Proof of the water resistance of steel-fibre-reinforced concrete

Concrete modified with steel fibres – waterproof even in hardness test

In recent years, concrete modified with steel fibres has become generally accepted in a variety of applications. In principle, the weather resistance of concrete is increasingly becoming a crucial factor in determining its use in construction. In terms of the expected service life, the interdependent characteristics, such as water absorption capacity, frost resistance and water resistance, are becoming more and more important – even in the case of steel-fibre-reinforced concrete.

By Dr.-Ing. Jacek Katzer,
Technical University of Koszalin, Poland

However, investigations into the water resistance of concrete samples after curing in the laboratory do not reflect the actual water resistance of the concrete in a finished structure. Every construction, even the simplest, 'works' under repeated applied and relaxed loading. The effect of the variability of static load application on the concrete parameters over time has already been well known for a long time, particularly in regard to compressive strength (2). These facts prompted the author to examine the water resistance of concrete which has been modified with steel fibres after subjecting it to different load application cycles.

During the investigation, 5 mixes were prepared for 18, 15 cm x 15 cm x 15 cm test pieces in each case and modified with steel fibres (Vf) from Polish production at concentrations ranging from 0 to 2 %. The geometries of the steel fibres are shown in Figure 1. The concrete was prepared with a water cement factor of 0.5 based on a fine-grained aggregate, the parameters of which are collected in Table 1. Taking into consideration that adding steel fibres to the concrete mixture consolidates its consistency to a significant extent, all concrete mixtures were also modified with 1.8 % plasticiser.

The test results were submitted to a statistical analysis in which the values weighted with rough errors were evaluated using the Smirnow Grabbs criterion. The objective nature of the investigation was ensured by selecting the sequence of individual experiments from a table of the random numbers. All calculations used to determine the values for the regression equations and graphical interpretation of the mathematical model obtained were performed using the 'Statistica' program.

Based on the test results described in (2), the test pieces from each mixture were divided into three independent groups and subjected to preloading – each group according to a different cycle. The first cycle consisted of applying the load to the samples eight times until the moment the stresses which make up 45 % of the fracture stress were released and the test pieces relieved. The test pieces were subjected to a uniformly increasing force corresponding to a rate of increase of stress of 0.5+/ 0.1 MPa/s. The pulse frequency obtained under these conditions amounted to 1/35 Hz. The first cycle is shown in Figure 2. The second cycle, consisting of applying the load to the samples once until the moment the stresses which make up 90 % of the fracture stress were released and the test pieces relieved, is shown in Figure 3. During the third cycle, the comparison cycle, the test pieces were not preloaded.

After the load application cycles, the samples were tested for their resistance to water. The water resistance of the concrete was tested using an instrument which supplies water from below and can test six samples under a pressure of 0.2 MPa to 1.2 MPa simultaneously. The test was carried out under constant pressure at 1.2 MPa in under 72 hours. After this, the test pieces were split and the depth of the water penetration measured. The results were expressed as the coefficient of flow velocity k_v (4) calculated according to Equation (1):

$$k_V = \frac{X_{max}}{2\Sigma h_i t_i} \quad (1)$$

▶

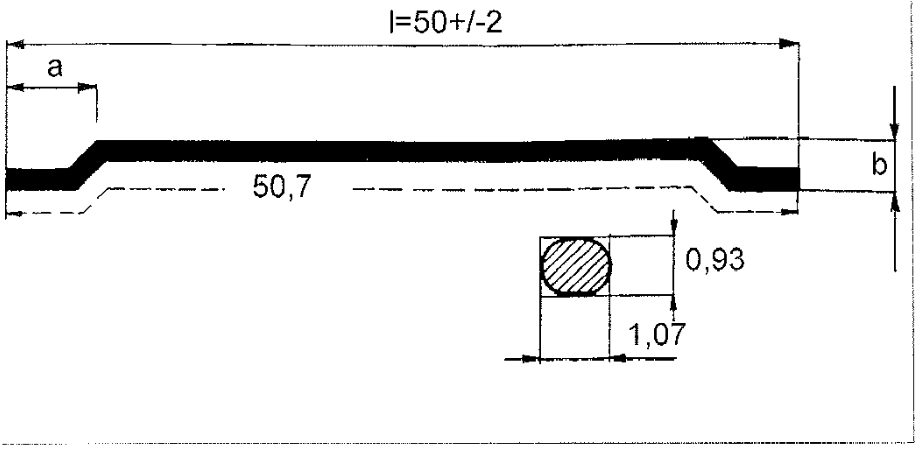

Figure 1: Shape of steel fibres manufactured in Poland. The nominal values a and b quoted by the manufacturer are 5±2 and 3±1 mm respectively.

where:
x_{max} - max. water depth in m,
h_i - water pressure in m H_2O,
t_i - pressure duration h_i in s

Expressing the water resistance by means of the coefficient kV allows the water resistance of the test pieces to be compared, by comparing those which were penetrated by the water during the test and those which remained impermeable to the end of the test. The water resistance of test pieces which were tested differently can be compared. It must be remembered that the coefficient k_V describes the unified flow velocity of water through the concrete, thus, the smaller the flow velocity, the more waterproof the concrete.

The water resistance of the sand concretes which were subjected to Preloading cycle no. 1 is shown in Figure 4. The water resistance of the concretes under discussion increases with the number of steel fibres. The increase in density is uniform and almost linear. The coefficient of flow velocity for the comparison mix was k_V=341 x 10^{-12} m/s and that for the most impermeable with the maximum addition of steel fibres was k_V = 202 x 10^{-12} m/s. Equation (2) represents the curve shown in Figure 4.

$$k_{V45} = 341{,}630 - 51{,}093x - 9{,}409x^2 \qquad (2)$$

Figure 5 shows the water resistance of the concrete composition subjected to Preloading cycle no. 2. The water

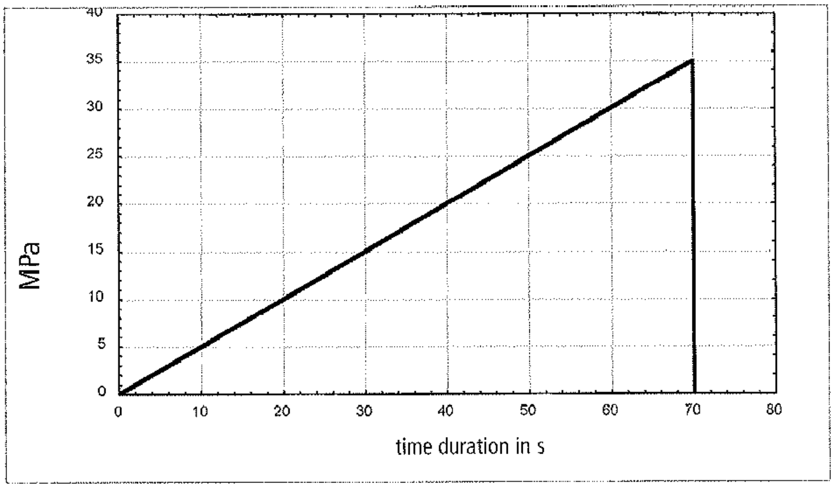

Figure 3: Sample load application cycle no. 2 – single load application on test pieces

resistance increases because of the increasing quantity of steel fibres. The coefficient of flow velocity for the comparison mix was k_V = 3985·10^{-12} m/s and that for the most impermeable with the maximum addition of steel fibres was k_V = 1311·10^{-12} m/s. Equation (3) is represented by the curve shown in Figure 5.

$$k_{V90} = 3985{,}140 - 1542{,}144x + 102{,}591x^2 \qquad (3)$$

The water resistance of the concrete composition which was not subjected to preloading is shown in Figure 6. The water resistance of the concrete without fibres, expressed by the coefficient k_V, amounts to 250x10^{-12} m/s. Modifying the concrete with steel fibres produces a water resistance k_V=101·10^{-12} m/s. Equation (4) is represented by the curve shown in this Figure.

$$k_{V0} = 257{,}986 - 232{,}976x + 142{,}571x^2 - 32{,}667x^3 \qquad (4)$$

The water resistance of the concretes which were not subjected to preloading moves to the level from k_V = 101 to 258·10^{-12} m/s. The concretes subjected to Preloading cycle no.1 have a water resistance of k_V = 202 to 341·10^{-12} m/s, compositions subjected to Preloading no.2, on the other hand, have a water resistance of k_V = 1311 to 3985x10^{-12} m/s.

If the water resistance of the concrete not subjected to preloading is taken as a point of reference, then the ratio of the water resistance of the fibre-free concrete not subjected to preloading to the water resistance of those subjected to Cycles 1 and 2 is 1:2:13. A similar ratio applies to concretes modified with steel fibres - 1:1, 3:15. From the above relationship, the magnitude of the influence of the steel fibres added and the kind of the preloading on the water resistance of the concrete can be clearly seen.

The effect of the amount of fibres added on maintaining the water resistance increases with increasing preloading. The 'working' concrete in the structure mostly transfers the applied load which gives rise to about half of the breaking stresses and changes within a certain time frame. For this reason, the water resistance of the concrete subjected to Preloading cycle no. 1 is the most important for construction applications.

The tests carried out by the author show that, apart from improving the

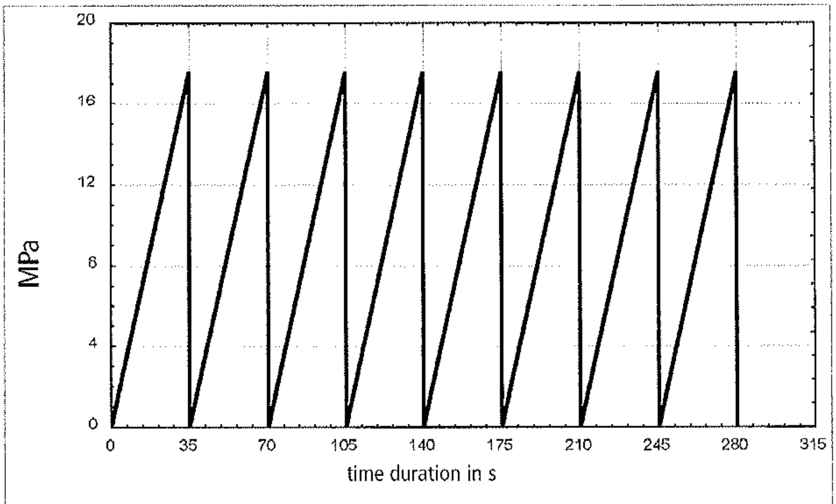

Figure 2: Sample load application cycle no. 1 – eight times load application and relief on test pieces

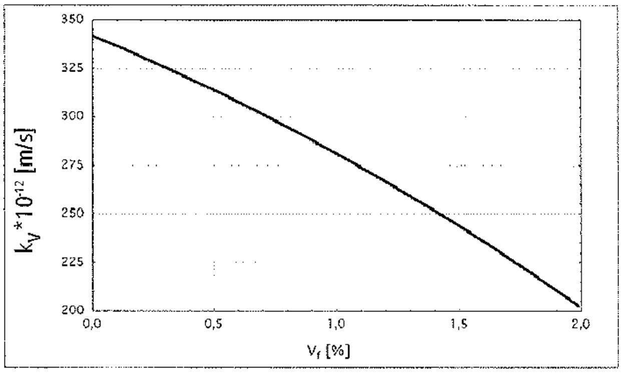

Figure 4: Water resistance of concrete composite after Preloading cycle no. 1 in relation to the addition of V_f.

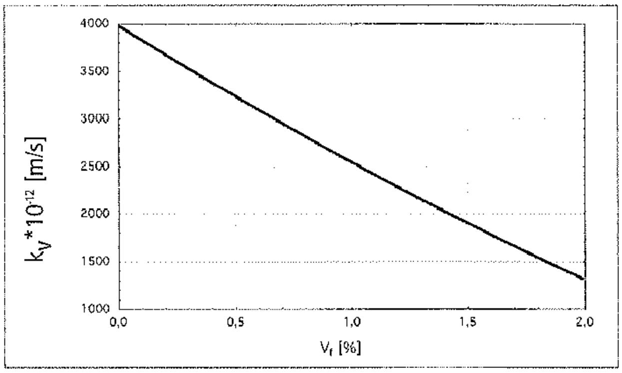

Figure 5: Water resistance of concrete composite after Preloading cycle no. 2 in relation to the addition of V_f.

structural characteristics of concretes (1), adding steel fibres also enables them to retain their relatively high water resistance after cyclic preloading, which is very important for the future use of concrete modified with steel fibres in general practice. However, it must also be borne in mind that the water resistance tested on test pieces which have not been subjected to loading does not allow any conclusions to be drawn in regard to the water resistance of the samples which have been subjected to preloading. ■

Property tested		Symbol	Size
Filling density in loose state		ρn^{l}	1631 kg/m³
Filling density in shaken together state		ρn^{z}	1805 kg/m³
Fine grain content		Z_p	0.8 %
Grading index according to	Kuczyński	U_K	3.279
	Abrams	U_A	2.205
	Hummel	U_H	66.37
Cavernosity of the aggregate in loose state		j_l	38 %
Cavernosity of the aggregate in shaken-together state		j_z	32 %

Table 1: Physical properties of the fine-grained aggregate

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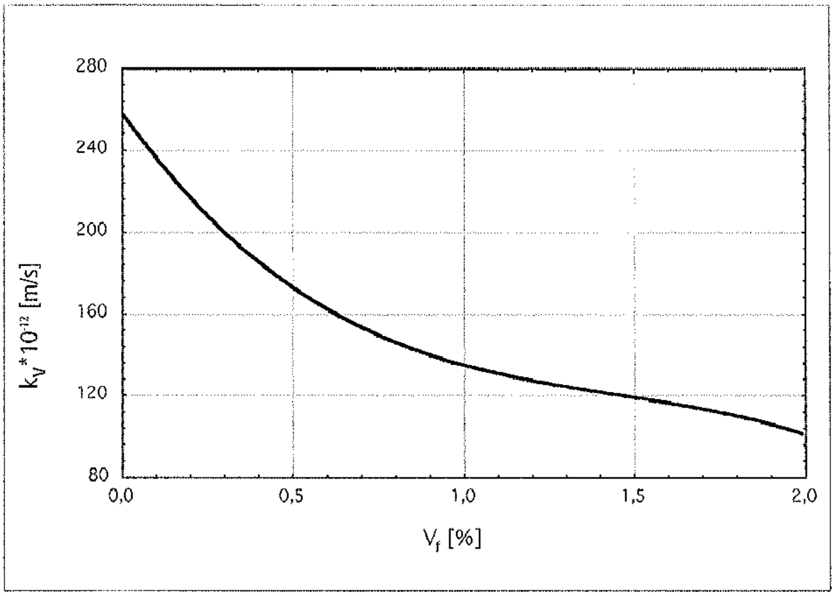

Further information:

Dr.-Ing. Jacek Katzer
Technische Hochschule Koszalin
ul. Kapitanska 4
75-206 Koszalin, POLAND
Tel.: ++48 94 341 6880
Fax: ++48 94 341 6880
E-Mail: katzer@tu.koszalin.pl

Figure 6: Water resistance of concrete composition without applied load according to Vf addition.