Vol. 9, No 1/2020, 47-54

DOI: 10.17512/bozpe.2020.1.05

Construction of optimized energy potential
Budownictwo o zoptymalizowanym potencjale energetycznym

ISSN 2299-8535 e-ISSN 2544-963X

Influence of maturing conditions of steel-fibre reinforced concrete on its selected parameters

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Abstract: In the article the impact of varying humidity conditions on selected strength properties of hardened steel fibre-reinforced concrete (such as Young's modulus and the compressive strength of concrete) were analysed. The analysis shows that the value of the Young's modulus of concrete cured under 100% humidity conditions is the highest; 35% higher compared to concrete hardening in the laboratory hall and about 18% higher than modulus measured in the concrete samples maturing in the chamber. A much higher compressive strength of approx. 25% was observed in samples hardening under 100% humidity conditions than in the other two environments. It was also observed that the non-uniform distribution of samples in the chamber and opening and closing the chamber during sample maturation had an impact on the dispersion of the results and due to the coefficient of variation, results can be even worse than in free-maturing samples.

Keywords: concrete, steel-fibre, fibre-reinforced concrete, compressive strength, Young's modulus

Please, quote this article as follows:

Czajkowska A., Raczkiewicz W., Bacharz M., Bacharz K., Influence of maturing conditions of steel--fibre reinforced concrete on its selected parameters, BoZPE, Vol. 9, No 1/2020, 47-54, DOI: 10.17512/bozpe.2020.1.05

Introduction

„The idea of sustainable development rely on using methods to meet our present needs without depriving future generations of the ability to meet their own needs" (Schimidheiny, 1992; Czajkowska et al., 2017; Guo et al., 2013). Therefore, the main purpose of the Sustainable Engineering Initiative (SEI) is the search and

implementation of new building materials and modern technologies, which not only meet the current standard requirements resulting from their use, but also generate the lowest possible cost of designing, constructing and operating of building objects with simultaneous care for environmental protection now and during their lifetime. Involved in the above processes should be everyone, starting from the state as legislator, researchers, designers, manufacturers and contractors (from the construction industry) to the users. One of the factors meeting the above requirements in reinforced concrete structures is the use of environmentally friendly materials (including admixtures and additives) which, among others, improve concrete strength parameters and thereby the durability of buildings, thus extending their lifetime without costly repairs and renovations.

One way to improve the strength parameters of concrete is to add various types of randomly dispersed microfibres to the concrete mix (Brandt, 2008; Glinicki 2010). Steel fibres are most often used due to good parameters and at the same time relatively low cost of their application. These fibres are available on the market in various shapes (straight, twisted, with hooked tips) and sizes (of varying fibre length and diameter) depending on the intended use in the structure. the fibre addition should not be less than 0.25% (by volume) per 1 m^3 of concrete to improve the performance of the concrete mix. It is possible to add a maximum of 2.5% of fibre to the concrete mix, however, as the amount of fibre increases, the workability of the mix decreases. Therefore, in each case of using fibres for concrete, it is also necessary to use plasticizers or superplasticizers, which, if too much fibre is used, can significantly increase the cost of the mixture. The main purpose of adding fibres is not only to increase the strength and mechanical properties of concrete (Lee et. al., 2003; Song et. al., 2004; Raczkiewicz et. al., 2018), but also to increase its consistency and homogeneity. Steel fibres "consolidate" the concrete matrix and prevent the formation of large pores in the concrete mix and limit the formation and development of shrinkage cracks arising during the setting and hardening of concrete, as well as cracks resulting from mechanical loads (Brandt, 2008; Glinicki, 2010). Thus, micro-reinforcement fibres "seal" concrete cover (Glinicki, 2010), which affects both the increase of concrete strength and the inhibition of corrosion processes and increase the durability of structural elements.

The article describes the tests carried out on fibre-reinforced concrete samples, in which steel fibres in the amount of 0.25% (by volume) per 1 m^3 of concrete mix were used. The impact of variable maturing conditions on selected strength properties of hardened fibre-reinforced concrete was analysed.

Twelve fibre-reinforced concrete samples maturing at 20±2°C constant temperature varied by ambient humidity were tested.

1. Purpose and subject of the research

The purpose of the research was to analyse the impact of concrete maturation conditions on its selected strength properties, i.e. Young modulus and the compressive strength of concrete. To achieve the set purpose, 12 concrete samples were prepared in the form of 150 x 300 mm cylinders according to the recipe in Table 1. It was examined how the values of Young's modulus and the compressive strength of concrete changed depending on its curing conditions.

Table 1. The recipe of the fibre-reinforced concrete (*own study*)

BS-0.25 – Concrete according to the base recipe + steel fibres 0.25%	
	[kg/m^3]
Cement 42.5 N MSR NA	384
Fine aggregate 0-2	680
Basalt aggregate 2-8	600
Basalt aggregate 8-16	650
Water	166
Plasticizer 0.5%/kg of cement	1.92
Aerator 0.2%/kg of cement	0.768
Steel fibres 0.25%/1 m^3 concrete mixture	19.65

2. Research methodology

The research was based on the guidelines contained in (Brunarski, 1998; Nagrodzka-Godycka, 1999; PN-EN 12390-1:200; PN-EN 12390-2:2001).
Compressive strength tests were carried out using the Zwick/Roell testing machine type SP-Z6000 with software in accordance with the requirements of the standard (PN-EN 12390-2:2001; PN-EN 12390-4:2001).

This machine consists of a hydraulic aggregate, load frame as well as measuring and control electronics. The destructive force is measured using a liquid pressure sensor and is recorded electronically. The maximum test force that can be achieved in the compression direction is 6000 kN (Michałowska-Maziejuk et al., 2018). During the test, the load increased steadily, without sudden surges of force at a speed of 0.5 MPa/s. The destructive force for each sample was saved automatically in the testXpert program controlling the machine.

The elements matured under constant temperature conditions of 20±2°C, differentiated by ambient humidity:

– 4 samples with the symbol H matured in the laboratory hall, where there were naturally variable humidity conditions (in the range of 20-40%) associated with its continuous use,
– 4 samples with the symbol K – matured in a thermal chamber in the humidity range 60-80%,
– 4 samples with the W symbol were cured in water (100% humidity) for 28 days in accordance to standard conditions [PN-EN 12390-2].

Relative humidity of the tested elements shown in Figure 1.

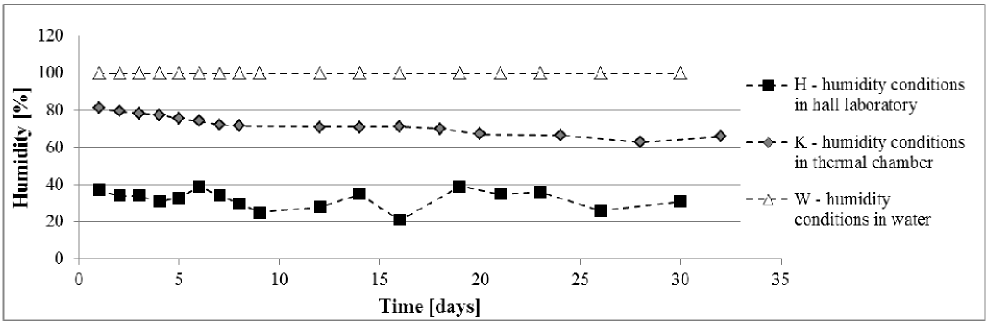

Fig. 1. Graph of relative humidity measured during the tests (*own study*)

The deformation was measured using an extensometer with a measuring base length of 120 mm, at 3 equal intervals around the cylinder surface. Before the test the specimen surfaces subjected to compression were plane and smooth. Then the individual samples were placed axially in the testing machine and loaded. The program of loading was based on 5 forming cycles and 1 main cycle. Loading and unloading was carried out at a rate of 2.5 MPa/s. Upper stress was 18.5 MPa, and the basic stress was 1.5 MPa. The extensometers, mounted before the tests, measured automatically strains and sent results to the testXpert computer program, which collected a ready result of the modulus of elasticity according to (DIN1048) (Fig. 2).

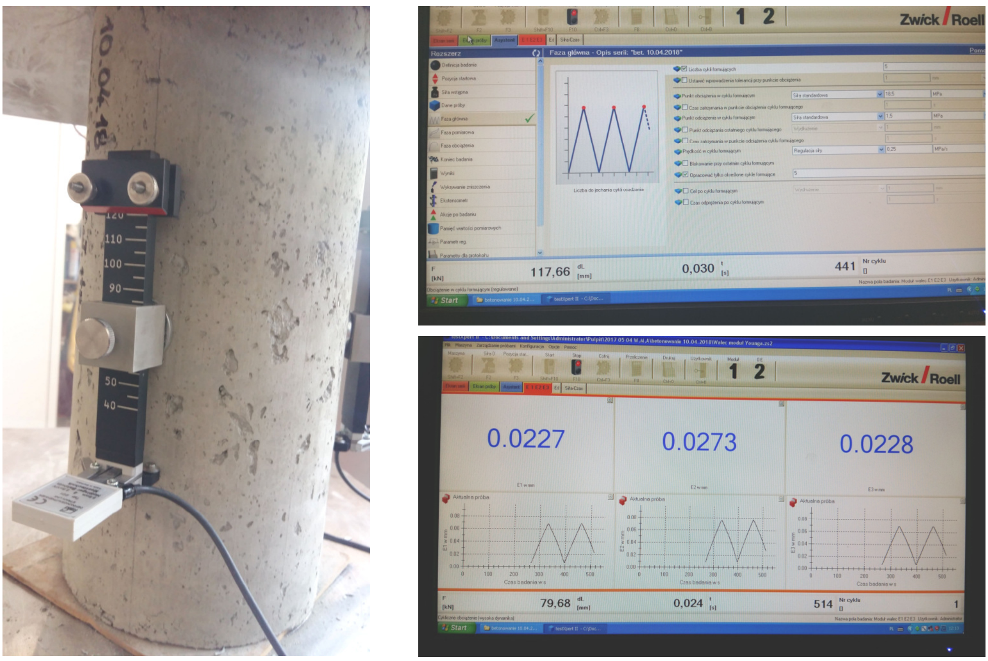

Fig. 2. Sample (150x300 mm) during the test and the screenshots (from testXpert program) of the results from the Young's module measurement (*own study*)

3. Research results and their analysis

The results for the twelve samples of the Young's modulus measurements are presented in Table 2, while the results regarding the measurement of compressive strength are presented in Table 3.

Table 2. Young's module measurements for the tested specimens (*own study*)

Maturation conditions	Specimen	Young's Modulus [GPa]	Average value [GPa]	Standard deviation	Coefficient of variation [%]
H – laboratory hall	$H_1$0.25	33.5	32.96	0.59	1.78
	$H_2$0.25	32.89			
	$H_3$0.25	33.41			
	$H_4$0.25	32.02			
K – thermal chamber	$K_1$0.25	38.85	37.74	0.85	2.25
	$K_2$0.25	36.46			
	$K_3$0.25	37.87			
	$K_4$0.25	37.78			
W – conditions according to PN-EN 12390-2	$W_1$0.25	45.46	44.71	0.64	1.44
	$W_2$0.25	43.78			
	$W_3$0.25	44.46			
	$W_4$0.25	45.12			

The analysis shows that the value of Young's modulus was the highest for samples (W) maturing in the environment according to standard (PN-EN 12390-2) which was to be expected. It was in the range of 43.78-45.46 GPa and averaged 44.71 MPa. The average Young's modulus of samples (K) stored in the thermal chamber was on average 37.74 GPa and was higher on average by 4.78 GPa compared to samples (H) stored in the laboratory hall. It is surprising, however, to compare the values of the coefficient of variation, which show that the most varied results were obtained for samples hardened in a thermal chamber (2.25%) (Table 2). The dispersion of results could be caused by the fact that other samples, which were extracted and tested separately each day, were also stored in the chamber. Also, most likely, the non-uniform distribution of samples in the chamber (closer and further away from the door) had an impact on the dispersion of results.
Similar compressive strength values of samples maturing in the hall (average value – 43.77 MPa) and in the chamber (average value – 43.22 MPa) was noted. As one would expect for samples cured in water (W) a higher strength was observed compared to the previous two environments (H, K) by about 25%.

This state is caused by humidity, which was the highest under standard conditions (100%). In the chamber, the samples were closed and released moisture to the environment, hence the humidity in the chamber, even at a constant temperature, decreased over the time. However, in the laboratory hall, the samples dried freely, the hall was ventilated and operated naturally. The temperature in these 3 environments was similar.

Table 3. Compressive strength results measured in the samples (*own study*)

Storage conditions	Compressive strength [MPa]	Average value [MPa]	Standard deviation	Coefficient of variation [%]
H – laboratory hall	43.35	43.77	0.41	0.94
	44.27			
	43.37			
	44.07			
K – thermal chamber	43.20	43.22	0.49	1.12
	42.90			
	42.77			
	44.02			
W – conditions according to PN-EN 12390-2	54.29	54.07	0.15	0.27
	54.06			
	53.88			
	54.03			

Also, the values of the coefficient of variation indicate the samples cured in water had the highest (homogeneous) compressive strength values; the coefficient of variation for specimens cured in water was the lowest – 0.27%. However, the worst, due to the coefficient of variation, were the samples hardened in the chamber (1.12% was their coefficient of variation). The thermal chamber ensured constant thermal conditions, but the unstable – falling below 95% – humidity significantly affects the deterioration of strength parameters of hardened fibre-reinforced concrete. And due to the coefficient of variation, results can be even worse than in free-maturing samples.

The percentage value of increase or decrease of the Young's modulus (longitudinal modulus of elasticity) and compressive strength for individual environments (W, K, H) is presented in Figure 3.

The analysis shows that the value of the Young's modulus of concrete samples maturing under standard conditions is 35% higher than those stored in the hall (Fig. 3, W/H ratio). The value of the elastic modulus of concrete matured under standard conditions is about 18% higher than those matured in the chamber. A 14% higher value of Young's modulus was observed in the concrete samples maturing in the chamber compared to those from the laboratory hall.

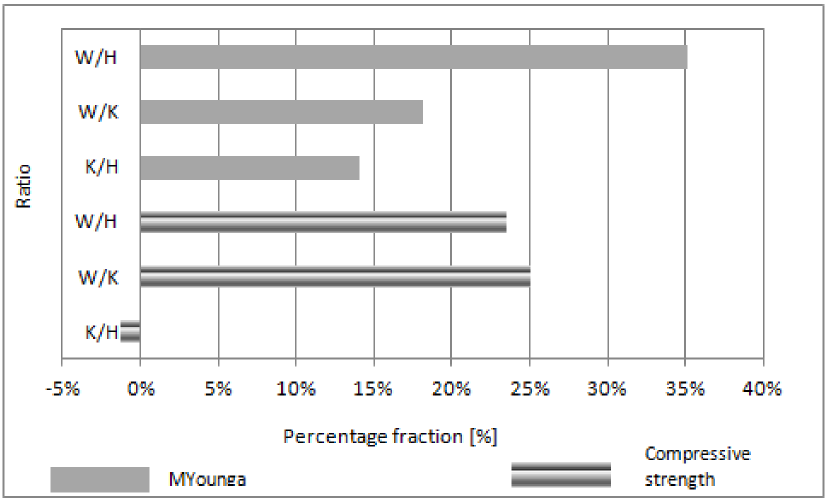

Fig. 3. Compressive strength of concrete depending on its curing conditions (*own study*)

The analysis shows that the value of compressive strength determined on samples maturing under standard conditions was higher in comparison to those from the hall and from the chamber (by 23 and 25%, respectively). The difference in strength values of samples maturing in the hall as well as in the chamber was insignificant (approx. 2%).

Conclusions

The analysis of the research shows that the conditions of concrete maturation largely determine the value of Young's modulus. Its value is the highest for samples maturing in water and the lowest for samples maturing in the lowest humidity range in the laboratory hall. The higher the ambient humidity, the higher the Young's modulus value.

The analysis also shows that the difference in ambient humidity within 20-40% when it was not approaching the standard values (above 95%) did not significantly affect the compressive strength values. A much higher compressive strength by approx. 25% was observed in the case of samples maturing under standard conditions (100% humidity), which is related to the proper course of the cement hydration and the elimination of autogenic and drying shrinkage, the consequence of which are internal defects reducing the concrete strength.

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