DAMAGES IN CONCRETE RAILWAY SLEEPERS IN FINLAND

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Synopsis

Properties of the concrete mix, the production process and the structure of sleepers provided the basis for the examination of damages in railway sleepers. Damaged sleepers have been examined using petrographic, analytical and physical methods.

Deterioration process was found to be caused by initial microcracks in the concrete structure. The cracks were formed during production; primarily caused by intensive heat treatment, which due to thermal movement and stresses produces a strong formation of microfissures and forms unstable chemical compounds in the concrete. Once the pattern of damage was established, the manufacture of concrete sleepers was changed to the extent of abandoning heat treatment. Sleepers manufactured using the new technique have been studied by means of expansion measurement and petrographic examination.

No damages due to the deterioration process were found in five-year-old concrete sleepers produced by the new method so far.

Key words:
Concrete railway sleepers
Deterioration process
Heat treatment

1. INTRODUCTION

Concrete railway sleepers have been used in Finland since 1964. Currently they make up around 15 per cent of the total.

Deteriorated sleepers were first observed in 1974 when 4 % of the concrete sleepers in the railway sections inspected were found to be in need of replacement due to deterioration process.

The need for replacement is estimated to grow annually, i.e. currently some 20,000 sleepers per year. This means that about 25 per cent of all concrete railway sleepers have to be replaced because of deterioration process.

Damages develop progressively in the sleepers. The stages of deterioration have been grouped into four classes with an estimate of the remaining service life of the sleepers.

Stage 1 Class 1. Netlike capillary cracking on the top surfaces of sleepers ends. Estimated remaining service life about 10 years.

Stage 2 Class 2. Longitudinal cracks and minor fractures. Service life about 5 years.

Stage 3 Class 3. More cracks and fractures. Concrete comes off the sleeper. Service life about 1 year.

Stage 4 Class 4. Prestressing bars are visible. Rail fastening has come out or the sleeper is broken. Replacement required immediately.

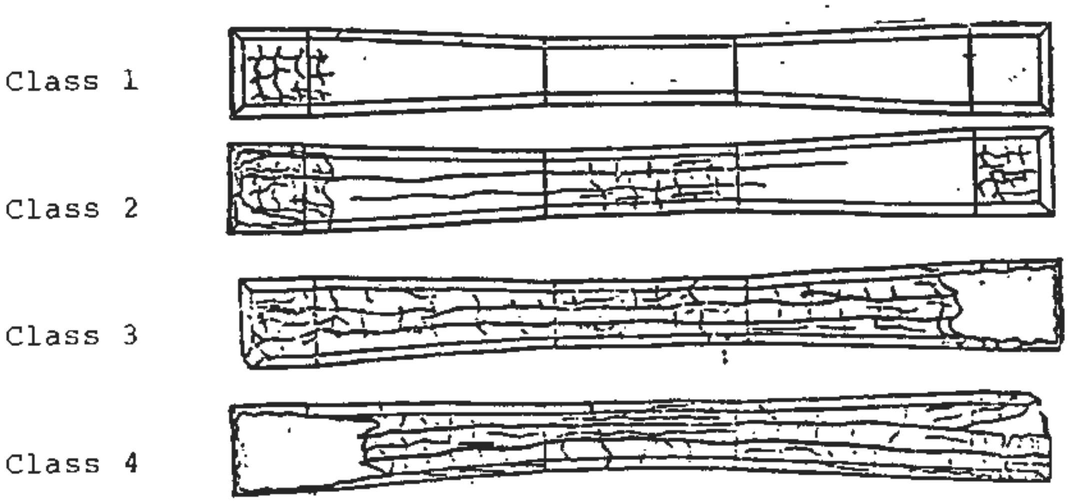

Figure 1. Progressive development of deterioration process

2. MANUFACTURE OF CONCRETE RAILWAY SLEEPERS IN THE 1960s AND 1970s

2.1 Concrete

In the 1960s and 1970s railway sleepers were made using Finnish rapid hardening Portland cement with the following average composition:

Table 1. Analysis of cement used in railway sleepers

CaO	%	62.0
SiO_2	%	21.0
Al_2O_3	%	4.5
Fe_2O_3	%	2.4
MgO	%	3.2
SO_3	%	3.7
Na_2O	%	0.5
K_2O	%	1.0
C_3S	%	49.1
C_2S	%	23.1
C_3A	%	7.8
C_4AF	%	7.3

compressive strength/SFS 3165	
1 d	22
7 d	44
28 d	54

Fineness Blaine m^2/kg 460-480.

The concrete mix used was a compound with a high content of cement and a low water-cement ratio. Table 2 gives the average data of two different years with the respective development of strength.

Table 2. Concrete mix - strength data of two different years

Year		1965	1971
Quantity of cement in kg/m^3		410	384
Max. grain size of aggregate mm		32	32
Water-cement ratio		0.36	0.39
Achieved development of strength MN/m^2:	1 d	56	43
	7 d	-	57
	28 d	72	67

2.2 Heat treatment

Heat treatment was used in the manufacture. Figure 2 gives the thermal profiles measured in the tent during the treatment.

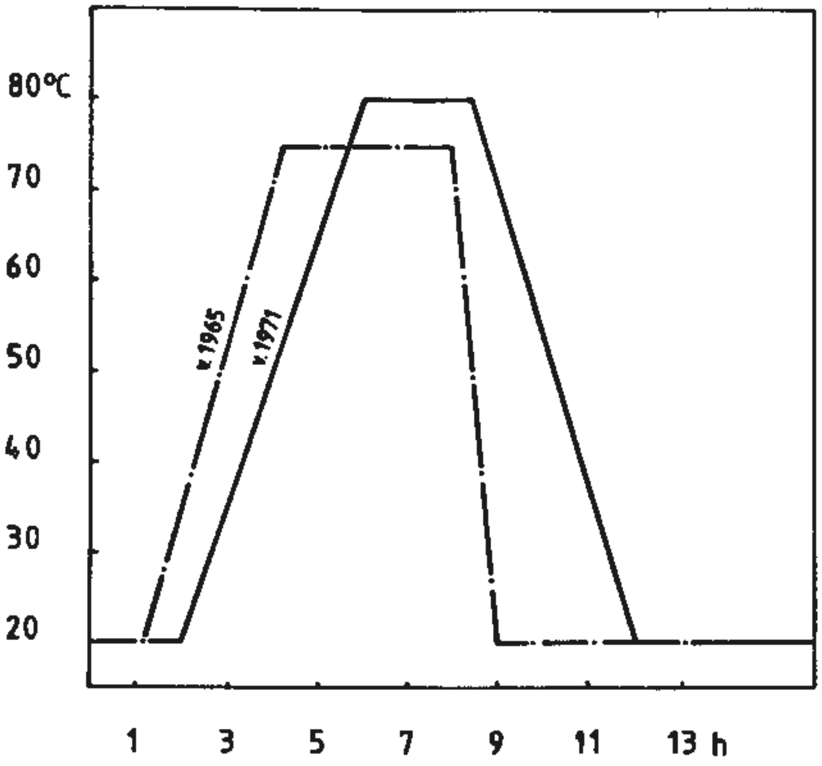

Figure 2. Thermal profiles of sleeper concrete in two different years

Initial storage was from 1 to 2 hours and it took about 3 to 4 hours for the temperature to reach its maximum. The maximum temperature measured in the tent was 75 to 80°C. Maximum temperature remained stable for 2.5 to 4 hours. Therefore it seems probable that the temperature inside the concrete was even higher.

2.3 Sleeper structure

The shape of the sleepers and the fastening of the rails varied to some extent in the 1960s and 1970s, but the basic structure remained unchanged.

Figure 1 shows the structure used in the sleepers. The ends of the sleepers are made somewhat wider than the middle section.

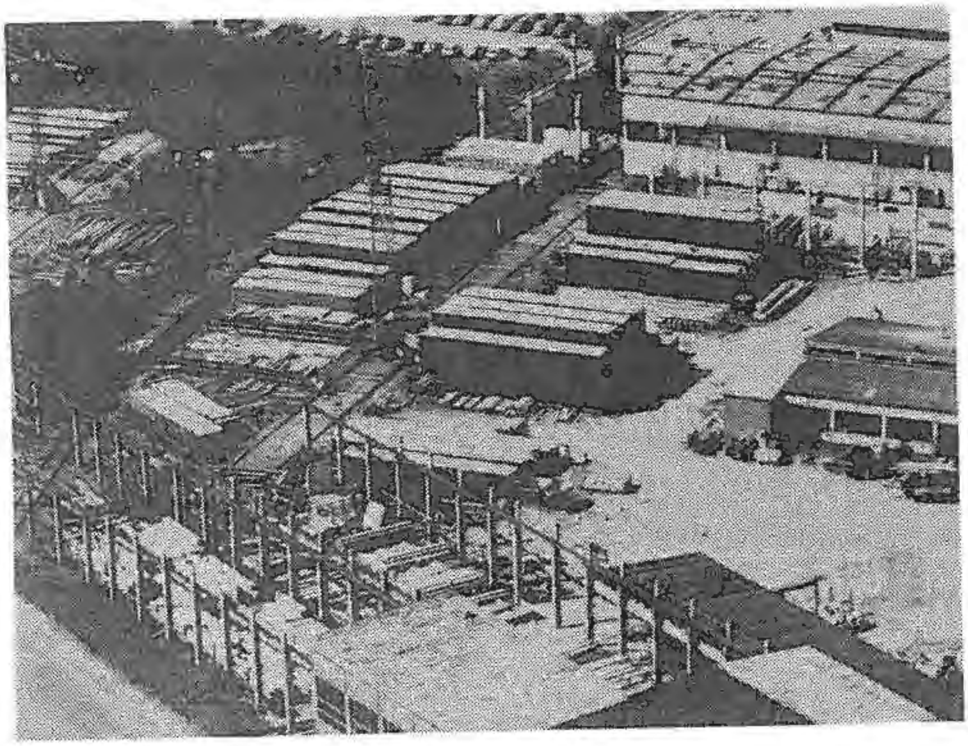

Figure 3. General view of the storage for concrete railway sleepers

3. ANALYSIS OF DAMAGE IN DETERIORATED CONCRETE RAILWAY SLEEPERS

In the period 1981 - 1986 several samples were taken of sleepers manufactured after 1964 currently in use or stored outdoors.

Samples were taken of visibly damaged sleepers and of sleepers appearing to be intact. Both types occurred among those in use and in storage. The number of samples was considerable.

Sampling was done by inspecting the entire sleeper - by sawing off specimens or by using drilled cores. Reference sleepers for comparison had never been installed in the railway.

Samples were subjected to the following examinations:

Testing of strength: Compressive strength
Splitting tensile strength

Petrographic examination: Visual inspection
Polished section
Thin section
SEM-EDAX analyses

X-ray diffraction.

3.1 Results

Testing of compressive strength and splitting strength failed to give a clear picture of the damages. Visibly damaged sleepers still had high strength values.

Table 3. Deteriorated railway sleeper manufactured in 1966

	Inner surface (1)		Under rail (2)		Sleeper end (3)	
Sample	CS	STS	CS	STS	CS	STS
5	81.2	8.8	113.3			6.3
	87.2		99.4			
6		7.4	76.5		85.1	6.1
			100.9		75.1	
X	84.2	8.1	97.6		80.1	6.2
S	4.2	1.0	15.3		7.1	0.1

CS = Compressive strength
STS = Splitting tensile strength
Inner surface = mid-sleeper
X = Mean value
S = Scatter

3.1.1 Petrographic examination

Visual inspection and examination of polished sections:

A macrofissure was frequently found between the joints at the rail fastening of seemingly intact (installed) railway sleepers dating from the 1960s or 1970s. The bottoms of sleepers often also showed ascending macrofissures. Cracks had been caused by the service loads on the railway; reference sleepers were free from such macrocracking.

3.1.2 Analyses of thin section and SEM examinations

The examinations revealed a great number of microfissures in some places. Partial filling up of pores and cracks was observed in all the examined sleepers dating from the 1960s or 1970s. The degree of filling correlates with the number of microfissures; practically all the pores and some of the larger cracks were found to be filled up in the more deteriorated sleepers.

The combination of SEM-EDAX revealed the pores and cracks to be filled up with macrocrystalline ettringites, which was confirmed by X-ray diffraction later on (figure 4). The ettringite had accumulated in the free space; cement gel showed no nucleation centres for formation of fissures.

In the more deteriorated sleepers the bond between large stones and cement gel was found to be poor. The pattern of fissures followed the edges of the stones.

Figure 4. a) Air pores filled with ettringite

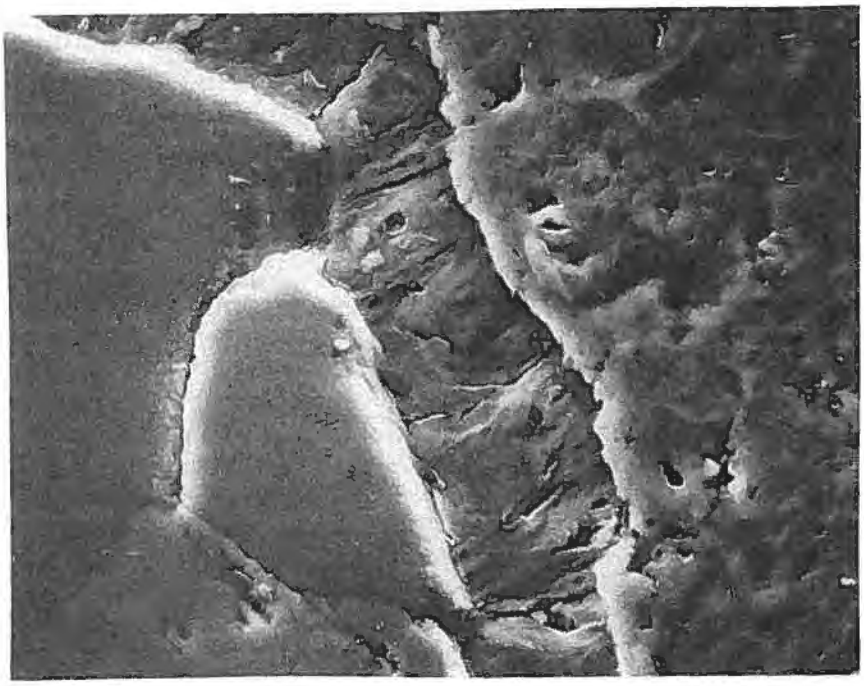

Figure 4. b) Totally filled up crack between stone and cement gel

4. MODEL OF THE DETERIORATION PROCESS IN CONCRETE RAILWAY SLEEPERS

4.1 Studies made in 1970s

To find a solution to the problem, the first studies were made in the mid 1970s with unused concrete sleepers and with sleepers that had been installed in the railway.

The results showed that the main reason for the deterioration problem was poor frost resistance of the concrete. To eliminate the problem, additional air-entraining agent was adopted and the maximum temperature in the tent was brought down from 80°C to 60°C, while the rate of temperature raising remained unchanged (see figure 2).

4.2 Studies made in 1980s

The problem showed signs of further growth in the early 1980s making new studies necessary, especially since it was suspected that there might be more to it than just poor frost resistance.

Based on the investigations made in the 1980s the deterioration process may be assessed as follows:

Short initial storage before the heat treatment and high maximum temperature cause microfissures in concrete. Temperature differences also cause stress-cracking. Damages are often observed in places where the temperature differences have been greatest and the concrete weakest, i.e. between the aggregate and the cement matrix. During the heat treatment the temperature of the concrete has exceeded 70°C, which is revealed by the large amount of recrystallized ettringite. In result of a temperature above 70°C at the initial stage of cement reaction, metastable monosulphate is produced in the concrete and it tends to form ettringite when the temperature drops.

A condition for recrystallization of ettringite is that the concrete contains enough moisture and reactive $CaSO_4$. If the C_3A reactions of the cement are disturbed too soon, or if the $C_3A - SO_3$ ratio is too low, it is possible that non-reacting $CaSO_4$ remains in the concrete leading to recrystallization of ettringite.

Experiments /1/ have shown that with a high $SO_3 - Al_2O_3$ molar ratio of cement larger quantities of crystallizing ettringite are formed in thermally treated specimens than in cements with a low SO_3 / Al_2O_3 ratio.

4.3 Discussion

Microcracks occurring in the concrete during the manufacture of sleepers are the primary cause of their deterioration.

Under the difficult environmental conditions during the service life of the sleepres, i.e. frost, load etc., cracks bring about a relatively rapid deterioration.

The occurrence of microcracks is influenced by the length of the initial storage before the heat treatment, the rate of the temperature raising and the maximum temperature, which all depend on the proportioning of the concrete, the cement grade used in the mix and the production technology.

German studies /2/ of the factors involved in the formation of cracks have arrived at the following limits:
- initial storage 3 hours
- rate of temperature raising 10-15°C/h
- maximum temperature 65-70°C.

The first studies in the 1970s suggested that the deterioration of the concrete in railway sleepers was primarily due to their poor frost resistance. Identical results were received with unused sleepers and with those that had been installed in the railway. This may lead to the conclusion that relatively young heat-treated railway sleepers have microcracks, and they are the reason for the poor frost resistance of the concrete.

Microfissures facilitate moisture movements in the concrete. The unstable compounds produced by the heat treatment react and form ettringite.

From this we may conclude that the problem with Finnish railway sleepers is primarily due to the formation of microcracks in result of the intensive heat treatment, causing the deterioration of railway sleepers, the formation of ettringite, and the occurence and growth of additional cracking.

5. CHANGE IN THE PRODUCTION METHOD DUE TO THE ANALYSIS OF DAMAGE

Based on the examinations, heat treatment and application of additional air-entraining agent were abandoned in the manufacture of railway sleepers in the early 1980s.

At the same time German-made PZ55 cement came into use because of early development of strength required by the production.

Table 4. Analysis of German cement

SiO_2	%	20.8
Al_2O_3	%	5.75
Fe_2O_3	%	1.9
MgO	%	1.0
CaO	%	65.4
SO_3	%	3.6
Na_2O	%	0.3
K_2O	%	0.7
C_3S	%	57.1
C_2S	%	16.5
C_3A	%	11.9
C_4AF	%	5.8

compressive strength/SFS 3165

1 d	31
7 d	56
28 d	67

Fineness Blaine m^2/kg 480-500.

The concrete mix was changed by reducing the grain size of the aggregate from 32 mm to 16 mm and by decreasing on the quantity of cement.

Without heat treatment, the temperatures measured in concrete ranged from 40 to 55°C.

The achieved development of strength in concrete:

1 d	68 MN/m^2
7 d	75 "
28 d	85 "

7. 5-YEAR FOLLOW-UP OF CONCRETE SLEEPERS MANUFACTURED USING THE NEW TECHNIQUE

7.1 Test procedure

Test sleepers were produced in 1982 without heat treatment using Finnish-made rapid hardening Portland cement and German-made PZ55. Besides comparison of the different cement grades, the examination also included the maximum grain size of the aggregate. Two maximum grain sizes, 16 mm and 32 mm, were used in the tests. Some of the sleepers were installed in the railway and others were stored outdoors next to the railway. Deformation was measured over the period of five years and in the winter of 86/87 samples were drilled off the sleepers for petrographic examination.

7.2 Results

Measurements showed no expansion at the time of the investigation. Follow-up continues. In the petrographic examination the reference sleepers, made of Finnish and German cements and placed next to the railway, were intact. Very few cracks were observed. (All) the sleepers installed in the railway showed some microcracking, a sign of the load the sleepers are subjected to in the railway. Recrystallization was not observed in the specimens. Reduction of the maximum grain size appears to affect the number of cracks. With a maximum grain size of 32 mm every sleeper used in the railway showed a macrocrack. With 16 mm no macrocracking occurred.

7. CONCLUSION

The manufacture of railway sleepers was changed on the basis of the extensive studies, which showed high temperature and inadequate initial storage to be the causes of deterioration years later. The entire manufacturing technique and the structure of the sleepers were also investigated very carefully. Based on these studies, the sleepers were made bigger in the winter of 86/87 and the acceptance criteria for concrete were made stricter. Sleepers made of concrete are in fact among the most closely/strictly controlled concrete structures in Finland.

Literature reference:

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