was not observed in cracks, voids and interfaces between aggregates and hardened cement pastes.

DISCUSSION

The alkali content of the concrete ties from cement and water reducing admixture was 6.4 kg/m^3. This value is twice as large as the safe threshold 3.0 kg/m^3 for alkali-silica reaction (Hobbs.1988) and far larger than the safe alkali content for alkali-dolomite reaction(Rogers and Hooton.1992). The railway ties placed out of doors were easy to gain moisture. Thus, the reactive siliceous and dolomitic aggregates may make

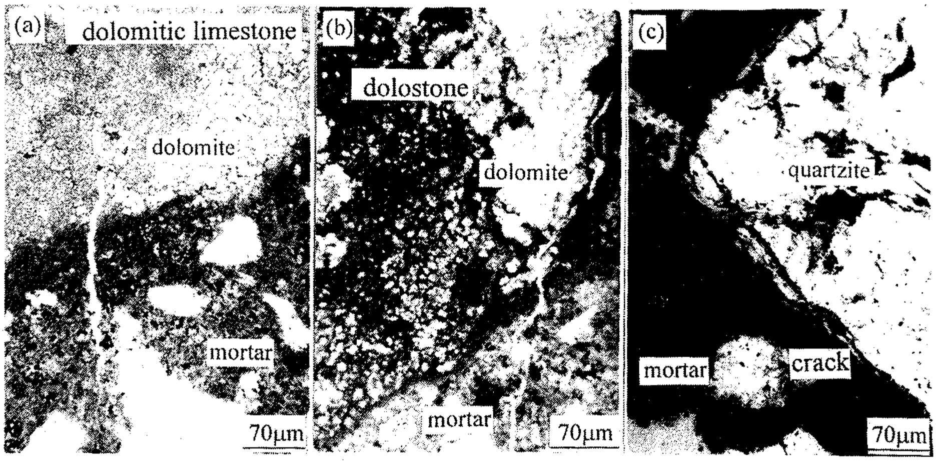

Fig. 4 The cracks in the deteriorated railway ties

the ties to suffer distress by alkali-silica reaction and alkali-dolomite reaction. The ties cracked by alkali-aggregate reactions may be further damaged by the motive load, and by freezing and thawing when laid in Northeast and North China. Eventually, the railway ties may be collapsed, as found in Herongjiang and Shanxi provinces.

The railway ties were precast units and were treated with heat steam during production. It was suggested that these ties might be deteriorated by secondary ettringite formation (Heinz and Ludwig. 1989). The molar ratio of SO_3 to Al_2O_3 in the cement was 0.66-0.69. The ties were almost placed in a climate with less than 95% relative humidity. W/C was 0.30. According to Heinz and Ludwig (1989), the railway ties in question might not be damaged by secondary ettringite. Petrographic examination shows that there was not a large amount of ettringite in the concrete. Therefore, the secondary ettringite formation was not, at least, the main reason of the deterioration. The cracking of concrete specimens suffered no heat treatment further confirms this conclusion.

CONCLUSION

The calcitic dolostone and dolomitic limestone aggregates in the railway ties were potentially alkali-dolomite reactive and the metamorphic quartzite included was alkali-silica reactive. Petrographic examination of the deteriorated concrete revealed the presence of typical features of alkali-dolomite reaction and alkali-silica reaction. It appears that alkali-aggregate reactions are a prerequisite for the deterioration of the concrete.

Acknowledgment

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