MECHANICAL PROPERTIES OF UHPC WITH DIFFERENT KINDS OF GLASS FIBRES

PERNICOVA Radka [1], DOBIAS Dan [2] , MANDLÍK Tomáš [3]

Abstract

The effect of the different kind of glass fibres on mechanical properties of ultra-high performance concrete (denote as UHCP) is analyzed in the paper. It was the use two types of micro fine high-dispersible alkali resistant fibres that increase tenacity and prevent the formation of shrinkage cracks caused by tensions accompanying concrete curing. In fact the difference between them is, that while one kind of fibres is bound by one hundred pieces in strand, second is dispersed one by one on individual fibres. In this work, we are also focused on the grain fineness of the basic component of concrete and their effects on mechanical parameters such as compressive and flexural strength, elastic modulus or fracture properties. Comparative measurements with normal strength concrete (denote as NSC) with and without glass fibres are done as well. On the basis of the experiments performed, it can be concluded that the mechanical prosperities of studied UHPC are similar and no matter what kind of glass fibre was used. On the other hand, the addition of fibres in NSC, is found to be more significant.

Keywords: fineness, glass fibre, mechanical parameters, strength, elastic modulus, UHPC, NSC, GFRC.

1. Introduction

Application of glass fibres in the concrete not appears until the mid nineties. It is caused by development of properties of glass material. Until then, there were not available suitable types of alkali resistance glass fibres used for cement based materials. Glass fibre has good properties, which make it ideal as a very good material for reinforcement of the concrete. The production processes of fibres is based on the technology of the molten glass with temperature 1560 ° C flows through the platinum iridium perforated board. Monofibres are rapidly cooled and on its surface is applicate lubrication, which besides protective function also ensures evenly distributed in the mixture. The modulus of elasticity used glass fibres must be higher than the elastic modulus of reinforcing materials [1].

For using glass elements in cement based materials is necessarily to take into account the requirement for resistance to alkaline environment, which in concrete is pH 12-14. Since the first alkali resistant fibre was developed in the late 60 years in Great Britain (zirconium type) its properties are constantly evolving. Alkali resistance is measured by special test

[1] PERNICOVÁ Radka, Klokner Institute of CTU, Šolínová 7,166 08 Prague, radka.pernicova@klok.cvut.cz

[2] DOBIÁŠ Daniel, Klokner Institute of CTU, Šolínová 7,166 08 Prague, daniel.dobias@klok.cvut.cz

[3] MANDLÍK Tomáš, Klokner Institute of CTU, Šolínová 7,166 08 Prague, tomas.mandlik@klok.cvut.cz

SIC (strand in cement). Result of the test is a tensile strength after exposure the cement sample to alkaline environment in water at high temperatures.

Use micro-fibrous reinforcement in concrete can be divided into two main parts. The first meaning is to prevent or significantly reduce the occurrence of cracks in the concrete during the maturation period. To ensure that micro fibrous reinforcement is effective must be in a cubic meter of concrete present in amounts hundred millions and its length long enough to span in the matrix a considerable distance. Fibres can effectively bridge the cracks and help with cracked concrete structure to withstand greater loads and ensure that the design will have elastic properties, due to the high tensile strength and possibility of applications in large quantities. Lubrication must fulfill the wetting ability of the cement paste and positively affect mixture rheology. The second important meaning is to increase the strength of hardened concrete, especially flexural strength, shock and toughness. Fibres must already operate in the strand.

Generally is UHPC defined as concretes attaining compressive strengths exceeding 100 MPa in practice and the direct tensile strength systematically higher than 15 MPa. UHPC concretes exhibits increased mechanical properties and superior durability to NSC (60 MPa) [2]. Which is the reason, why we primary focused on the impact of the fibres on strength of UHPC in this paper.

The fibres provide a non-corrosive solution in view of the fact that the fibres are alkali resistant. One of the most important advantages of using glass fibres is also easy processability and not overlaps from the surface. There is no need of cover layer for reinforcement so structure can be thinner and lighter.

2. Experimental measurement

2.1 Materials

All ingredients used for concrete preparation are chosen from major producers in the Czech Republic. All additives (slag, micro silica and ground quartz GQ300) were selected as fine-grained material, whose fineness of grinding, respectively huge specific surface area, provide better mechanical properties [3]. Average particle size of binder and additives is in the unit of μm, Specific data are summarized in Table 1. The particle size distribution was measured by the device Malvern, which works on the principle of laser scanning of particle size through the hydro medium. The size distribution curves of applied limes are shown in Figure 1.

Tab.1: Measurement data of particle size distribution

Additives	Specific Surface Area	Partical Analysis		
	$[m^2kg^{-1}]$	$D_v(10)$	$D_v(50)$	$D_v(90)$
Cement	254	5.6	19.9	47.3
Slag	1247	1.81	14.8	46.5
Micro silica	107	23.7	143.0	390.0
GQ 300	905	2.77	11. 9	32. 5

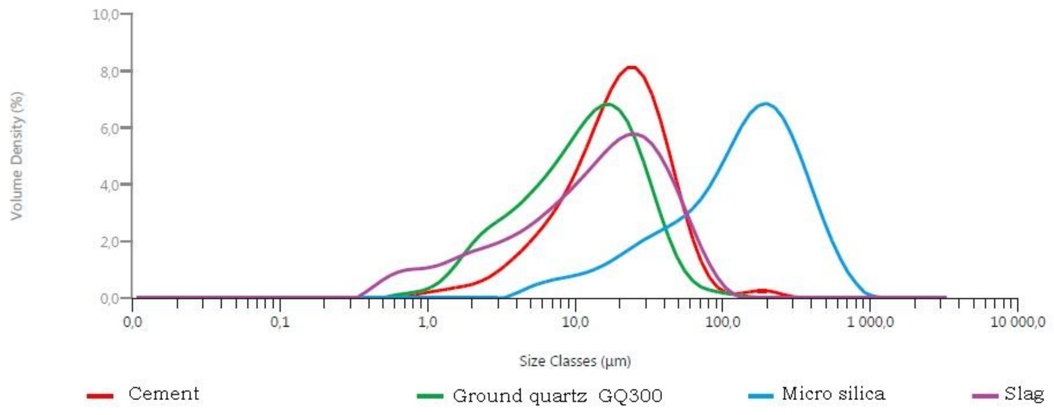

Fig. 1: Size distribution curves of used additives

In designing of concrete recipe was used the fibres made glass with the high content of zirconium oxide, which together with its surface lubricity provide resistance to alkaline environments of cement based materials. The fibres are health unobjectionable, high modulus (72 GPa) and high strength (3500 MPa as mono and 1700 MPa as strand fibre). In this experiment it was tested two kinds of glass fibres made according to norm ISO 9002. Both glass elements have length 12mm and ratio to its diameters (14µm) is 587:1.

One of them is fibre HD (high dispersible), which after mixing in the concrete disintegrates into individual mono fibre and in the mixture operate separately. These fibres are designed primarily to prevent to crack creation induced tension accompanying maturing concrete. Strand of glass fibres HP consists of 100 pieces of mono fibres, which are also sufficiently bonding by the lubrication, so even after vigorous mixing maintains the integrity and function as primary dispersal micro fibrous reinforcement increasing tensile strength and shock.

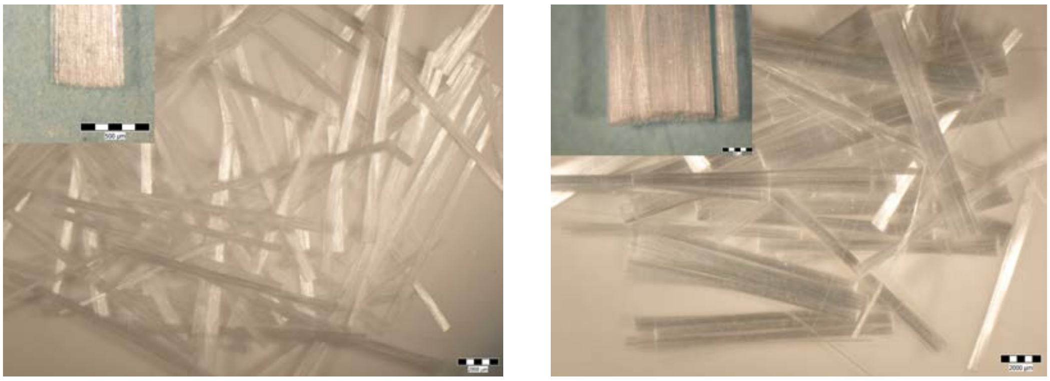

Fig. 2: Glass fibres: HD (left) and HP (right)

2.2 Samples

In the order to analyze the effect of glass fibres (two type: HD and HP) in the concrete on mechanical parameters, six different mixtures with and without glass fibres were prepared. Both concrete (UHPC and NSC) were prepared in mass of ingredients: a binder (cement including additives) and standardized sand. Samples were mixed according to ČSN EN 196-1. Compositions of concrete are given in Table 2 and Table 3.

Tab.2: Composition of concrete mixture

Quantity [kg]	UHPC	NSC
Aggregate (max. grain size)	114.8 (2mm)	181.4 (8mm)
Cement	69.3	29.7
Additives (slag + microsilica+GQ300)	24.8	-
Water + fluidizing admixture	19.8	22.2

Tab.3: Amount of fibres in mixtures

Type of mixture	**U 1**	**U 2**	**U 3**	**N 1**	**N 2**	**N 3**
Concrete	UHPC	UHPC	UHPC	NSC	NSC	NSC
Fibres HP [kgm^{-3}]	-	-	3.0	-	-	3.0
Fibres HD [kgm^{-3}]	-	0.6	-	-	0.3	-

2.3 Experimental methods

As fundamental physical material characteristics, bulk density ρ_b [kg m^{-3}], matrix density ρ_m [kg m^{-3}], and open porosity ψ [%] were determined. On this account, firstly, basic physical properties were measured on the vacuum saturation principle using Archmides' weight. The measurement of basic parameters took place in a air-conditioned laboratory at the temperature of 22 ± 1 ˚C and 25-30% relative humidity. Each result represents the average value from five measurements.

Investigation of mechanical parameters was carried out according to the norm ČSN EN 196-1. Five samples of each concrete mixture were done measured after 28 days of hardening period.

The flexural strength f_{ct} [N/mm^2] was measured using standard three-point bending test, and calculating according to equations (1) and (2):

$$f_c = \max \sigma_t = \frac{\max M}{W} \tag{1}$$

$$M = \frac{F_t l}{4} \tag{2}$$

where F_t is load at the moment of break [N], l is distance between bracket, σ_t is tensile stress [MPa], M is flexural moment [N.mm] and W is section modulus at point of break [mm^3]. For each measurement standard prisms 40 x 40 x 160 mm were prepared.

The compressive strength was determined using the same test device on the remainders of the specimens after bending test (standard prisms 40 x 40 x 160 mm) and cube speciment with dimension 100 mm. The individual compressive strength f_c [Nmm^{-2}] was calculated from the following formula:

$$f_c = \frac{F}{A_c} \tag{3}$$

where F is maximum load at the moment of break [N], and A_c is sectional area of specimen, on which is applied load force [mm^2]. Each result represents the average value of six, respectively three, in the case of cubic compressive strength.

Modulus of elasticity, also known as the tensile modulus, is a quantity used to characterize materials. Elastic modulus is measure of the stiffness of any solid material which will return to its original shape after being deformed. Data were calculating according to equations (4) and (5):

$$E = \frac{\sigma}{\varepsilon} = \tag{4}$$

$$\varepsilon = \frac{\Delta l}{l_0} = \tag{5}$$

where σ is tensile stress [MPa], ε is extensional strain [-], l_0 is the original length of the object [mm] and Δl the amount by which the length of the object changes [mm].

3. Results and discussion

3.1 Basic physical parameters

At first, basic material properties of all tested lime plasters were determined. Basic properties of all materials are summarized in Table 4.

Tab.4: Basic physical properties

Type of mixture	**U 1**	**U 2**	**U 3**	**N 1**	**N 2**	**N 3**
Matrix density [kgm^{-3}]	2370	2350	2360	2530	2520	2520
Bulk density [kgm^{-3}]	2250	2230	2230	2190	2180	2160
Open porosity [%]	4.86	5.03	5.42	13.56	13.63	14.34

Table 4 shows that both types of concrete achieved very similar values of bulk and matrix density. Only open porosity value is significantly different. The NSC exhibited almost three times higher open porosity than UHPC. This result can be explained by the formation of hydration products as a result of the reaction of additives such as slag, micro silica or ground quartz. Different values of open porosity caused a slight difference in the values of matrix and bulk density between UHPC and NSC samples.

To take account measured data, it can be observed the influence of individual fibre types. Concrete with fibres that remain in the bunch generally have about 6 percent higher open porosity than the dispersible fibres and about 8 percent higher than concrete without fibres.

3.2 Mechanical Parameters

The compressive and flexural strengths and stress modulus were determined as the most important mechanical parameters for concrete.

Tab.5: Mechanical parameters

Type of mixture		**U 1**	**U 2**	**U 3**	**N 1**	**N 2**	**N 3**
Flexural strength	[MPa]	16.3	17.1	17.2	9.5	9.8	9.9
Compression strength (40x40x160mm)	[MPa]	105.9	107.0	105.1	49.5	48.5	51.5
Compression strength (100x100x100mm)	[MPa]	92.4	92.5	82.3	49.3	48.9	52.4
Elastic modulus	[MPa]	45 040	45 960	45 280	29 560	30 180	28 960

Table 5 shows mechanical parameters. Strength of concrete UHPC by their very nature is several times higher than concrete NSC, which is achieved due to its extremely low porosity.

The addition of fibres into the UHPC mixture had not significantly changed final value of compressive and flexural strength. It can even notice a slight increase in flexural strength, which is in the range of 4-5%, independently on the type of used fibre and concrete mixture. For compressive strength, the influence of different kind of fibres was not unambiguous. The UHPC and NSC exhibited different behaviour regarding compressive strength. The compressive strength of UHPC increases with additions of HD fibres (operating in the beam) up to 1-2% and decreases with additions of HP fibres 5-10%. As for the effect of HP fibres on the compressive strength of UHPC it was surprisingly low, taking into account previous measurements of flexural strength. Values at the NSC show the opposite trend. Adding HP fibres compressive strength is markedly increased (5-8%). Elastic modulus was determined also after 28 days of hardening period as the other mechanical parameters. That measurement shows that UHPC elastic modulus values are about three times higher than the values NSC and it does not matter on additions of glass fibres. The difference is about one percent, which can be considered a measurement error.

4. Conclusions

The influence of glass fibres on mechanical properties of UHPC and NSC presented in this paper have shown that the addition of any types of glass fibres not let to significantly deterioration properties of concrete mixture even in some cases improved slightly. This improvement of flexural strength was completely independent on the type of used fibre or concrete mixture.

The addition of various kinds of fibres (HD-dispersible one by one, HP - bound in strand by 100 pieces) causes different behaviour of compressive strength. HD fibre type is due to its multiplicity of mono fibres very effective in intercepting the tension during concrete curing, however compressive strength of normal strength concrete is lower. Although, these values would not significantly influenced or even markedly limited the using of this mixture. While fibres bound in strand HP are primarily designed to improve the strength of the concrete, UHPC has higher compressive strength in recipes with high dispersible fibres HD. It is the probable causes by its very nature, when composition of UHPC consist only very fine-grained components (Chapter 2.1).

For Further studies would be useful to verify the other properties of UHPC with glass fibres, especially the influence of the environment and aggressive substances and resistance of surface layers. Some of them have been already tested, such as the chloride resistance, degradation by thermal stress or water transport properties etc. [4], [5].

Acknowledgements

This research has been supported by GACR Agency of the Czech Republic No. GACR 14-20856S. Acknowledgment also belongs to the company STACHEMA CZ s.r.o., whose material and technological experts contributed to develop concrete recipes.

References

[1] FERREIRA, J.P.J.G., F.A.B. BRANCO. *The use of glass fibre-reinforced concrete as a structural material*. Experimental techniques 2007. Vol. 31 Issue 3 s. 64-73.

[2] GRAYBEAL, B., J. TAMESI. *Durability of an ultrahigh-performance concrete*. Journal of Materials in Civil Engineering 2007. Vol.19(10) s. 848-854.

[3] PERNICOVA, Radka, Milena PAVLIKOVA, *Comparison of Mechanical Properties of Modified Plasters with Different Grained Lime Binder.* Mathematics and Computers in Science and Engineering 2009. s. 25-28.

[4] DOBIAS Daniel, Radka PERNICOVA. *Diffusion of Chloride Ions in Ultra High Performance Concrete.* Advanced Materials Research 2015. Vol. 1106. s. 21-24.

[5] KOSTELECKA Michaela. *The influence of hot water on UHPC boards with different types of textiles armatures.* EAN 2014 - 52nd International Conference on Experimental Stress Analysis. Marianské lázně 2014. ISBN: 978-802310377-6