

POSSIBLE MECHANICAL DETERIORATION OF FIBRES INFLUENCED BY MIXING IN CONCRETE



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Favourable experience with fibre reinforced concrete (FRC) resulted in its increasing use worldwide. The properties of fibre reinforced concrete are mostly influenced by the fibre type and the amount of fibres. Fibre properties (tensile strength, length, surface characteristics, shape and density) are normally defined by the fibre producers. However, the properties of hardened FRC are influenced by the properties of fibres existing after mixing.

The question is whether the properties of fibres can be significantly influenced by the mixing procedure. Herein we studied how the 2 to 30 minute mixing time in concrete influences the fibre properties of different fibre materials and fibre shapes. According to our experimental study some of the fibres were deteriorated during the mixing in concrete. The type and degree of deterioration significantly depends on the properties of the fibre. The typical deterioration types of the tested fibres were summarized in our article.

Keywords: fibre, mechanical deterioration, tensile strength of fibre, FRC, Fibre Reinforced Concrete, CMOD, residual flexural strength

1. INTRODUCTION

Since 1874 A. Bernard used to strengthen concrete by the help of addition of steel splinters (Maidl, 1995). Porter in 1910 mentioned the possibility of applying short wire in concrete (Katzer, 2006). In 1965, J. P. Romualdi (USA) applied a patent on steel wire reinforced concrete already reported by him in 1963 (Palotás, 1977).

More and more fibre types were developed with better and better properties because of the good experiences. There are a large number of different fibre materials (steel, polymer, glass, carbon, basalt, natural fibres) which can be used in practice (Fig. 1).

The homogeneous dispersion of the fibres is very important to achieve the best performance of FRC. The manufacturers of the fibres specify the type of mixing (dry or wet) and the minimum mixing time after addition of fibres in concrete.

The main question is whether the properties of fibres can be significantly influenced by the mixing procedure. Herein

we studied how the 2 to 30 minute mixing of concrete influences the fibre properties of different fibre materials and fibre shapes.

2. LITERATURE REVIEW

Almost all the properties of FRC depend on the bond of fibres (Naaman, Najm, 1991). Several researches (Feng, Sun, Wang,

Fig. 2: Tensile stress of the fibres with different lengths (l_c - critical length=fibre length at which the fibre first breaks instead of being pulled out) (Kelly, 1973)

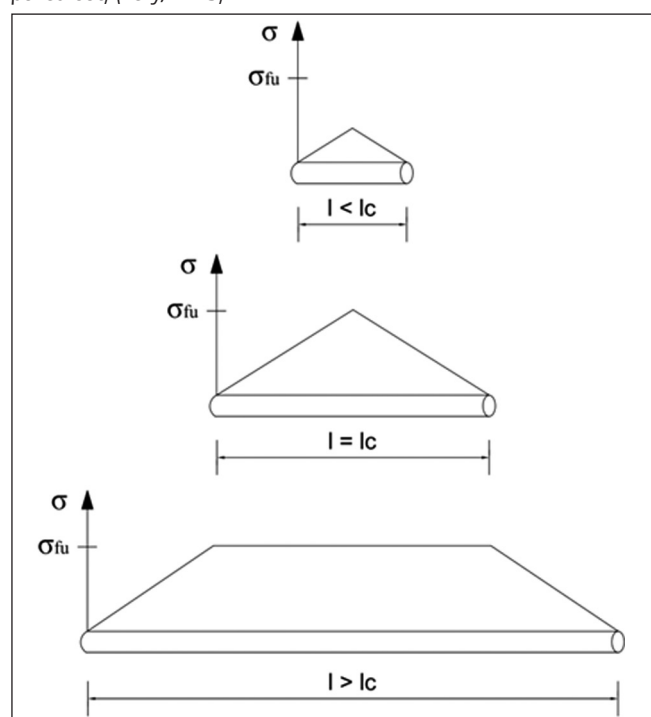
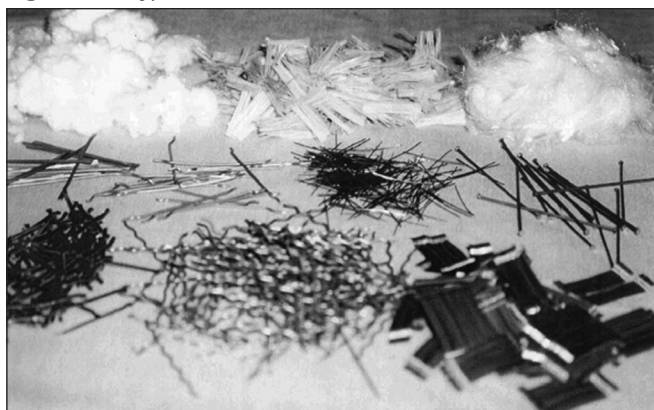


Fig. 1: Some typical fibres used in concrete



Shi, 2014; Halvax, Lublóy, 2013; Kopecskó, 2002; Zile, Zile, 2013) dealt with the bond of different fibres.

The bond of fibres mainly depend on material, shape, surface of fibres and the mechanical properties of the matrix, the amount of fibres and the loading rate (Balázs, Polgár, 1999; Kovács, Balázs, 2003). Consequently, almost all properties of FRC changes with the changing of the surface and the shape of fibres.

The appropriate fibre length is very important for effective usages of fibres. If the fibre lengths are too short the fibres will pull out from the mixture and the whole load bearing capacity of the fibres cannot be utilized (Fig. 2).

As written in the introduction, the homogeneous dispersion of the fibres is particularly important. Fibres may even negatively influence the properties of concrete if quality of casting is poor (Fig. 3). Too many fibres will concentrate at certain locations; therefore, the slurry cannot totally surround the fibres. Bond of these fibres will not be appropriate. At other parts of the mixture there will be less fibre than planned. As a result, the manufacturers of the fibres determine the minimum mixing time after addition of fibres into the concrete.

Fig. 3: Possible changing of properties of FRC depending on the volume fraction of fibres (Schematic curve: A, B, C, D curves mean different fibres types and different quality of casting) (Naaman, Paramasivan, Balázs et al., 1996)

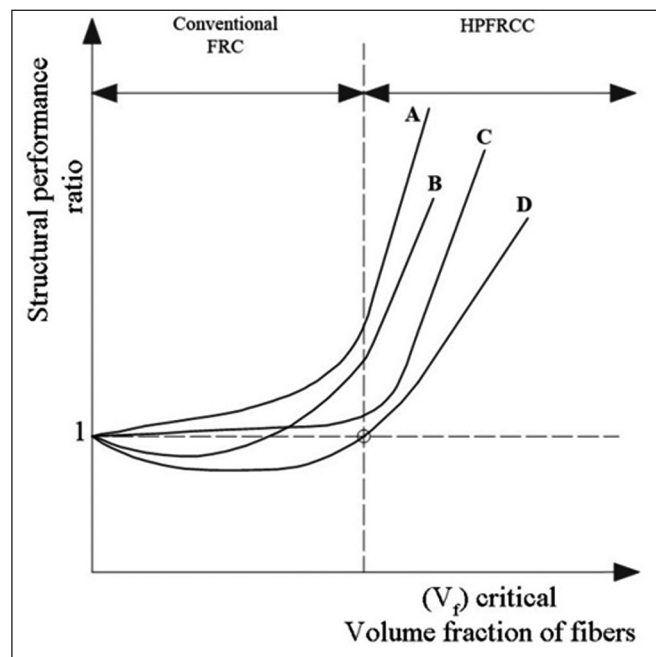


Fig. 4: Three-point bending test set-up (dimensions are in mm)(fib Model Code 2010, 2013)

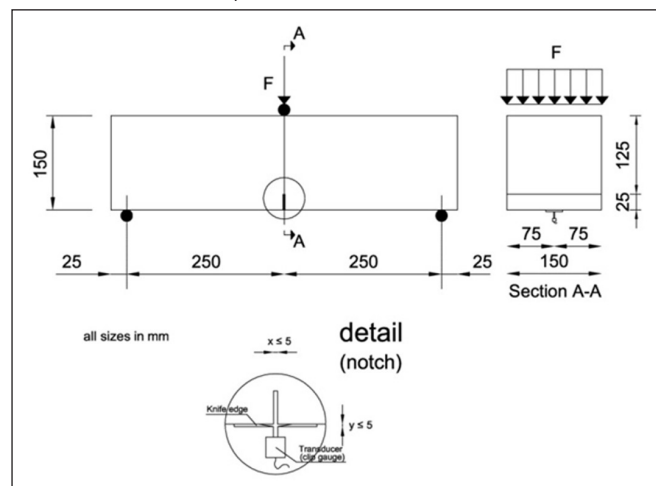


Fig. 5: Typical load/ deflection (stress/ strain) diagrams of fibre reinforced concrete (Cement and Concrete Association of New Zealand, 2009)

Several researchers tested the durability of FRC. Those showed that some types of fibres (different glass fibre types) could deteriorate in the concrete because of the high pH of concrete (Kopecskó, 2004). We have got only a few information about the influence of the mixing procedure on the properties of fibres.

Herein we studied how the 2 to 30 minute mixing of concrete influences the fibre properties of different fibre materials and fibre shapes. We tested the tensile strength of fibres and performed three-point bending tests on notched FRC beams according to EN 14651:2005+A1:2007.

FRC has residual flexural strength after cracking. The residual post-crack flexural strength of FRC depends on the fibre type and the fibre dosage. The post-cracking flexural strength of FRC beams can be even higher than the flexural strength caused by the cracking moment (Fig. 5).

3. EXPERIMENTAL PROGRAMME

We tested two types of steel fibres (a fibre without coating and another with brass-coating), three types of macro polymer fibres and two basalt fibres (with different lengths) (Tab. 1). (Macro polymer fibres are designated as polymer fibres with higher than 0.3 mm diameter (EN 14889-2:2006)).

During our tests similar mix composition (Tab. 2) and same consistence (flow class: F4) were used. Quartz aggregates ($d_{max}=16$ mm, fineness modulus = 5.6) were used for all mixtures. The particle size distribution curve of the aggregate is included in Czoboly and Balázs (2014). The fibre type, the fibre content (0,3V%, 0,5V%) and the quantity of superplasticizing admixture (Glenium C300) were different in the different mixtures. The fibres were added to the fresh concrete. The mixing process was done with forced type concrete mixer. After removing the specimens from the formwork they were stored in water for 7 days then kept at laboratory conditions until testing. 28 days old specimens were tested in three-point bending test.

We developed a procedure to isolate the fibres (even the fibre diameter is only a few μ m) from the fresh concrete without further deterioration, consequently we could test the fibre properties before and after mixing.

Table 1: Properties of tested fibres

	Material	Fibre length [mm]	Fibre diameter [μm]	Density [kg/m^3]	Tensile strength [N/mm^2]
S-1	Steel	50	1000	7850	1000-1200
S-2	Steel (Brass-coated)	12	200	~ 7850	3000
P-1	Polymer (Modified olefin)	48	~ 800	900-920	640
P-2	Polymer (Polyolefin)	50	500	910	510
P-3	Polymer (Polypropylene)	54	320	910	> 500
B-1	Basalt	12	13-20	~ 1900	
B-2	Basalt	24	13-20	~ 1900	

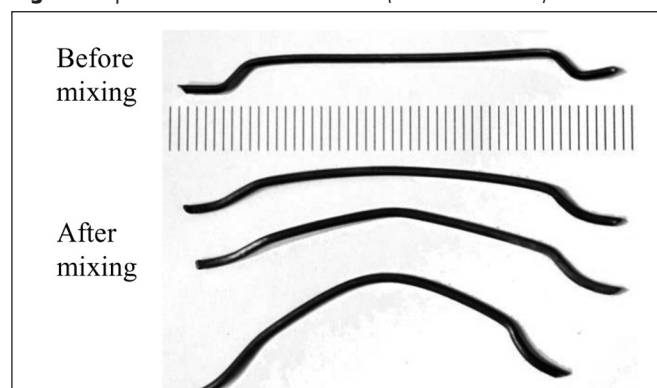
4. CHANGING OF FIBRE PROPERTIES DURING MIXING IN CONCRETE

Our laboratory tests indicated different changes of fibre properties for different fibres due to mixing. Different ways of mechanical deterioration was observed depending on the material, production technology, coating, size and surface of fibres. The mechanical deterioration methods depended mainly on the fibre material. We summarized the typical mechanical deterioration for different fibre materials in *Tab. 3*.

We did not experience significant change of properties of fibres in case of non-coated steel fibre (S1 fibre in *Tab. 1*) caused by mixing in concrete. Shape deformation was observed for some fibres during mixing (*Fig. 6*). The shape deformation probably does not significantly influence the properties of FRC. Abrasion of coating and also shape deformation were observed in case of coated fibres (S2 fibre in *Tab. 1*) during mixing.

The surfaces of macro polymer fibres were changed during the mixing (P1, P2 and P3 fibres in *Tab. 1*). The surface pattern of the polymer fibres abraded and the surface started to nap during mixing (*Fig. 7*). The nap of surface was increased as mixing time increases. The nap of surface was observed in all macro polymer fibres which were tested. The degree of the nap of surface depended on the material of fibre, the diameter and the surface of the fibre. The abraded fibre materials were isolated from the fresh concrete (*Fig. 8*).

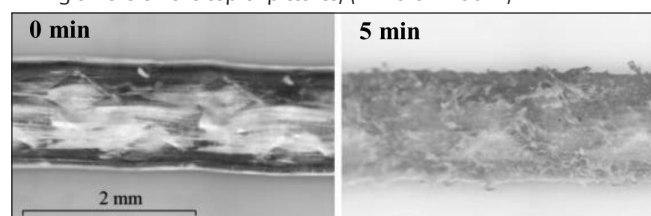
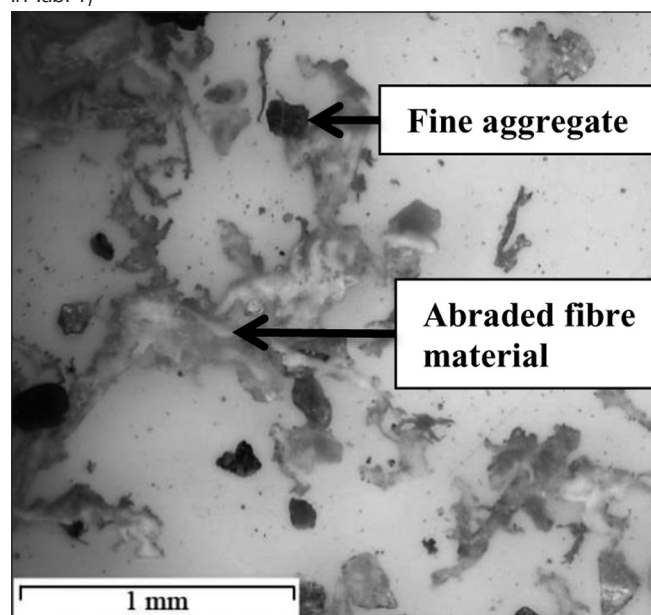
Some typical mechanical deterioration modes can be seen in *Fig. 9*. These deterioration modes were observed already after 2 minutes long mixing of concrete and the number of deteriorated fibres increased as mixing time increases.

Fig. 6: Shape deformation of steel fibres (S1 fibre in *Tab. 1*)**Table 2:** Concrete composition

Material	Type	Mass [kg/m^3]	Volume [litre/m^3]
Aggregate	0/4 mm fraction	45%	824
	4/8 mm fraction	55%	1008
	Σ	100%	1832
Cement	CEM I 42,5 N	380	123
Fibre	...	...	...
Water	$m_w/m_c =$	43,0%	163
Admixture cem. m%		0,70%	2,66
Air			15

The slurry was stuck on the napped surface of the fibre and some aggregate penetrated into the fibre (*Fig. 10*). The density of some fibres increased during the mixing of concrete. The macro polymer fibres floated on the water before mixing (density of fibre was cca. 890 kg/m^3) and some fibre sunk in the water after mixing (density of these fibres was more than 1000 kg/m^3) (*Fig. 11*).

The fibres were added to fresh concrete. The mixing times were measured from the moment of addition of fibres. Samples were removed from the fresh concrete after 5 and 30 minutes. The fibres were isolated from the fresh concrete. Tensile tests were carried out on the P2 type (in *Tab. 1*) fibres without mixing, after 5 minutes mixing and 30 minutes mixing in concrete. The tensile tests were carried out on 30 pieces of fibres per mixing times (0 min, 5 min and 30 min) with

Fig. 7: Abrasion of surface pattern of the macro polymer fibre (the mixing time is on the top of pictures) (P1 fibre in *Tab. 1*)**Fig. 8:** Microscope picture about the abraded fibre material (P2 fibre in *Tab. 1*)

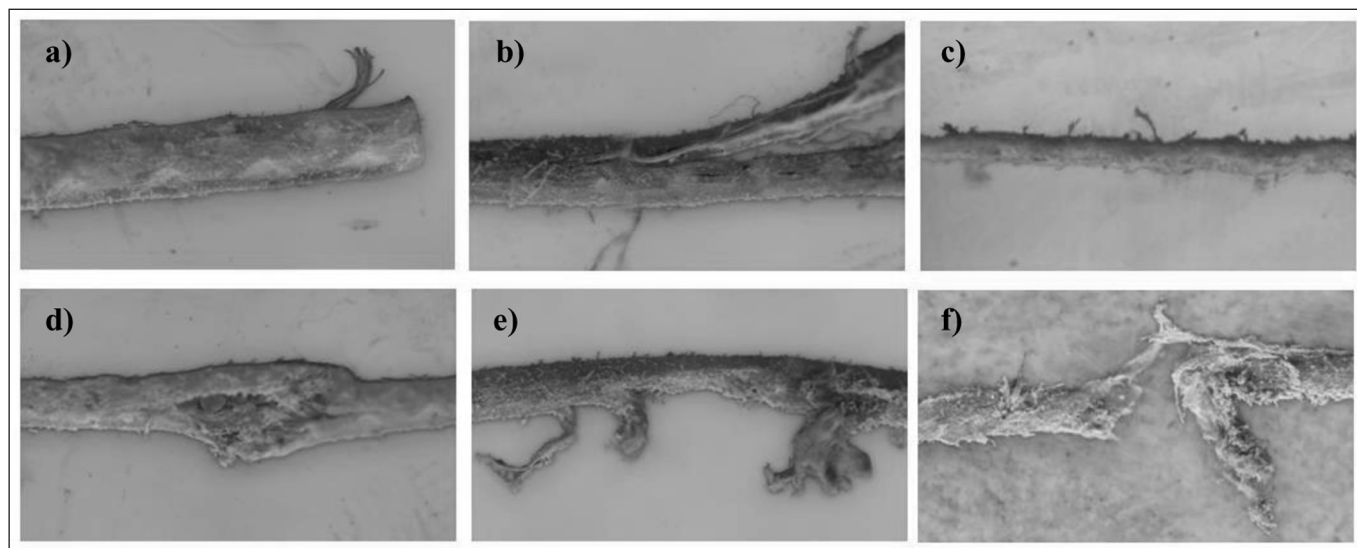


Fig. 9: Mechanical deterioration of polymer fibres (P1 fibre in Tab. 1)
a) disintegration of fibre end, b) opening of fibre end, c) splitting of fibre, d) bruise of fibre, e) notch in fibre, f) shortening of fibre length

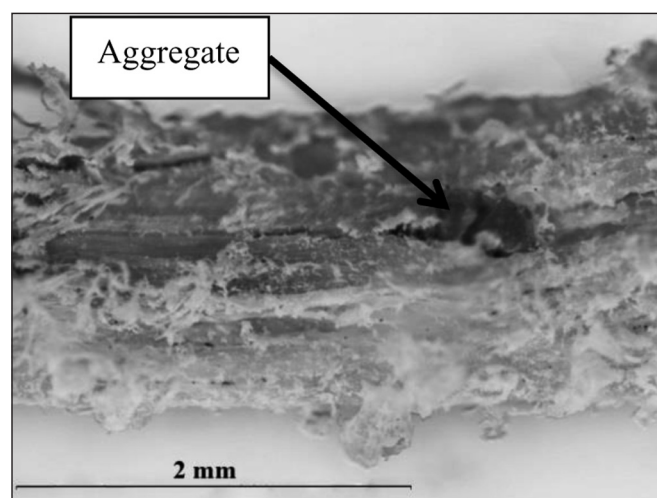


Fig. 10: Aggregate penetration into the fibre during mixing in concrete (P1 fibre in Tab. 1)

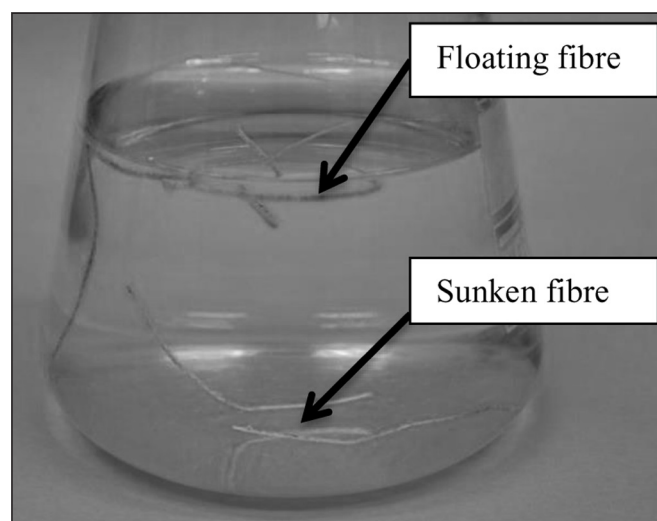


Fig. 11: Behaviour of macro polymer fibres in water after mixing in concrete (P1 fibre in Tab. 1)

10 mm/min loading rate according to *EN 14889-2:2006* standard. The results of tensile tests can be seen in *Fig. 12*. The thick lines show the 2nd order fitting curve to the average of the results of 30 pieces of fibres. Mixing time increased scatter of results as indicated in *Fig. 12*.

The tensile forces of the macro polymers fibres (P1 fibre in *Tab. 1*) decreased as the mixing time increases. In *Fig. 12*

Table 3: Possible mechanical deterioration of fibres influenced by mixing in concrete

Fibre type	Type of fibre deterioration		See
Steel fibre	deformation of shape		Fig. 6
	abrasion of coating (if exist)		
Macro polymer fibre	abrasion	abrasion of surface pattern	Fig. 7
		abrasion of fibre material	Fig. 8
		nap of surface	Fig. 10
	deterioration starting from the end of fibre	disintegration of fibre end	Fig. 9/a
		opening of fibre end	Fig. 9/b
		longitudinal splitting of fibre	Fig. 9/c
	destruction of fibre	local damage of fibre	Fig. 9/d
		opening of fibre in its middle portion	
		notch in fibre	Fig. 9/e
		shortening of fibre length	Fig. 9/f
	aggregate penetration into the fibre		Fig. 10
Mono basalt fibre	shortening of fibre length		Fig. 14

it can be seen that the deviation of the Force vs. Strain curves increased as the mixing time increases. The inclination of the curves decreased as the mixing time increases. The decrease of the inclination of the curves might be explained by the abrasion of fibre material, and also by the smaller diameter of the fibres and by the different type of mechanical deterioration of the fibres.

We observed that the mechanical deterioration of the fibres and the decrease of tensile forces of the fibres significantly depend on the properties of the applied fibres (material, tensile strength, surface characteristics, shape and size of fibres). The mechanical deterioration of the fibres might be explained also by the properties of fresh concrete (grain of aggregate, ratio of fraction of aggregate, density of aggregate, consistence of fresh concrete), mixing method, abrasion of mixing paddles, mixed volume, adding moment of fibres (to fresh concrete or to dry components).

Three-point bending tests were made on notched FRC

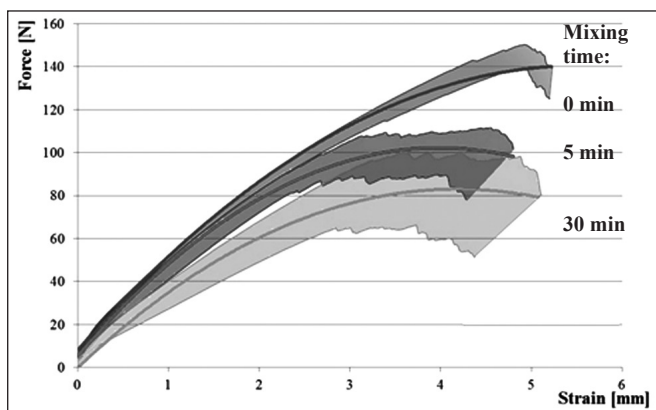


Fig. 12: Average and distribution of Force vs. Strain diagram of tensile test of P2 fibres (in Tab. 1) without mixing, after 5 min and 30 min mixing in concrete (The tensile tests were made on 30 pieces of fibres for each mixing times (0 min, 5 min and 30 min) with 10 mm/min loading rate.)

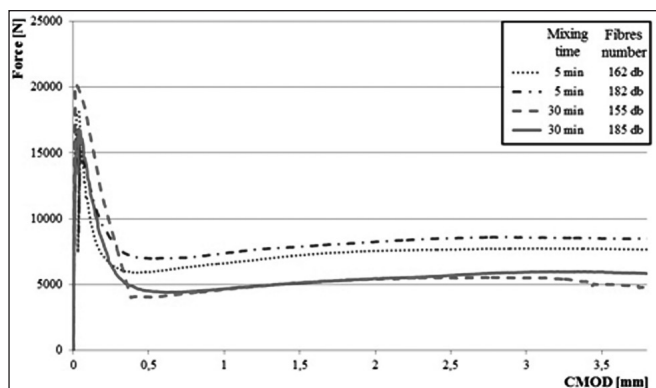


Fig. 13: Force-CMOD curves of Three-point bending tests of FRC beams with P2 fibres (in Tab. 1), (each curve shows a measurement, the number of fibres was counted in the cracked cross-section)

beams according to *EN 14651:2005+A1:2007*. In Fig. 13 can be seen the results of three-point bending tests of FRC beams with the P2 sing fibres (in Tab. 1). The post-cracking flexural forces of FRC beams decreased by the longer mixing times (for same fibres numbers). The decreasing of the post-cracking flexural forces might be explained by the decrease of tensile forces of fibres in case of longer mixing times.

We also tested the mechanical deterioration of mono basalt fibres. The shortening of fibre length of mono basalt fibres (B1 and B2 fibres in Tab. 1) were observed after mixing (Fig. 14).

The fibres were isolated from the fresh concrete after 5, 10, 15 and 20 minutes mixing times. The lengths of fibres were measured on pictures taken by digital microscope. In Fig 15, the mean length of fibres can be seen of different mixing times in concrete. (Each value is the average of 100 measurements.) Fig. 15 indicates that the mean value of fibre length decreased as the mixing time increased. The intensity of decrease of mean fibre length was higher in the first 5 minutes

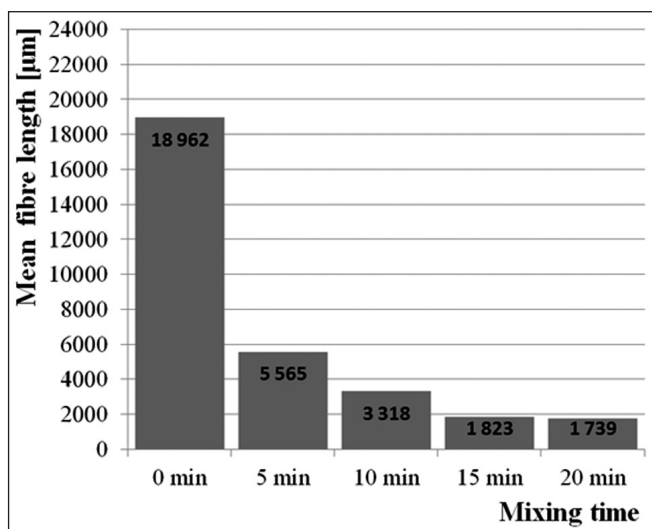


Fig. 15: Mean fibre length of mono basalt fibres (B2 fibre in Tab. 1) without mixing and 5, 10, 15, 20 min mixing in concrete (Each value is an average of 100 measurements.)

than later. The intensity of the decrease of mean fibre length continuously decreased until 20 minutes mixing time.

5. CONCLUSIONS

Main purpose of our experimental study was to determine the effect of mixing time (2 min to 30 min) on the properties of fibres FRC, respectively. We tested two types of steel fibres (one without coating, and another with brass-coating), three type macro polymer fibres and two basalt fibres (having different lengths).

A procedure was developed to isolate the fibres (even if the fibre diameter is only a few µm) from the fresh concrete without further deterioration. We tested the fibre properties both before and after mixing.

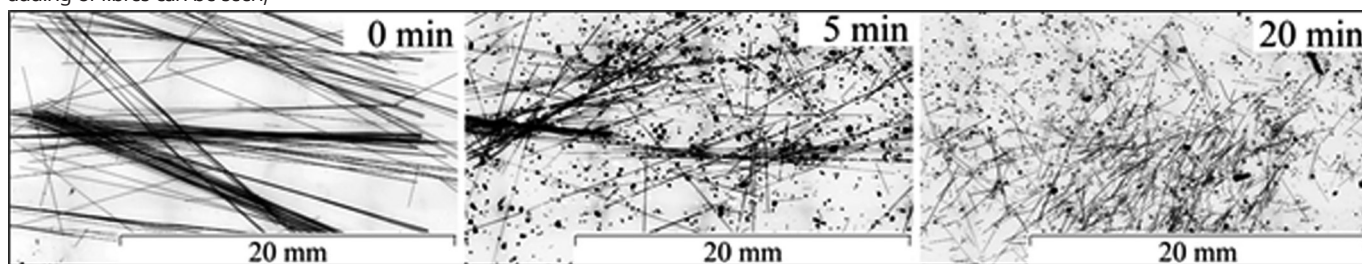
According to the results of our experimental study some of the fibres were deteriorated during mixing in concrete. The type of deterioration and the degree of deterioration significantly depended on the material, production technology, coating, size and surface of fibres. Typical deterioration types of the tested fibres were summarized in our article.

Shape deformation was observed in case of some steel fibres during mixing. This shape deformation probably does not influence significantly the properties of FRC. Abrasion of coating and also shape deformation were observed for coated fibres during mixing.

In case of the macro polymer fibres abrasion, deterioration that started from the end of fibres and destruction of fibres occurred.

The tensile forces of the tested macro polymers fibres decreased as the mixing time increased. The deviation of the Force-Strain curves increased as the mixing time increased.

Fig. 14: Shortening of fibre length of mono basalt fibres (B2 fibre in Tab. 1) during mixing in concrete (at the top of the pictures mixing time after the adding of fibres can be seen)



The steepness of the curves decreased as the mixing time increased. The decrease of the steepness of the curves might be explained by the abrasion of fibre material, by the smaller diameter of the fibres and by the different type of mechanical deterioration of the fibres.

The post-cracking flexural forces of FRC beams decreased as the mixing times increased (for same fibre type and fibre numbers). The decrease of the post-cracking flexural forces might be explained by the decrease of tensile forces of fibres in case of longer mixing times.

Shortening of mono basalt fibres were observed after mixing in concrete. The fibre length decreased as the mixing time increased.

Type and degree of mechanical deterioration of the examined fibres were different for the same mixture and mixing time because the fibres had different impact at different locations in the concrete. Some fibres spent longer time near the mixing paddles and the others contacted only with the aggregates. Sometimes the degree of mechanical deterioration of fibres was different along the fibre length.

Mechanical deterioration of fibres also can be seen after 2 minutes, but the degree of deterioration and the number of deteriorated fibres increased as the mixing time increased.

7. ACKNOWLEDGEMENT

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