# SCALING RESISTANCE AND RESISTIVITY OF CONCRETES CONTAINING FLUIDIZED BED COMBUSTION FLY ASH

Daria Jóźwiak-Niedźwiedzka

**Abstract**
The subject of the investigations was damage of the concrete due to cycles of freezing and thawing in the presence of the NaCl solution. The air-entrained concretes were tested with 15% and 30% cement replacement by fluidized bed combustion fly ash.
The scaling resistance of concrete was determined according to the CEN/TS 12390-9:2007, slab method. Also the concrete resistivity development was measured and recorded.
The microstructure of concretes was analyzed on the polished sections and the measurement of air voids sizes and their distribution using digital image analysis was carried on according to EN 480-11:2000.
Obtained results showed a significant influence of partial cement replacement by fly ash from Circulating Fluidized Bed Combustion boilers on the scaling resistance of concrete. It has been found that this kind of addition reduced considerably the scaling resistance and increased the concrete resistivity.

**Keywords:** fly ash from Circulating Fluidized Bed Combustion boilers (CFBC), scaling resistance, resistivity, porosity, microstructure of air-voids

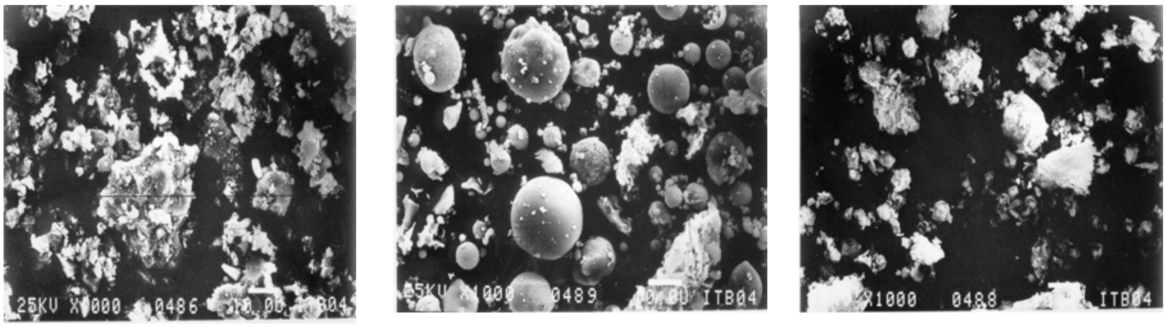
## 1 Introduction

In addition to the corrosion of reinforcement, scaling of concrete surface exposed to salt-frost attack is the most serious and frequent damage of concrete structures. Concrete structures exposed to saline sea water or deicing salts on roads and pavements during winter are examples where a salt-frost resistant concrete is required in order to prevent damage, [1].

Scaling was for the first time recognized as a serious problem in the 1920s [2], however the mechanism of salt scaling is still explored, [3-6]. The principal observations are as follows, [4]:

i. The damage is worst when water contains a moderate amount of solute, approximately 3%NaCl.
ii. The damage consists of small flakes of material removed from the surface.
iii. No scaling occurs without free liquid on the surface of concrete, i.e. saturated surface-dry samples do not scale.
iv. Entrained air reduced damage.

If a concrete structure with low salt-frost resistance is exposed to an aggressive environment, its surface may be severely damaged. In addition to aesthetic degradation, damage can result in loss of strength and can open the way for other damage mechanisms, possibly leading to necessity of high repair or replacement costs. From the other hand, except the concrete durability ensurance, the cost reduction is connected with the utilization of the thermal-electric power stations by-products i.e. fly ash (FA). Also ecological and economical reasons initiated a change in the development of different types of cement and different types of additions. It is due to the quick increase of the number of power plants using so-called “clean” combustion technology. This technology based on combustion of coal in presence of ground limestone as sulfur oxide sorbent is commonly developing around the world. Due to the limestone in combustion process and low temperature of combustion (about $850^0$C) fly ash differs distinctly in its physical, chemical and mineralogical properties from ash commonly used as a mineral additives in concrete industry, [7]. As it is shown in the Fig. 1. fly ash from CFBC – further called fluidized fly ash – differs also from conventional fly ash and Portland cement as to the size and shape of the grains.



Portland cement CEM I | Conventional FA | Fluidized FA

Figure 1: The fly ashes grains and cement grains in SEM observations, magnification 1000x, [7]

The fluidized fly ash is relatively a new by-product and its influence on the concrete durability is not well known. However, certain preliminary test where fluidized FA was used both as concrete additive and component of Portland cement revealed very good properties of this material, [7].
In the paper the influence of fly ashes from CFBC on the salt-frost resistance of concrete was analyzed. Two kinds of fluidized FA coming from fluid bed combustion in two power plants in Poland have been studied. The effect of cement replacement by fluidized FA on compressive and tensile strength, air-void microstructure, resistivity and scaling resistance of concrete was investigated.

## 2 Laboratory tests

### 2.1 Materials and mixture proportions

The aim of investigations was to compare the scaling resistance of air-entrained concrete made with fluidized fly ash and without this addition. The concrete resistivity was also monitored during 180 days, in order to obtained additional information about the connectivity of the pore system in the concrete surface layer. Five series of concrete specimens were made in the laboratory conditions.
Ordinary Portland cement CEM I 32.5 R from Małogoszcz cement plant was used. Gravel from “Nivka” deposit, fractions 2-8 mm and 8-16 mm, and sand fraction 0-2 mm, was used. Concrete mixes were designed with constant water to binder ratio *w/b* = 0.45. To keep the

relatively constant slump and a porosity of fresh mix around 5% - 6%, different amounts of superplasticiser were applied. A plasticiser, a superplasticiser and air-entrainer were used correspondingly in amount of 0.9%, 0.65% – 1.25% and 0.1% of the mass of binder (cement and fluidized fly ash) to achieve approximate workability and porosity of the fresh mix. The ordinary concrete without any additive was made and the concretes with 15% and 30% cement replacement by fluidized fly ash. Fluidized fly ash from hard coal combustion in the thermal-electric power station "Katowice" (C15K and C30K) and brown coal from power plant "Turów" (C15T and C30T) were used. The mixture proportions of concretes are shown in Table 1.
All the concrete specimens were made in the Institute of Building Materials and Structures, the Faculty of Civil Engineering, Cracow University of Technology, under supervision of Professor Jacek Śliwiński. The fresh mix properties and the mechanical properties of concretes were also determined.

Table 1. The mix proportions, kg/m$^3$

| Series / Composition | C0 | C15K | C30K | C15T | C30T |
|---|---|---|---|---|---|
| Cement CEM I 32.5R | 380 | 323 | 266 | 323 | 266 |
| Fluidized fly ash Katowice (K) | - | 57 | 114 | - | - |
| Fluidized fly ash Turów (T) | - | - | - | 57 | 114 |
| Water | 171 | 171 | 171 | 171 | 171 |
| Sand 0-2 mm | 583 | 580 | 577 | 579 | 576 |
| Gravel 2-8 mm | 692 | 689 | 685 | 688 | 684 |
| Gravel 8-16 mm | 547 | 544 | 541 | 543 | 540 |
| Plasticizer | 3.4 | 3.4 | 3.4 | 3.4 | 3.4 |
| Superplasticizer | 2.7 | 2.5 | 3.4 | 3.8 | 4.8 |
| Air-entraining admixture | 0.4 | 0.6 | 0.6 | 0.6 | 0.6 |

The specimens were cast in cubical moulds 150x150x150 mm. Fresh mixes were consolidated by vibration. After 48 hours the specimens were demoulded and cured in high humidity conditions RH > 90% at the temperature 18-20 $^0$C until the age of 28, 90 and 180 days.

## 2.2 Testing procedures

The following tests were performed on the fresh mix:

- Consistency by slump method EN 12350-2:2001 Testing fresh concrete – Part 2: Slump test,
- Consistency by flow table method EN 12350-5:2001 Testing fresh concrete – Part 5: Flow table test,
- Porosity EN 12350-7:2001 Testing fresh concrete – Part 7: Air content – Pressure methods,
- Density EN 12350-6:2001 Testing fresh concrete – Part 6: Density.

and on concrete specimens:

- Compressive strength EN 12390-3:2002 Testing hardened concrete – Part 3: Compressive strength of test specimens,
- Tensile strength EN 12390-6:2002 Testing hardened concrete – Part 6: Tensile splitting strength of test specimens,

– The microstructure of air-voids (total air content $A$, spacing factor $\bar{L}$, specific surface $\alpha$ and micropores below 300 µm - $A_{300}$) - EN 480-11 Admixtures for concrete, mortar and grout - Test methods - Part 11: Determination of air void characteristics in hardened concrete,
– Scaling resistance according to CEN/TS 12390-9:2007 Testing hardened concrete – Part 9: Freeze-thaw resistance – Scaling,
– Resistivity using Wenner method.

Air-content $A$, specific surface $\alpha$, spacing factor $\bar{L}$ and $A_{300}$ - content of micropores below 0.3 mm in the hardened concrete specimens were measured with EN 480-11 method on plane sections (computer program Image Pro Plus) after 28 days.

Salt scaling tests were performed according to CEN/TS 12390-9:2007. Freeze/thaw exposure was carried on one-dimensionally on the upper horizontal surface of the specimens – cutting surface, while the remaining surfaces were isolated against humidity and heat transfer. After 28 days of curing the top exposed surface was covered with 3% saline solution. Then the cooling and thawing cycles, each of 24 hours, were applied. The scaled material was collected and weighed after given numbers of freeze/thaw cycles, and the results expressed as mass per unit area have been recorded. The test of the specimens according to the Standard ended after 56 cycles.

The Wenner method involves placing 4 probes in the concrete surface at equal spacing. The probes are connected to the concrete resistance test set. The test set allows to pass a known amount of current through the outer two probes and measures the voltage drop between the inner two probes. On the basis of the ohms law the output is the resistivity value.

## 3. Test results and discussion

The data on the workability, density and porosity are given in Table 2. Table 3 shows the characteristic of the microstructure of air-voids.

Table 2. The properties of fresh concrete

| Properties / Series | Consistency | | Porosity [%] | Density [kg/dm$^3$] |
|---|---|---|---|---|
| | Slump [mm] | Flow [mm] | | |
| C0 | 115 | 390x375 | 6.2 | 2.24 |
| C15K | 95 | 380x380 | 6.8 | 2.21 |
| C30K | 120 | 390x400 | 5.8 | 2.23 |
| C15T | 135 | 400x405 | 6.6 | 2.22 |
| C30T | 115 | 395x405 | 6.2 | 2.23 |

The addition of fluidized FA did not reduce the workability. More the fly ash addition was used, more the admixture dosage was applied in order to keep good and similar workability. The porosity of fresh mix was maintained at the level 6%.

The effect of fluidized fly ashes on compressive and tensile strength after 28, 90 and 180 days was determined. The compressive and tensile strength of concretes performed as 15% and 30% replacement of cement was approximately on the same level. Only concrete C30K has shown higher strength than concrete C0 without any addition. The value of tensile strength amounts to 7%-8% of the compressive strength.

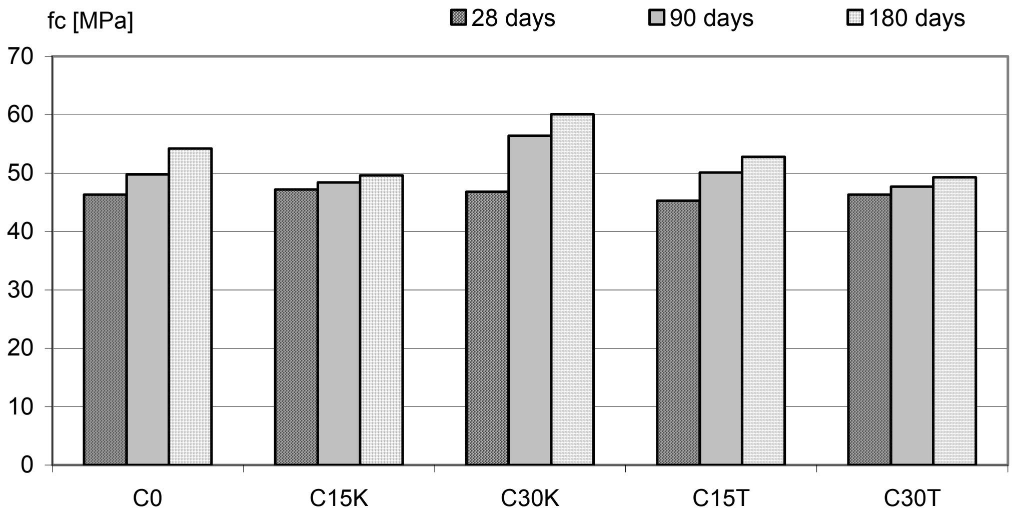



Figure 2: The compressive strength tested after 28, 90 and 180 days

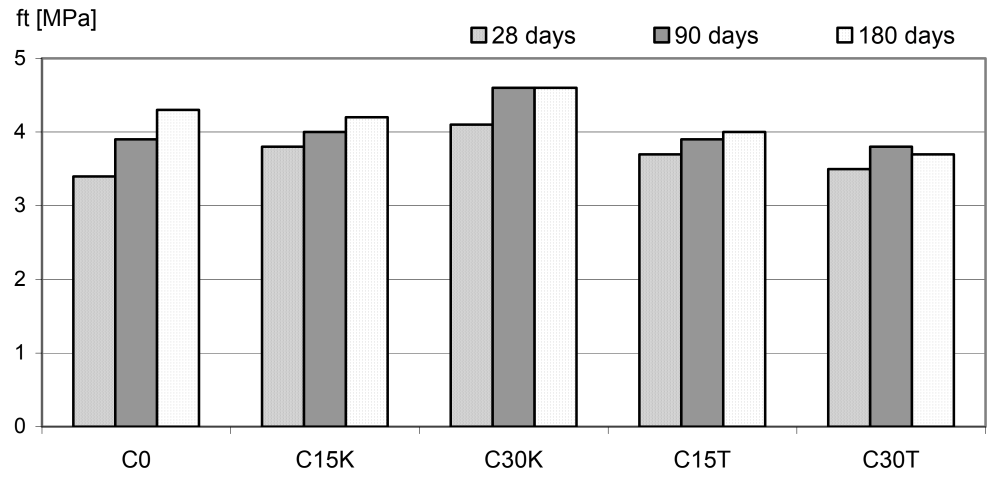



Figure 3: The tensile strength tested after 28, 90 and 180 days

The values of air content $A$, and consequently that of specific surface $\alpha$, spacing factor $\overline{L}$ and content of micropores $A_{300}$ showed very large dispersion. In the first place the values of porosity measured in the fresh mix varied from the values of air-content measured on concrete plane section. The total air-content of concretes varied from 4.59 to 5.13%. However, concrete without fluidized fly ash addition has not showed smaller porosity than other concretes. The best air-void microstructure with respect to freezing and thawing resistance was observed in the concrete with 30% replacement with fluidized fly ash from "Katowice" – C30K.

Table 3. The  microstructure of air-voids

| Series | Air content $A$ [%] | Spacing factor $\bar{L}$ [mm] | Specific surface $\alpha$ [$mm^{-1}$] | Micropores below 300 μm $A_{300}$ [mm] |
|---|---|---|---|---|
| C0 | 4.59 | 0.317 | 14.37 | 0.71 |
| C15K | 4.61 | 0.259 | 17.52 | 1.04 |
| C30K | 4.68 | 0.297 | 15.86 | 0.95 |
| C15T | 4.45 | 0.310 | 19.74 | 0.92 |
| C30T | 5.13 | 0.199 | 20.51 | 1.72 |

Figure 4 presents the resistivity of air-entrained concretes vs time. The influence of freezing and thawing cycles in contact with 3% sodium chloride solution on resistance of concretes with different amount and type of fluidized fly ash is shown in Fig. 5.
The value of resistivity has showed that the cement replacement by fluidized fly ash, both 15% and 30%, sealed the concrete structure. The highest resistivity values were obtained for concrete with 30% fluidized fly ashes. After 120 days the increase rate became smaller. The resistivity of concretes with 30% replacement was four times higher than of concrete without this addition.

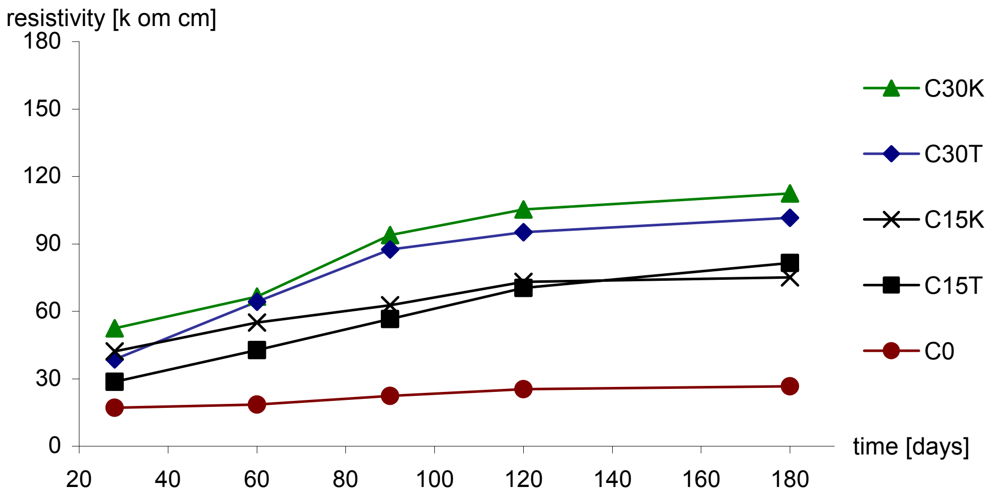



Figure 4: The resistivity of tested concretes vs. time

Fig. 5 shows that the specimens C30K and C30T failed the scaling test, each point of the diagrams represents mean value from four specimens. As it was expected, the positive results were achieved for air-entrained concrete without any addition – C0. The concretes made with 15% of both kinds of fluidized fly ash showed similar results after 56 cycles of cyclic freezing and thawing, about 0,6 $kg/m^2$.

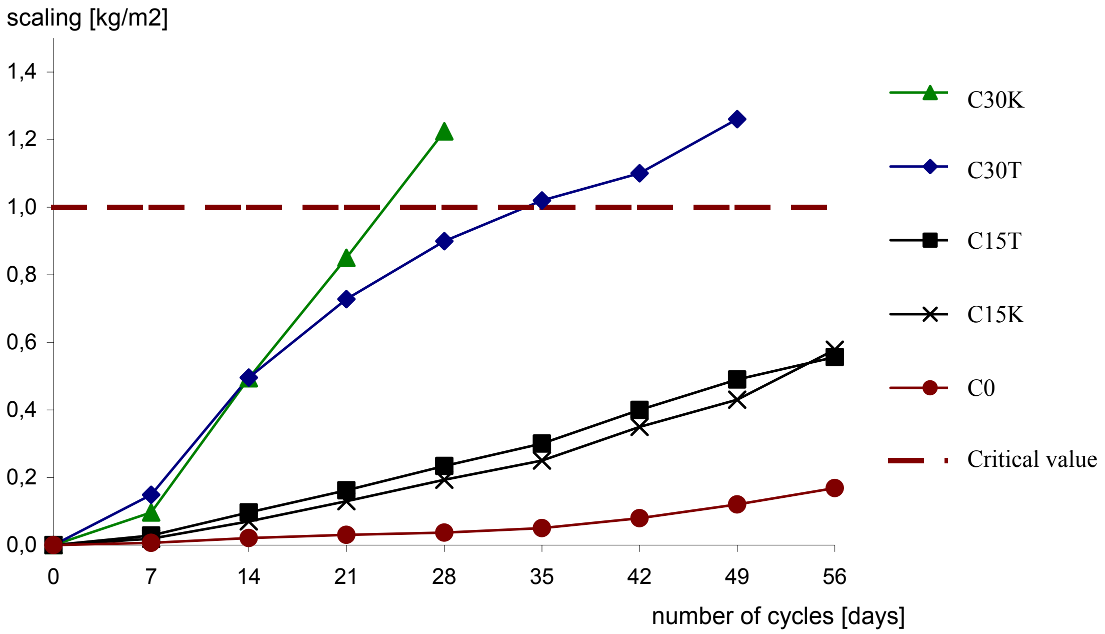



Figure 5: Results of the scaling resistance tested according to CEN/TS 12390-9:2007

It was expected that concrete with the best air-void microstructure parameters concerning frost resistance ($A$>5%, $\bar{L}$ <0.20, α>20 and $A_{300}$>1.5) – C30T, will achieve the positive results of scaling resistance test. Probably, the addition of fluidized fly ash modified the microstructure of concrete in such a way that, in spite of high resistivity, the freezing and thawing resistance in presence of 3% NaCl was low. This apparent contradiction will be explained by future investigations.

## 4. Conclusions

The following conclusions can be drawn from this preliminary study:

1. The values of compressive and tensile strength all concretes, with and without fluidized fly ash were similar (15 and 30% cement replacement);
2. The Wenner method is an easy and simple test to determinate the resistivity of concretes surface layer but it does not explain how does FA influence on the scaling resistance;
3. The fluidized fly ash addition does not deteriorate the air-void structure in the air-entrained concrete, but it reduces the scaling durability;
4. The 30% cement replacement by fluidized fly ash cannot be applied for scaling resistant concrete;
5. Future research is needed in following directions:
   - The influence of the replacement of fluidized fly ash on the internal frost resistance, e.g. determined according to ASTM C 666 A or B method.
   - The influence of the 10% and 20% cement replacement by fluidized fly ashes on scaling resistance,
   - The SEM observations of the difference in the microstructure of concretes with fluidized fly ashes (interfacial transition zone).

**Acknowledgements**
This work was supported by Project nr R04 013 01 sponsored by the Ministry of Research and High Education, Warsaw, Poland, to which the author is grateful.

## References

[1]Utgenannt P., The influence of ageing on the salt-frost resistance of concrete, Report TVBM-1021, Lund Institute of Technology, 2004, pp.346.
[2]Lankard D., Scaling revisited, Concrete International, May 2001, 43-49.
[3]Setzer M. J. The micro ice lens pump – a new sight of frost attack and frost testing, Proceedings Third International Conference on Concrete Under Severe Conditions, Edited by N. Banthia, k. Sakai and O. E. Gjørv, The University of British Columbia, Vancouver, Canada, 2001, CD, 428-438.
[4]Valenza II J.J., Scherer G.W., Mechanisms of salt scaling, Materials and Structures 38 (May 2005) 479-488.
[5]Çopuroğlu O., Schlangen E., Modelling of frost salt scaling, Cement and Concrete Research 38 (2008) 27-39.
[6]Jóźwiak-Niedźwiedzka D., Scaling resistance of high performance concretes containing a small portion of pre-wetted lightweight fine aggregate, Cement and Concrete Composites, 27 (2005) p.709-715.
[7]Zieliński M., Properties and structure of concretes with addition fly ashes from the coal combustion in fluidized bed combustion boilers, PhD thesis, Institute of Fundamental Technological Research, Polish Academy of Sciences, Warsaw, 2005, pp. 204.

***Daria Jóźwiak-Niedźwiedzka, Ph.D.**, Institute of Fundamental Technological Research, Polish Academy of Sciences, 21 Swietokrzyska Str., 00-040 Warsaw, Poland, tel. + 48 22 8274650, e-mail: djozwiak@ippt.gov.pl*