

# The prognosis of durability of concrete pavements made of the recycled aggregates from 80-year-old road concrete

J. Jasiczak & M. Kucz

*Poznan University of Technology, Department Of Civil Engineering, Poznań, Poland*

**ABSTRACT:** In the years between 1933 and 1937 at the western Polish border two sections of highways were made of cement concrete. The first was Breslau - Liegnitz (12 December 1933-27 September 1936), the second one – Bunzlau – Sagan (21 March 1934 – 27 November 1937) [Web1, Web2]. In 1995, the concrete surfaces were used to upgrade a 7-km into stretch Golnice – Krzyżowa and a dual carriageway was built from the concrete surface (the former A12). The authors of the paper were involved in the processing of the concrete debris and assessed the quality of the recycled concrete. The demolition of the cement concrete surfaces took place from 1995 to 1997, the cement debris was used to construct the lower layers of the present A18 motorway. It is a well-known fact that recycled concrete is produced similarly to traditional concrete. Implementation of the recycling techniques in the construction of the motorway has been analyzed to give a clear picture of the issue. Old concrete panels with resistance of approximately 80MPa were used in the recycling process. After breaking them into pieces, the panels were crushed to separate fractions, which was further used to form two kind of pavements: concrete lower layer – recycled concrete aggregate from the fraction 2/8, 8/16 and 16/32 and sand (original) 0/2 mm, upper layer all-in aggregate (original) of fraction 0/16. In 2012, the samples taken from the 80-year-old concrete and more than 15-year-old recycled concrete, both stored in PUT laboratory, were re-examined. The physical and mechanical characteristic of the two concrete groups were specified. The textures were assessed by means of scanning electron microscopy.

**KEY WORDS:** Recycled concrete, durability of concrete, SEM analysis.

## 1 INTRODUCTION

Many older and newer communication routes are planned to be built (or renovated) in the nearest future. Such harshness of a road development program will cause a rise in demand for building materials, mainly for binder and all-in aggregate. It is suspected that if such expansion and exploitation of all-in aggregates can take place, the processes can influence the ground water proportion of mining areas. If the above is taken into account, recycling seems to be a good solution [Hansen1992, Hansen 1983, Jasiczak 1997, Proceedings 1994, Prezzi 2011]. Recycling concrete is a relatively simple process. It involves breaking, removing, and crushing existing concrete into a material with a specified size and quality. The crushing characteristics of hardened concrete are similar to those of natural rock and are not significantly affected by the grade or quality of the original concrete. Recycled concrete aggregates produced from all but the poorest quality original concrete can be expected to pass the same tests required from conventional aggregates.

## 2 THE RESEARCH

### 2.1. Materials

The recycled aggregate were produced from crushing concrete from the old A18 road in Poland. The sieve analysis results for recycled aggregates are shown in the diagram below (Figure 1 and Figure 2). The recycled aggregate was produced by crushing 100m<sup>3</sup> of about one year, free of contaminants concrete, crusher jaws 20mm spacing in the closed position. The repentant product detained for 25 mm BS sieve was crushed with 13mm spacing jaws in order to obtain additional fines concrete. Then the crushed and sieved products were combined to obtain the quality of the components similar to granite sand and coarse aggregate. Based on the analysis of grading curves (Figure 1), it was found that the fine aggregate decidedly different requirements of code. For this reason, research recommending the use of fine aggregate recycling was limited.

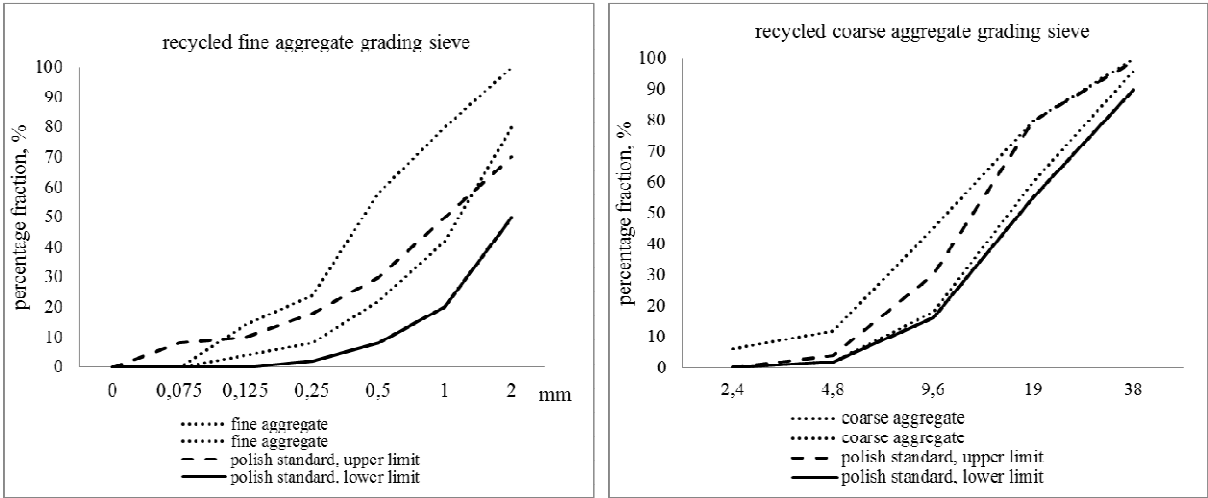


Figure 1: Recycled fine aggregate grading sieve.

Figure 2: Recycled coarse aggregate grading sieve.

To evaluate the properties of concrete made with various recycled aggregate compositions, three series of tests with different types of aggregate and w/c ratio were undertaken. These series were named GS, RS and RR, respectively. Coarse and fine aggregate in Series I and II were successively natural and recycled ingredients. The water-cement ratio (the weight) ranged between 0.30 and 0.70. In series III, all three had the same mix water-cement ratio of at 0.57. This allowed the authors to investigate the effect of using the recycled aggregates on the properties of medium strength concrete, both in fresh and hardened state. In the three mixtures different combinations of coarse and fine aggregates were used and dried in the air. Before mixing the specified moisture content and weight of added water was adjusted to saturate the surface intended for dry conditions. The content of cement, aggregates and water in three mixtures and the details of concrete mixes are presented in table below (Table 1).

Table 1: Components of concrete mixes and w/c ratio.

Series	Type of mix	Cement (kg/m <sup>3</sup> )	Aggregate (kg/m <sup>3</sup> )	Water (kg/m <sup>3</sup> )	w/c ratio
		379	2004	114	0,3
		365	1932	146	0,4

I	GS	352	1864	176	0,5
		340	1800	204	0,6
		329	1740	231	0,7
II	RR	379	1840	114	0,3
		365	1772	146	0,4
		354	1710	176	0,5
		340	1652	204	0,6
		329	1598	231	0,7
III	GS	344	1818	196	0,57
	RS	334	1692	190	
	RR	244	1668	196	
GS – crushed gravel and natural sand, RS – coarse recycled aggregate and natural sand, RR – fine and coarse recycled aggregate					

Half of the samples tended series III (dried) laboratory air at an average temperature of  $30\pm 2^{\circ}\text{C}$  and a relative humidity of  $80\pm 10\%$ . For mature concrete samples different tests were carried out, which specified compressive strength of 100 mm cubes on the 3rd, 7th, 28th and 90th day. For each composition, 10cm cubic specimens were prepared for different tests, to specify compressive strength. The basic property test results are summarized in the table below (Table 2). All tests were performed on the basis of Polish Standards [PN-EN 933-1:2012, PN-EN 206-1:2003, PN-88/ B06250]. A minimum of six samples were tested in every series of research.

Table 2: Test results for three type of concrete mix.

Mixture	GS		RS		RR	
Testing age	Type of curing					
	water	air	water	air	water	air
Compression strength [MPa]						
28	33,8	29,9	29,4	22,7	28,0	21,7
Tension strength [MPa]						
28	2,41	1,86	2,13	1,70	1,93	1,51
Flexural strength [MPa]						
28	4.88	3,84	4,39	3,80	4,15	2,87
Static module [ $\text{kN/mm}^2$ ]						
7	26,1	22,2	20,9	18,7	19,7	14,2
28	29,0	24,3	24,7	19,1	21,5	15,3
90	29,1	25,0	25,2	20,4	22,3	16,1
Shrinkage ( $\cdot 10^{-6}$ ) [mm/m]						
7	43	75	76	90	96	117
28	95	152	194	208	261	246
90	204	223	325	333	430	406

The results for three different mixtures lead to a conclusion that concrete curing in water gives worse parameters than that curing in the air. As expected, the concrete with fine and coarse recycled aggregate has worse parameters than the other two types.

## 2.2. Production of a new concrete pavement

The production of recycled concrete is similar to production of traditional concrete. The authors of the paper analysed the recycling techniques used to construct the motorway to picture the issue more precisely. Old concrete panels (of resistance of about 80MPa) were processed. Firstly, they were broken into pieces, then transported to a storage place. Later, they were crushed and sifted to separated fractions, to be eventually used to form two kinds of concrete pavements. In this case two kinds of pavement concrete were used:

- concrete of lower layer – recycled concrete aggregate – from the fraction 2/8, 8/16 and 16/32mm and all-in rinsed sand – 0/2mm ( GS mix, Table 1 and 2),
- concrete of upper layer – all-in aggregate of fraction 0/16mm.

Samples taken from the old and new concrete panels are shown in Figures 3 and 4.



Figure 3: Cross section of old concrete motorway



Figure 4: Cross section of the new motorway with recycled concrete aggregate

The compressive strength was chosen as the base for the results analysis. It was examined 7 and 28 days after the concrete was prepared. To verify the results of the test the experiment was carried out twice: first time in a field conditions, second – in the laboratory, (Table 3).

Table 3: Comparing test results for recycled concrete.

Realization	Compressive strength [MPa]	
	HEILIT+WOERNER building site	PUT Poznan laboratory
Road A18		
$f_{c7}$	35	38
$f_{c28}$	45	46
Road A18	Flexural strength [MPa]	
$f_{28}$	4,88	4,95

The value of compression strength is satisfactory and this kind of concrete is suitable to use as pavement, because German requirements are 40MPa for I-IV class roads and 30MPa for V-VI [ZTV Beton - StB 93, HOELIT+WOERNER 1996].

### 3 THE DURABILITY OF CONCRETE PAVEMENTS MADE OF THE RECYCLED AGGREGATES

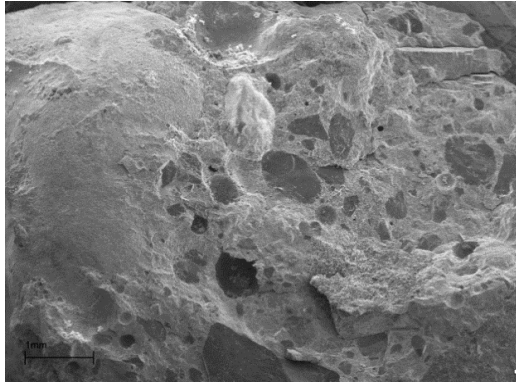
The concrete samples taken in 1997 from the old road and new concrete for A18 pavement were cured in the air for 15 years (outdoor storage), as described in articles [Washa 1975, Washa 1989]. During this time the influence of changing weather conditions on the concrete samples was tested. Physical and mechanical properties of concrete are compared in Table 4.

Table 4: Comparisons concrete parameters samples after outdoor storage during 15 years.

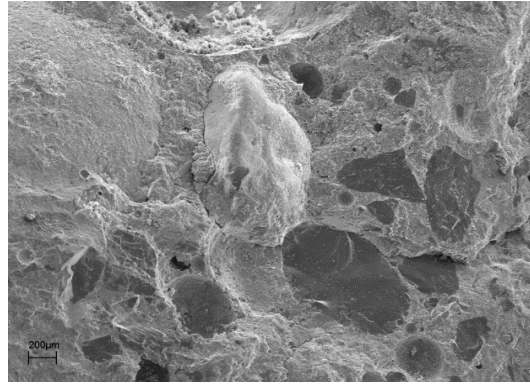
Parameters	80-years-old first concrete	15-years-old new concrete made with the crushed 80-years concrete
Density, kg/dm <sup>3</sup>	2,78	2,39
Compressive strength in 1997 year, MPa	80,0	46,0
Compressive strength in 2012 year, MPa	74,3	60,6

The results showed that the density of the 80-year-old concrete is 14% higher than that of 15-year-old recycled concrete. As for the strength of concrete, during 15 years of storage (storage outdoor) it decreased by 7,1% for the original concrete while it increased by 31,7% for the recycled one. The difference in the original and the recycled concrete results is certainly due to the type of cement, which in the case of old-type concrete was analysed in [Jackson 1958] and the present day concrete in, for example, [Neville 1996]. The declining results of old concrete, which is the starting material for recycled aggregates are interesting and require extensive commentary, especially since the results cited in papers [Washa 1989, Jackson 1958] also noted decreases in the strength of over 50-year-old concrete. These publications point out that for concrete stored outdoor there may be a 6,1% ([Washa 1975] concrete from 1923, w/c = 0,51) or only 3% ([Washa 1989], concrete from 1937, w/c=0,49) decrease in the strength of the material. Unfortunately, the source (these publications) do not explain the drops in strength of decades old concrete.

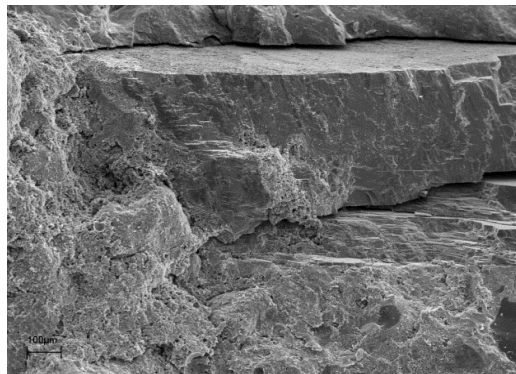
For this reason SEM photomicrographs were done using scanning electron microscope type Evo40 (Carl Zeiss) with an accelerating voltage of electron beam adjusted to 17 keV. The zooming scale was appropriately 1mm, 100µm, 10µm to provide both a general picture and a tenfold or even a hundredfold magnification of selected details. Photomicrographs made for original 80 years old concrete and 15 years old recycled aggregate concrete are presented in Figure 5 (six pictures) and Figure 6 (four pictures). The images indicate that the concretes vary considerably. Photos 5.1 and 5.2 show a very compact structure of 80-year-old concrete, which is in accordance with the laboratory test results showing its high density and its initial strength. Fine aggregate is very well embedded in a matrix of cement, aggregate is locally cracked (damaged) (basalt) zone pin (5.3). CSH phase is very well developed in (5.4). The Portlandite crystals have cracked surfaces. Moreover, their edges are visibly spalling (exfoliation) (5.5 and 5.6). The damages in the weakest phase on the Portlandite Ca(OH) cement store may signal the onset of cement deterioration and decline in its strength.



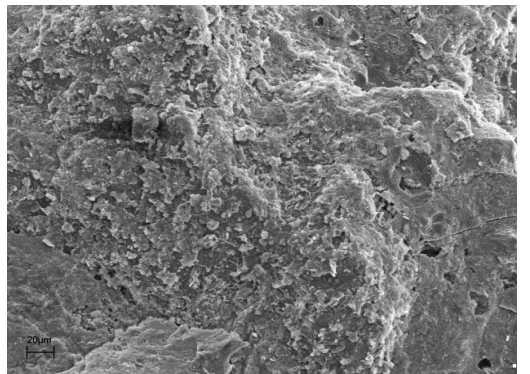
1. Cement mortar.



2. ITZ between cement paste and aggregate.



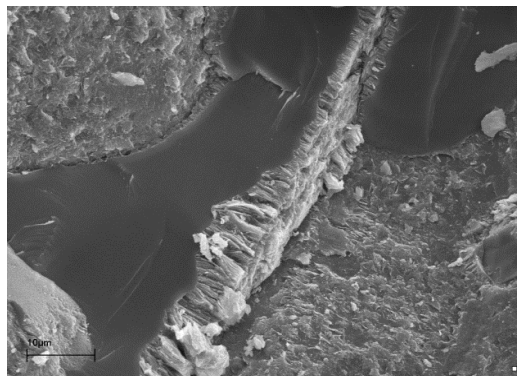
3. ITZ between cement paste and aggregate.



4. CSH phase.



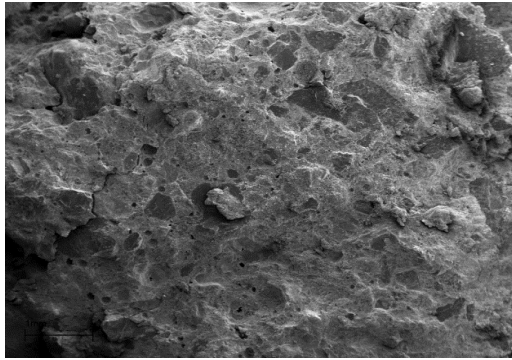
5. Spalling of Portlandite.



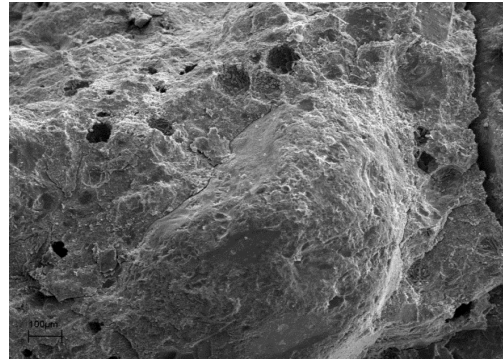
6. Spalling of Portlandite (another place).

Figure 5: SEM analysis concrete samples taken from the 80-year-old concrete (Symbols: ITZ – interfacial transition zone, CSH – hydrated calcium silicates).

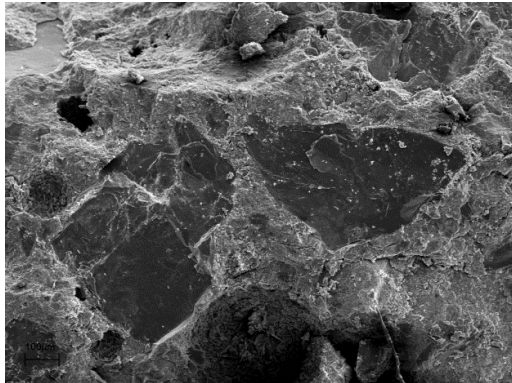
The images of the 15-year-old concrete are different from those presented above. The porosity is apparently higher (6.1., also due to higher air content). There are also visible caverns (6.2., cavities) resulting from ash and cinder reaction (slag). The significant increase in the strength of concrete after 15 years of maturation is a result of the presence of those additives. Further, the Portlandites are well formed, the edges lack spalling. There is no prognosis for the 80-year-old concrete durability. (Weather durability for the 80-year-old concrete remains unknown.)



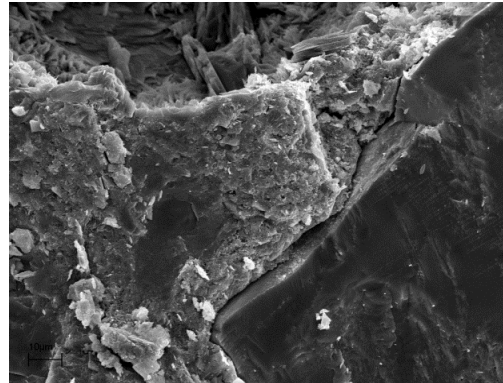
1. Cement mortar.



2. ITZ between cement paste and aggregate.



3. CSH phase and Portlandite.



4. Lack of Portlandite Spalling .

Figure 6: SEM analysis concrete samples taken from 15-years-old concrete with recycling aggregate

#### 4 THE CONCLUSIONS

The focus of the paper was to analyse the usefulness of the concrete waste as a source of aggregate. Nowadays the construction industry should comply with the next century requirements. Building materials should be resistant to time and the influence of environment pollution. Apart from technical, there are also economic aspects of this issue. The following conclusions can be drawn from the research on the aggregates and the features and recycled concrete:

- Recycled aggregate generally has lower density and higher absorbency in comparison with all-in aggregate. In the analysed case the input concrete showed very high strength, which resulted in the excellent quality of recycled coarse aggregate (Figure 3 and Figure 4).
- Use of crushed waste concrete as a source of fine aggregate can influence negatively forming concrete mix. It is advised to use sand fraction 0/2mm when amount of 20-30% complete content of sand in the concrete mix.
- Value of compressive strength and bending while stretching for concrete produced from recycled concrete are satisfactory and do not differ in resistance compared to traditional concrete.

As for the conclusions from this 2012 publication:

- The compressive strength of 80-year-old original concrete pavement decreased from 80MPa to 74,3MPa (7,1% loss of strength), comparing tendencies after 25-50 years exploitation outdoor storage concrete samples are described by the authors of paper [Washa 1989, Jackson 1958].

- The compressive strength of 15-year-old recycled concrete increased from 46MPa to 60,6MPa (31,7% increase in strength). The increase in strength of concrete in the first 25 years was confirmed in the cited publications. Later on, a decline is observed, however, it largely depends on the environmental conditions.
- It is difficult to determine clearly whether the process of deterioration of the 80-year-old concrete in the last 15 years will result in a decrease in the price of recycled concrete. It will depend on the amount of the original cement mortar (partly with crushed basalt), the tightness and properties of the very cement, additional debris (a new fine aggregate), minerals and chemical additives and on the traffic load.
- 80-year-old cement matrix is more compressed (packed, concentrated) (density 2,78 kg/m<sup>3</sup>) than 15-year-old recycled concrete (density 2,39 kg/m<sup>3</sup>); which will have an influence on the durability of the recycled concrete pavements (more than 30 years, but 80 years?).
- SEM analysis has shown, that after long term road exploitation deterioration of concrete quality is observed. Both destruction process as well as cement stone generally and cement phases – portlandite spalling processes, CSH and other can be noticed. Scanning microscopic and EDS methods may help explain the durability problems in the near future.

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