FIRE BEHAVIOUR OF PLAIN SELF-COMPACTING CONCRETE (SCC)

BRANDVERHALTEN VON UNBEWEHRTEM SELBSTVERDICHTENDEN BETON (SVB)

COMPORTEMENT DU BETON PLEIN ET AUTOCOMPACTANT DANS L' INCENDIE

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SUMMARY

In this research Self-Compacting concretes designed as Powder Type, Viscosity-Agent Type and Combination Type were investigated with respect to their behaviour at fire conditions. Therefore cubes with an edge length of 300 mm without reinforcement were cast and subjected to a fire with a duration of 2 h according to ISO 4102 T. 2 after storage of 180 d. The spalling of the concretes depended on the $(w/c)_{eq}$-ratio and the cement-powder ratio (c/p). The concretes showed a relatively high residual compressive strength which depended also on the $(w/c)_{eq}$-ratio and the cement-powder ratio (c/p) of the mix.

ZUSAMMENFASSUNG

Bei diesen Untersuchungen wurden Selbstverdichtende Beton (SVB) nach dem Mehlkorntyp, dem Stabilisiertyp und dem Kombinationstyp auf ihr Verhalten bei Brandbeanspruchung untersucht. Dazu wurden unbewehrte, würfelförmige Probekörper mit einer Kantenlänge von 300 mm hergestellt und nach 180 d Lagerungsdauer einem 2-stündigen Brand nach ISO 4102 Teil 2 ausgesetzt. Die Oberflächenschädigung der Betone war abhängig von dem equivalenten Wasserzementwert und dem Zementmehlkornverhältnis. Des Weiteren verfügten die SVB über vergleichsweise hohe Restdruckfestigkeiten, die ebenfalls von dem $(w/z)_{eq}$-Verhältnis und dem z/mk-Verhältnis beeinflusst wurden.

RESUMÉ

Dans ces recherches les bétons autocompactants sont explorés avec l´effort de l´incendie. Les bétons sort au type de poudre, au type de stabilisation et au type de combination. Pour cela des cubes avec une longueur de 300 mm ont été faits sans armature. Après 180 jours de stockage ils ont été exposés a une incendie de deux heures selon ISO DIN 4102 part 2. Le dommage de la surface des bétons a dependu d´équivalent du rapport eau/ciment et du rapport ciment/poudre. De plus par comparaison les bétons autocompactants ont en la disposition de la haute resistance residuelle qui a été influencée par l´équivalent du rapport eau/ciment et du rapport ciment/poudre.

KEYWORDS: SCC, fire, spalling, residual compressive strength

The results presented in this paper are a brief summary of a research that was supported by the DAfStb. Details of the investigations and an overview of research related to fire behaviour of SCC can be found in [1].

1. RANGE OF INVESTIGATION AND MIX COMPOSITION

The compressive strength of the individual concretes was determined on separately cast cubes of an edge length of 150 mm at an age of 28 days. These cubes were stored for 7 days at 20 °C and 100 % RH and for 21 days at 20 °C and 65 % RH. The specimens for the fire tests were stored in the same manner for the first 28 days. After this time they were placed in a room with a temperatur of 22 °C and 40 % RH till the age of 180 days. The loss of weight due to drying of these specimens was measured every month. The loss of mass of the cubes can be calculated as follows:

$$\Delta m_T = (\frac{m_i}{m_0} - 1) \cdot 100\,\% \qquad [\%\ \textit{by mass}] \qquad (1)$$

with:

Δm_T = loss of mass of the specimen due to drying [% by mass]

m_i = mass of the specimen at time i [kg]

m_0 = mass of specimen after 1 day [kg]

After the fire test the damage caused by the fire was documented and the specimens were cleaned by brushing off the loose parts. The loss of mass of the specimens due to spalling was calculated with the following equation:

$$\Delta m_B = (\frac{m_{nach}}{m_{vor}} - 1) \cdot 100\,\% \qquad [\%\ by\ mass] \tag{2}$$

with

Δm_B = loss of mass af the specimen due to fire [% by mass]

m_{vor} = mass of the specimen before the fire test [kg]

m_{nach} = mass of the specimen after the fire test [kg]

Additionally to the spalling of the concretes the residual compressive strength of the concretes was measured. For this purpose a core was drilled from one specimen of each concrete mix.

The composition of the different concretes is presented in table 1. The designed compressive strength of the concretes varies between 25 MPa and 75 Mpa. The nomenclature of the mixes is as follows: the initial letter represents the type of SCC. K stands for Combination Type, M for Powder Type and S for Viscosity Agent Type. The following number describes the designed compressive strength of the SCC. That means the mix M55/67 ist a Powder Type SCC with a strenghth class of C55/67.

Table 1: mix composition of the investigated SCC.

	Combination Type			Powder Type				Viscosity Agent Type
	C20/25	C35/45	C55/67	C20/25	C35/45	C55/67	C60/75	C25/30
General:								
Cement	CEM II/A-LL 32,5R	CEM II/A-LL 32,5R	CEM II/A-LL 42,5R	CEM II/A-LL 32,5R	CEM II/A-LL 32,5R	CEM II/A-LL 42,5R	CEM II/A-LL 42,5R	CEM II/A-LL 32,5R
Cement content [kg/m³]	240	300	350	240	300	350	500	265
Water content [kg/m³]	170,4	166,4	170,4	168,0	166,4	170,4	183,0	172,3
Volume of aggregates [dm³/m³]	624	644	619	618	633	624	582	672
Weight of aggregates [kg/m³]	1624	1675	1611	1608	1634	1624	1524	1747
Fillers:								
Fly ash [kg/m³]	0,0	99,0	118,8	0,0	99,0	118,8	136,5	0,0
Limestone powder [kg/m³]	315,8	104,1	78,9	338,4	133,6	66,4	0,0	160,0
Admixtures:								
Superplasticizer	Wörmann FM/BV 375	Wörmann FM/BV 375	Wörmann FM/BV 375	Wörmann FM/BV 375	Wörmann FM/BV 375	Wörmann FM/BV 375	Wörmann FM/BV 375	Wörmann FM/BV 375
Content of superplasiticizer [% v.C.]	1,25	1,35	1,35	1,25	1,25	1,35	1,45	1,50
Viscosity agent	Wörmann UW - Compound	Wörmann UW - Compound	Wörmann UW - Compound	--	--	--	--	Wörmann UW - Compound
Viscosity agent content [% v. C.]	0,20	0,10	0,10	--	--	--	--	0,45
Powder content [kg/m³]	569	516	560	594	545	548	637	442
$(w/c)_{eq}$ - ratio [-]	0,71	0,49	0,43	0,70	0,49	0,43	0,33	0,65

The $(w/c)_{eq}$-ratio used in table 1 is calculated as follows:

$$(w/c)_{eq} = \frac{w}{c + 0,4f} \qquad (3)$$

with:

w = amount of water in the mix [kg/m³]

c = amount of cement [kg/m³]

f = amount of fly ash (f countable≤ 0,33 c) [kg/m³]

2. FRESH CONCRETE PROPERTIES

Before the specimens for the fire tests were cast, the usual fresh concrete tests to characterize the rheological properties and the tendency of blocking of the mixes were performed. Bleeding and segregation was estimated direcly at the fresh concrete. Additionally the distribution of the coarse aggregates within the cubes with an edge length of 150 mm was investigated after the compressive tests were performed. The results of the fresh concrete tests are shown in table 2.

Table 2: results of the fresh concrete tests.

Mix	Funnel time [s]	Slump flow [mm]	Slump flow with J-ring [mm]	Air content [% by vol.]	Fresh concrete density [kg/dm³]	Fresh concrete temperature [°C]
K20/25	10,5	750	750	3,8	2,24	23,9
K35/45	13,0	720	725	2,9	2,30	24,1
K55/67	18,0	690	690	1,5	2,36	24,2
M20/25	11,0	780	785	4,8	2,19	23,4
M35/45	12,0	740	730	0,8	2,35	23,6
M55/67	15,5	745	750	0,8	2,33	24,9
M60/75	12,0	770	730	1,3	2,36	26,5
S25/30	8,0	680	635	0,9	2,34	22,8

The fact that some slump flow results with J-Ring are larger than those without J-Ring can be explained by the inaccuracy of this test and the inherent distribution. This is possible to occur when single measurements are performed. All the used concretes showed no tendency to blocking and no segregation of coarse aggregates [1].

3. RESULTS

3.1 Compressive strength

The results of the compressive strength tests with the cubes with an edge length of 150 mm are shown in figure 1. The compressive strengths of the concretes with comparable $(w/c)_{eq}$-ratios are all within the same magnitude.

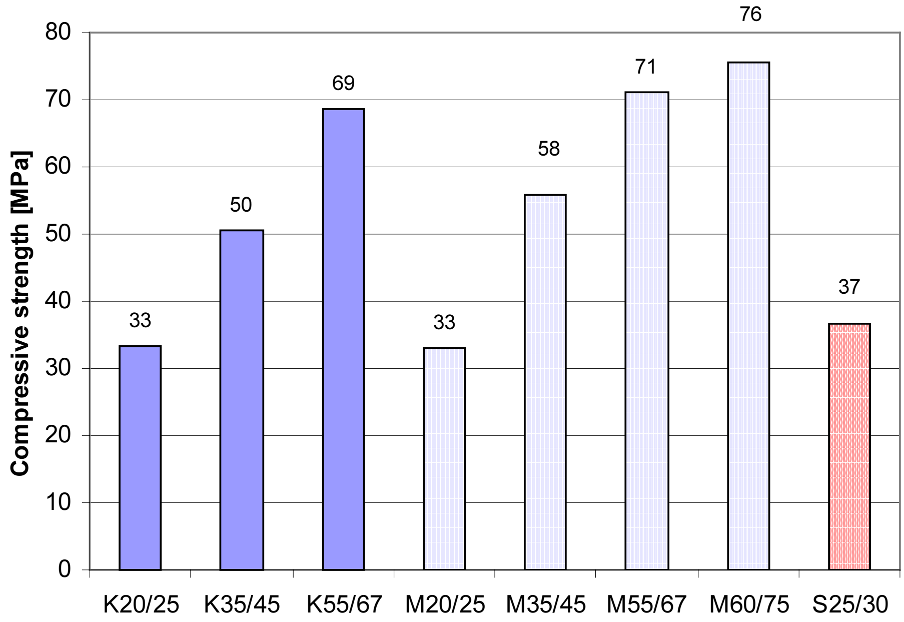

Figure 1: compressive strength of the SCC used after 28d.

The difference between M55/67 and M60/75 however is relative small compared to the difference in mix composition. This can be explained by the different air contents of the mixes (see table 2). The different air contents of concrete mixes can be taken into account with the following equation [2]:

$$f_C = f_{C0} \cdot 10^{-0,035\,p} \qquad (4)$$

with:

f_C = compressive strength with air pores [Mpa]

f_{C0} = compressive strength of the concrete without air [Mpa]

p = air content [% by vol.]

When this formula is used the difference between those two mixes increases from 4.4 MPa to 8.0 MPa. A difference in this magnitude seems reasonable considering the difference in the $(w/c)_{eq}$-ratio so the relatively high air content of M60/75 is the reason for the low compressive strength of this mix.

3.2. Residual compressive strength after fire test

Figure 2 shows the residual compressive strengths of the used concretes related to the compressive strength of the concretes at the age of 28 days.

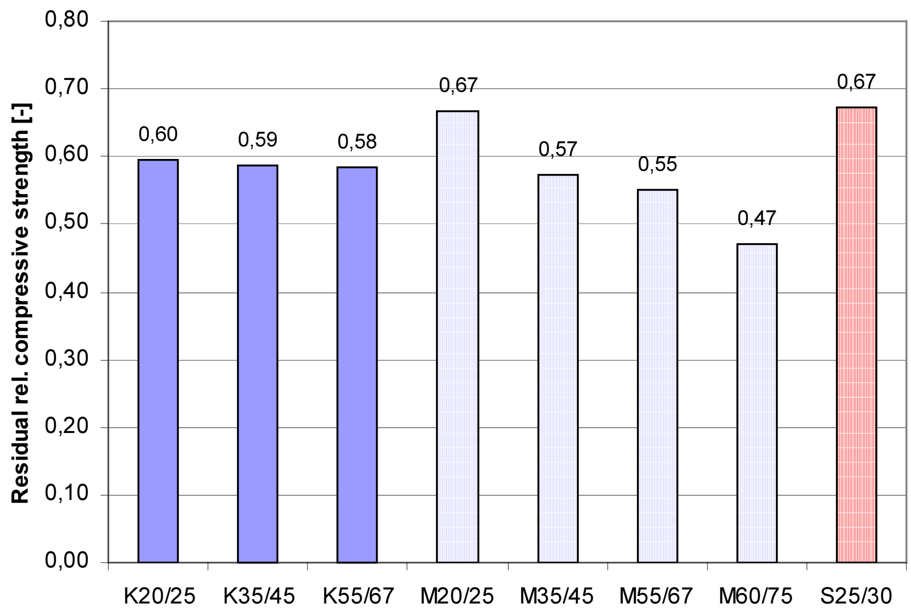

Figure 2: residual relative compressive strength after the fire related to the compressive strength after 28 days.

The residual compressive strength of the tested SCC's is relatively high compared to normal concretes [3, 4, 5]. There is a clear correlation between the $(w/c)_{eq}$-ratio of the concretes and the residual strength (see figure 3).

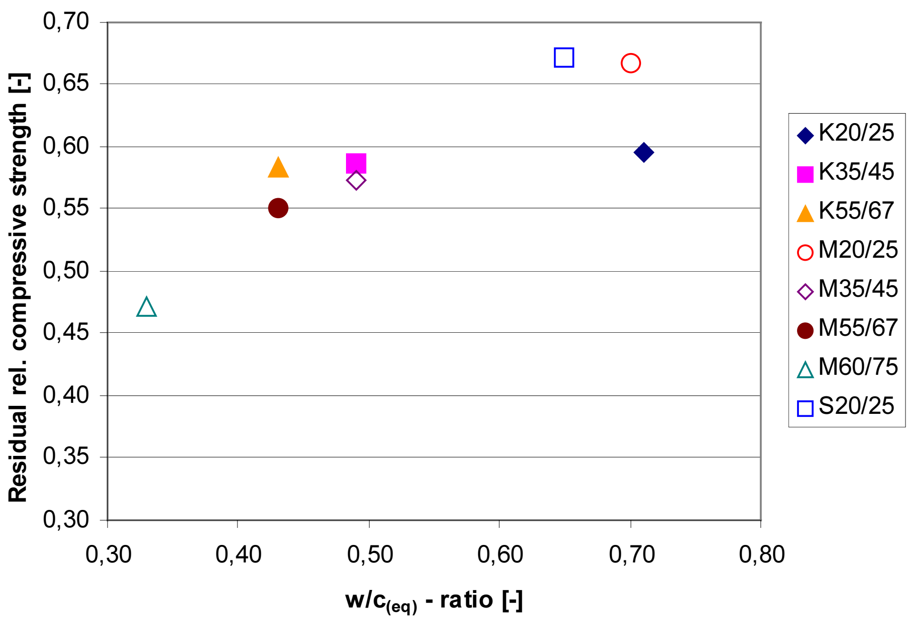

Figure 3: residual compressive strength vs. the $(w/c)_{eq}$-ratio

An increasing $(w/c)_{eq}$-ratio results in an increasing residual compressive strength of the concrete. Additionally the residual compressive strength is related to the cement-powder ratio c/p of the individual mix. An increasing c/p-ratio leads to a reduction of the residual compressive strength (see figure 4).

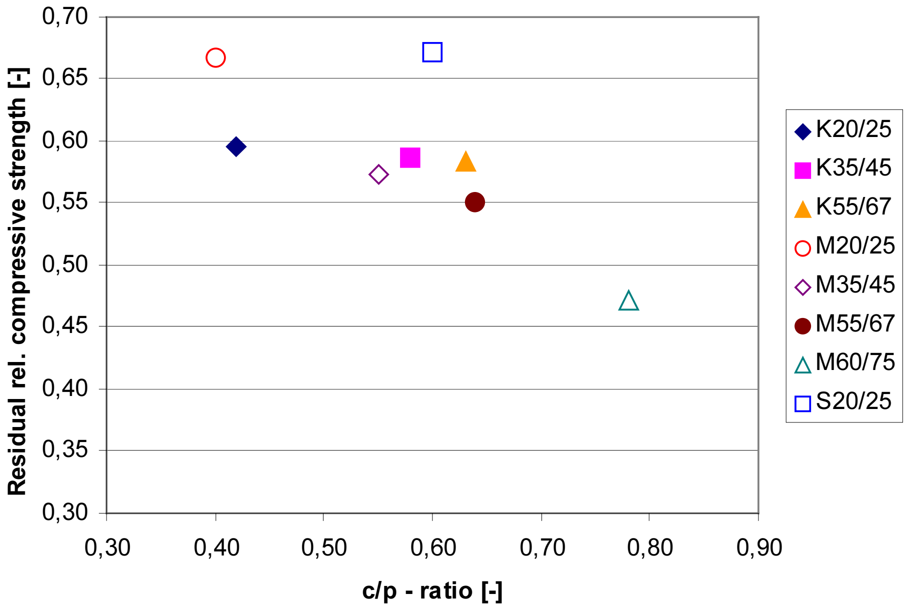

Figure 4: Residual compressive strength vs. the cement-powder ratio.

3.3 Loss of mass in fire test

Those high residual compressive strengths of the SCC mixes are quite astonishing as the spalling of the specimens was relatively strong. The loss of weight reached values between 44.8 % and 62.8 % of the initial mass of the specimen (see figure 5).

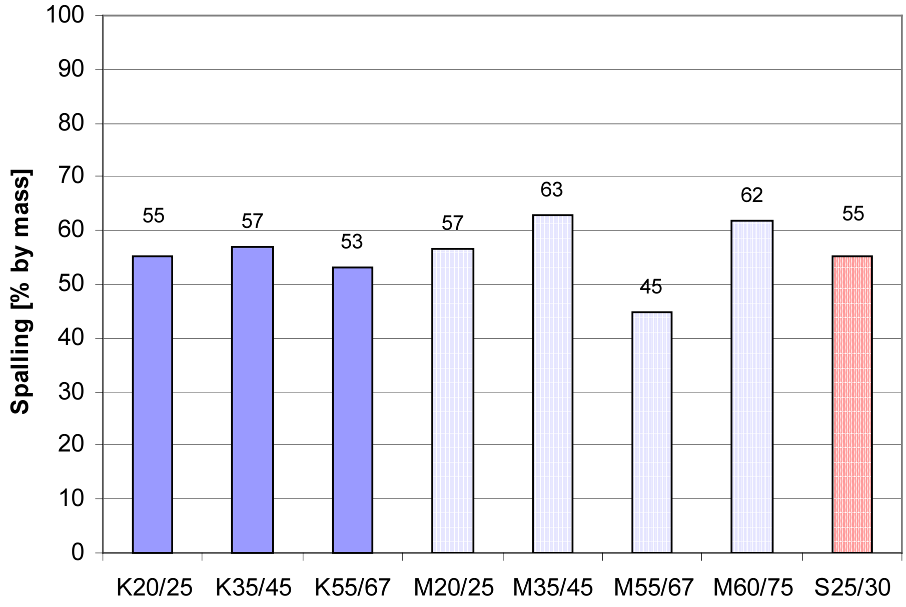

Figure 5: spalling of the concretes due to fire (mean of 3 cubes).

It is important to note that after the fire almost all specimens had still the shape of a cube (see figure 6). But the outer parts of the concrete could easily be removed by brushing (see figure 7). Though these loose parts of the concrete do not have any strength left they still can act as thermal insulation for existing reinforcement in the structure. So the spalling is possibly not as bad as it seems. But to reconfirm this assumption further research with reinforced specimens is necessary.

Figure 6: cube 3 of mix K55/67 after fire

Figure 7: cube 3 of mix K55/67 after brushing off the loose parts.

Analogous to the residual strength there is a correlation between the spalling of the concretes and the $(w/c)_{eq}$-ratio (see figure 8). This correlation is not as good as it is for the residual strength and more tests are necessary to confirm this statement.

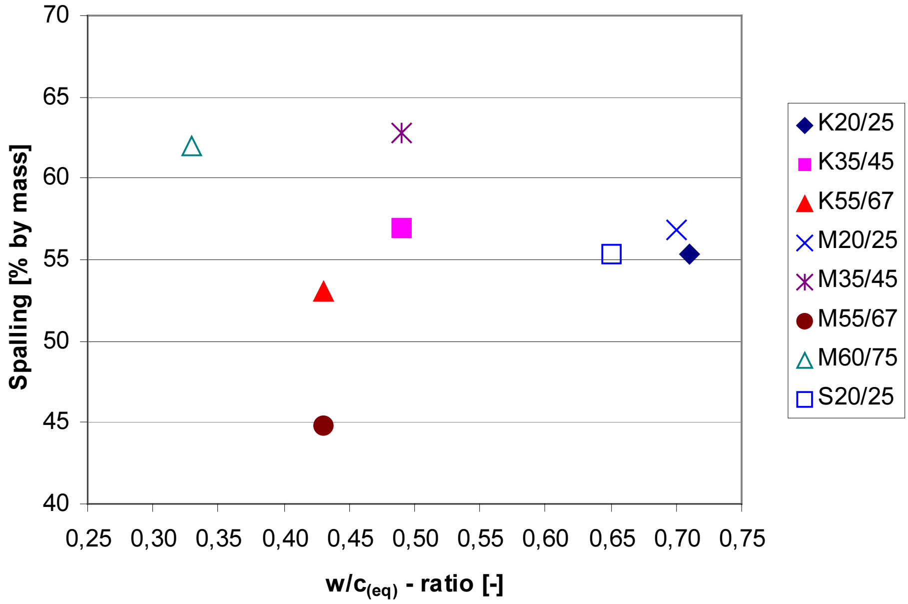

Figure 8: spalling vs. the $(w/c)_{eq}$-ratio.

It seems that the spalling decreases with increasing $(w/c)_{eq}$-ratio. There is also a relationship between the spalling of the concrete and the cement-powder ratio (see figure 9). But here also more data is necessary to confirm this correlation.

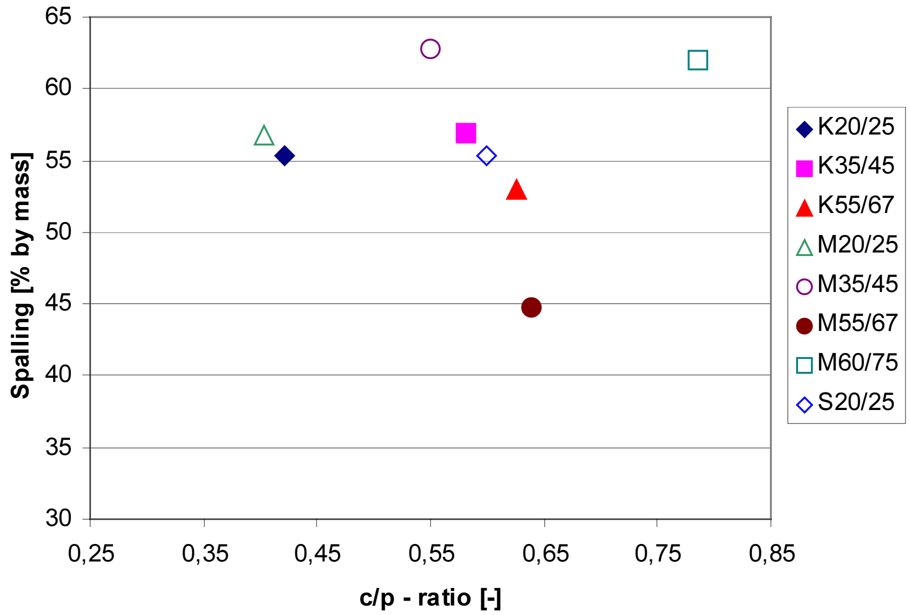

Figure 9: spalling vs. the cement-powder ratio.

CONCLUSIONS

Fire tests with eight Self-Compacting Concretes (SCC) with different compositions have been carried out. The tested concretes showed a relatively high residual strength after the fire ranging from 47 % to 67 %. A strong correlation between the $(w/c)_{eq}$-ratio and the residual compressive strength of the concretes was found. With increasing $(w/c)_{eq}$-ratio the residual strength of the mixes increased too. There was also a good correlation between the cement-powder ratio c/p and the residual compressive strength. Here a increasing c/p-ratio leads to a decreasing residual strength.

During the fire test only little spalling occurred. The specimens showed numerous cracks while testing and after cooling down to room temperature but still had the shape of a cube. The outer parts of the specimens however could easily be removed by brushing. Concerning the condition of the specimens after brushing, spalling between 45 % and 63 % was measured. There is also a correlation between spalling and the $(w/c)_{eq}$-ratio and also between spalling and the c/p-ratio but more data are necessary to confirm these findings.

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