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Long-term Study on Fibre Reinforced Fine Aggregate Concrete Beams Based on Waste Sand

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1. Introduction

Continuously enlarging waste sand dumps in northern Poland (Fig. 1) cause more and more interest of various communities (entrepreneurs, ecologists and scientists).

Fig. 1. Waste sand dump – northern Poland
Rys. 1. Hałda piasku odpadowego – północna część Polski

The solution that would please them all is to use these dumps for industrial production. For a few decades there has been carried out research on application of waste sand as a basic component of a concrete mix [15, 19]. Application of sand being a residue from aggregate hydroclasification is rather marginal and mainly involves production of industrial floors. [13]. There has also been conducted continual research on how to use waste sand for statically or/and dynamically loaded structure elements [4, 5, 21, 22]. Equally relevant, or maybe the most important, is study on using waste sand for long-term loaded elements. Such loads reflect real conditions in which the elements work in a structure. Also particularly important is long-term research on structure elements in which are used atypical components of a concrete mix. This is why in this article the author presents study on fine aggregate concrete beams containing steel fibres, which are long-term loaded in conditions of constant humidity and temperature.

2. Used Materials and Mix Proportions

Basic component of the fine aggregate concrete mix in the research programme was waste sand from aggregate mine located in Sępólno Wielkie (region of west Pomerania). This sand does not meet the standards of norms EN 206-1 [7] and EN 12620 [10] in relation to aggregate for plain concretes. Figure 2 presents grading curve of harnessed waste sand in comparison with grading curves obtained by other researches. Sand used in this study (Fig. 2) has shown to have the best granulometric properties. Fineness modulus and median grain was the best from presented curves and respectively amounted to: 98.4 % and 0.57 mm.

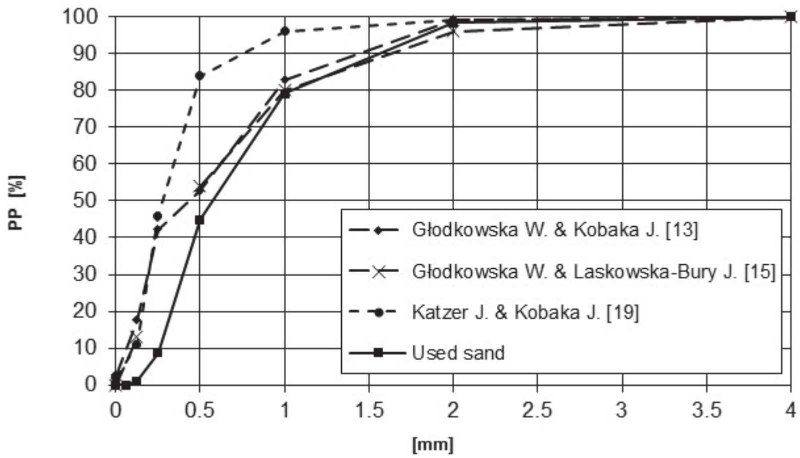

Fig. 2. Grading curve of harnessed waste sand
Rys. 2. Krzywa uziarnienia zastosowanego piasku odpadowego

Another component of the concrete mix was the Portland cement CEM II/B-V 32.5 R, which after 28 days reached 40.8 MPa strength and met the requirements of EN 197-1 [6]. According to EN 1008 [9] the author used drinking water. In order to obtain required consistence in compliance with ACI [1] the author also applied superplasticizer FM 34. Last components of the concrete mix were hooked steel fibres characterized by diameter 0.55 and 0.8 mm or length 30 and 50 mm (accordingly to EN 14889-1 [11]). The fibres were protected against corrosion and were produced using cutting method (analyzed in [2]). Properties of used fibres are presented in paper [18]. Final composition of fine aggregate concrete mix containing steel fibres is presented in Table 1.

Table 1. Mix proportions of one cubic meter
Tabela 1. Proporcje składników mieszanki na 1 m^3

Concrete / Series	Components					
	Sand [kg]	Cement [kg]	Water [dm^3]	FM 34 [dm^3]	Steel fibres [kg]	
					30/0.55	50/0.8
B9	1835	374	150	3,47	–	33
B10	1855	378	140	3,51	34	–

Additionally, in some specimens the author used ribbed reinforcement steel bars (ϕ 8 and 10 mm) made from steel 34GS and smooth reinforcing steel bars (ϕ 4.5 mm) made from steel St3SX-b.

3. Curing and Casting

The specimens were produced in series (in autumn- winter season in a room of approximately 25°C temperature) maintaining equal technological regime. There were two series of specimens produced (B9 and B10), which differ in terms of used steel fibres. Each series of specimens consists of a beam (150×200×3300 mm), a cylinder (150×300 mm) and 9 cubes (150×150×150 mm). In beam elements the author used longitudinal reinforcement (in tension zone: 3#10 mm; in compression zone 2#8 mm) and transverse reinforcement in the form of bars (diameter of 4.5 mm), placed every 13 cm (Fig. 3).

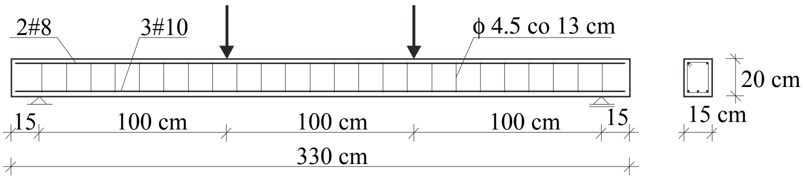

Fig. 3. Beam geometry and location of reinforced steel bars
Rys. 3. Geometria belek i rozmieszczenie prętów zbrojeniowych

For the first 24 hours (until the moment of demolding) and next six days the specimens ripen in the conditions of increased humidity, i.e. tightly covered with foil. After these seven days of growing, the specimens were transported to an air-conditioned room, where they were kept until the end of the study. The conditions in the room were as follows: temperature of 20 ± 2°C; humidity at 50 ± 3%. Humidity and temperature measurement was taken using EBI-2 register, programmed to record every 30 minutes.

4. Methodology and Programme of Research

The tests on small sized elements (cylinders and cubes) were conducted in accordance with valid norms and recommendations. Concrete compression strength, concrete tension strength during splitting and modulus of elasticity were tested after 28 days of curing. The shrinkage phenomenon was recorded from the moment of demolding cylinders until the end of studies. Creep analysis started after 28 days from the moment of making the specimens (cylinders) and lasted for over a year. In Fig. 4 there are presented small sized specimens from B9 series.

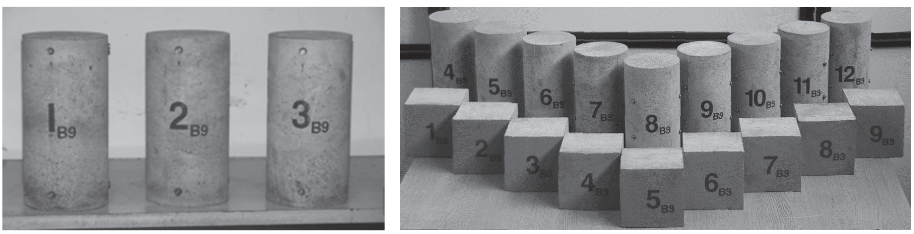

Fig. 4. Small-sized specimen elements of B9 series
Rys. 4. Drobnowymiarowe elementy próbne serii B9

The work-stand, where long-term tests on beam elements were conducted, consisted of steel channel sections along with lever system attached (Fig. 5). Static scheme for the analyzed elements is a single-span beam loaded with two concentrated forces imposed in one third of a span between the axes of supports. There were situated two supports on a stand: a roller support and a pinned support. The forces were imposed by a steel beam loaded with compound lever with disc weights. The weight of loads was chosen precisely so that during the study the bending moment for both beams would be on a level of 6 kN·m.

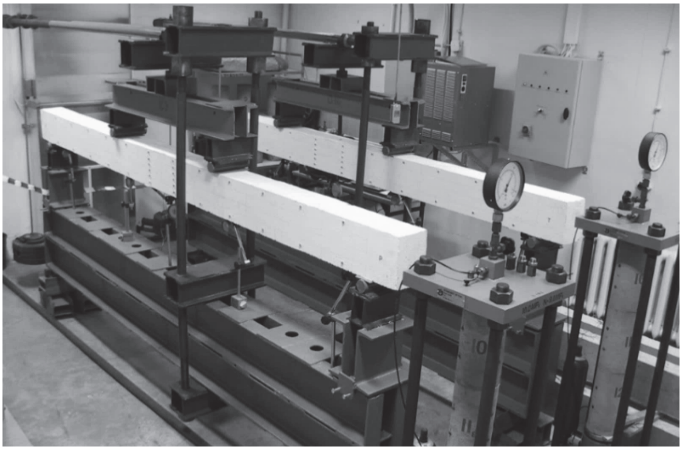

Fig. 5. The work-stand for long term research (beams and cylinders)
Rys. 5. Stanowiska do badań długotrwałych (belek i walców)

Measurement of beam vertical displacement (deflection) was conducted on its lower surface in 5 places (in the span center of beams, in the place of application of concentrated forces and at the distance of 100 mm from the axes of support) using dial gauges of a 500 and 100 mm range and of 0.01 mm accuracy (Fig. 5).

Crack widths measurement was done using a microscope of 0.02 mm accuracy with 36- fold enlargement.

Readings of long-term properties of researched elements were taken in the following days: 0 (day of loading) 3, 7, 14, 28, 56, 90, 120, 150, 180, 210, 240, 270, 300, 330 and 365.

5. Results and Discussion

The results of strength properties of composites in question were determined on cylinders and cubes specimens after 28 and 365 days of curing, and are presented in table 2. Comparing both analyzed specimens series, there is a significant difference in strength, what is most likely caused by the size of used steel fibres and their special distribution in the elements [14, 21]. Moreover, in series B10 larger amount of shorter fibres was used, what certainly had an impact on the obtained values.

Table 2. Strength properties of analyzed composites with fibres
Tabela 2. Cechy wytrzymałościowe badanych fibrokompozytów

Concrete / Series	Certain material properties					
	$f_{cm,28}$ [MPa]	$f_{c,cube,28}$ [MPa]	$f_{ct,sp,28}$ [MPa]	$E_{cm,28}$ [GPa]	$f_{cm,365}$ [MPa]	$E_{cm,365}$ [GPa]
B9	31.0	39.5	3.6	29.3	38.0	30.1
B10	45.8	46.3	4.3	29.4	49.6	31.7

The results of the rheological strains determined on cylindrical samples are presented in fig. 6 and 7.

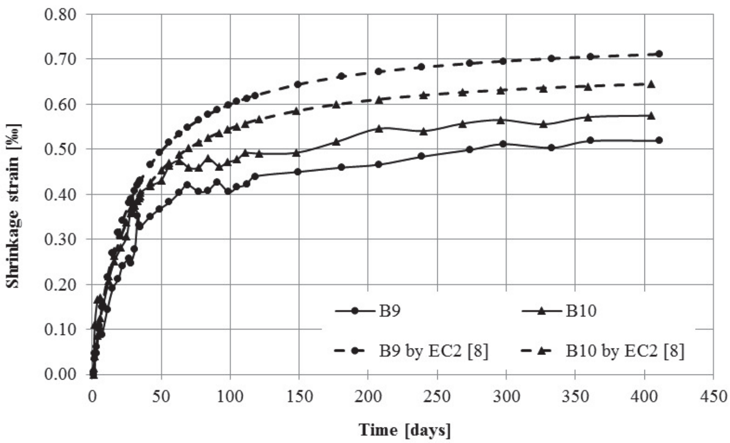

Fig. 6. Shrinkage strains measured and calculated in accordance with EC2 [8]
Rys. 6. Odkształcenia skurczowe pomierzone i obliczone wg EC2 [8]

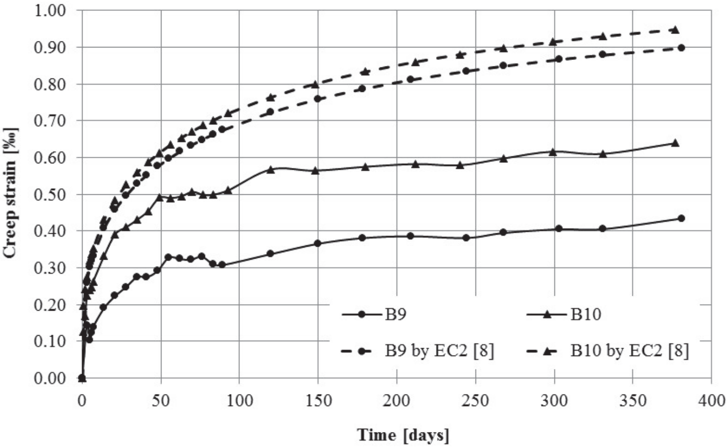

Fig. 7. Creep strains reduced by the value of shrinkage strain, calculated in accordance with EC2 [8].
Rys. 7. Odkształcenia pełzania, skorygowane (pomniejszone) o wartość odkształceń skurczowych oraz obliczone wg EC2 [8]

Additionally, in these graphs the author presents curves calculated according to EC2 [8], with regard to the strength qualities of analyzed composites with fibres. Both shrinkage and creep strains defined by EC2 [8] highly differ from values obtained from the tests. It confirms that adding steel fibres to the concrete mix reduces the level of shrinkage and creep strains [13, 23]. These differences are also caused by maladjustment of the normalization methodology to fine aggregate concrete containing steel fibres. The values of creep coefficient for both composites, which were obtained from the study, amount to 1.19 and 1.31 (respectively for B9 and B10 series). The average of these values is twice as low than calculated according to EC2 [8].

The analysis of serviceability limit state (i.e. deflection and cracking), induced by a long-term load, was conducted using beams measuring 150×200×3300 mm. In fig. 8 and 9 there is presented an increase in the value of beam deflection (B9 and B10) from day "0" to day 365. Comparing the results obtained from the study it is clear that differences between beam deflections are yet visible on the day of the load and last until the day 365 (B9 – 5,27 mm, B10 – 4,21 mm). The relation between deflections results obtained from the study and calculated according to EC2 [8] has shown large differences. The deflection rate calculated according to EC2 is higher approximately by 35%. This could be caused by the fact that calculation method applied accordingly to EC2 [8] is not adopted to the analyzed fine aggregate concrete beams containing steel fibres [3, 23].

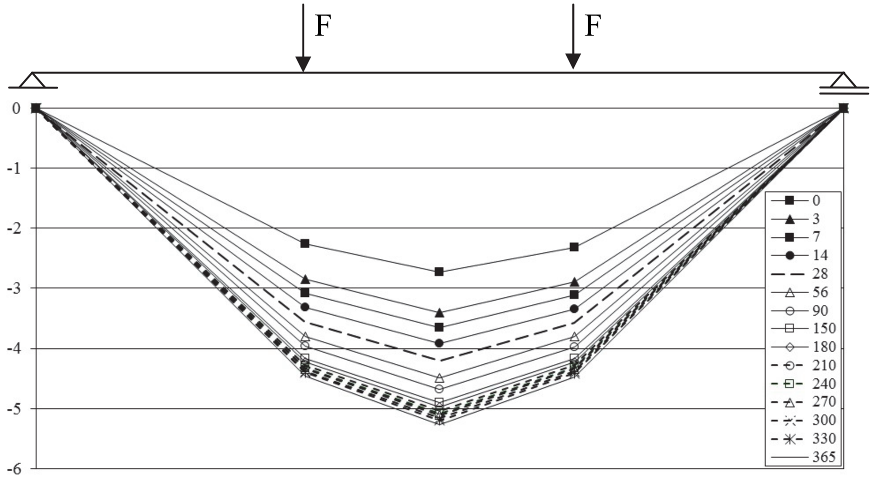

Fig. 8. Deflection of B9 beam [mm] during the time of load
Rys. 8. Ugięcie [mm] belki B9 w kolejnych dniach obciążenia

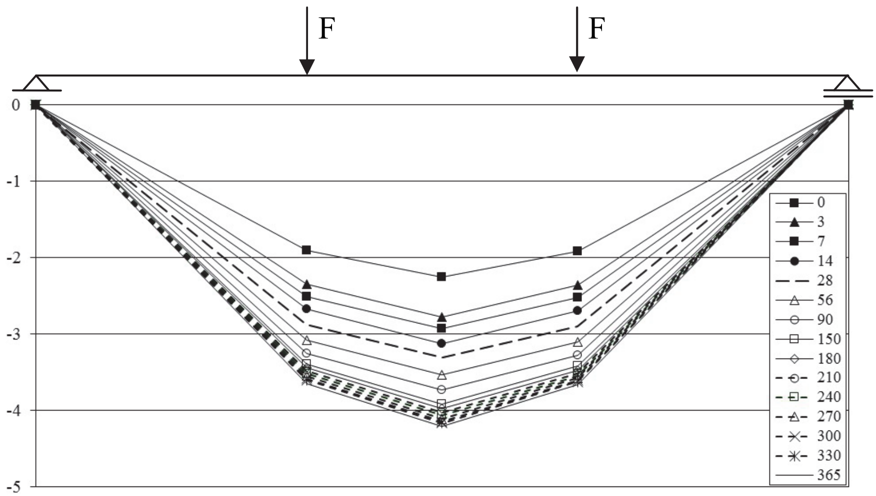

Fig. 9. Deflection of B10 beam [mm] during the time of load
Rys. 9. Ugięcie [mm] belki B10 w kolejnych dniach obciążenia

Cracking of beams was another analyzed serviceability limit state. Cracking moment of both beams (B9 and B10) was measured and was amounted respectively to 3,7 and 3,6 kN·m. The cracking was observed along the entire length of beam specimens, from both sides (Fig. 5). However, the analysis was limited to the area between forces (section loaded only with the bending moment – Fig. 10 and 11, left side “L” and right side “R” of the beams).

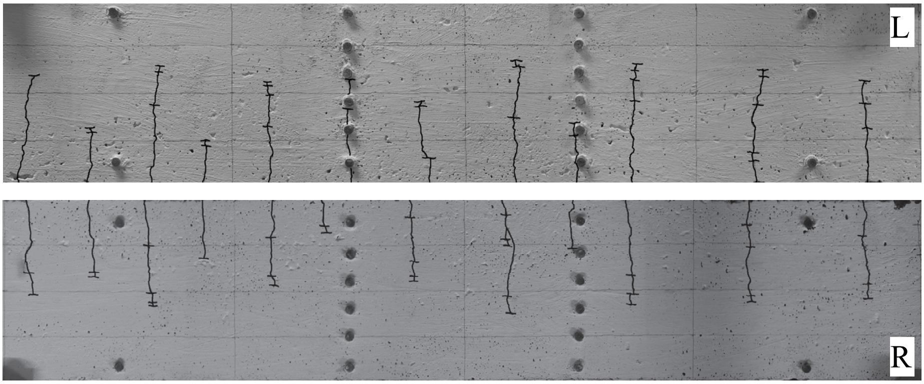

Fig. 10. Cracks distribution for beam B9 in section between forces
Rys. 10. Zarysowanie belki B9 na odcinku pomiędzy siłami

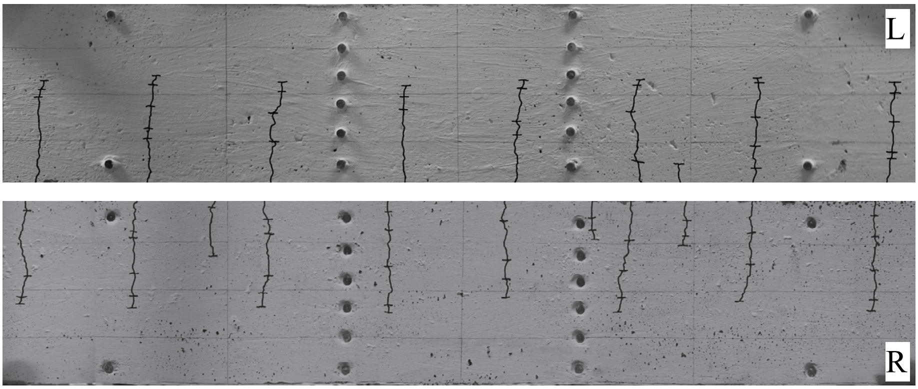

Fig. 11. Cracks distribution for beam B10 in section between forces
Rys. 11. Zarysowanie belki B10 na odcinku pomiędzy siłami

The level of stabilized cracking (lack of more cracks until the end of the study) was reached on the day of loading with the bending moment value on the level of 6 kN·m. Mean crack spacing was 83 and 102 mm, respectively for B9 and B10 beams. On the other hand the maximum crack width was 0.05 and 0.06 mm for B9 and B10 beams, which are the values allowed by EC2 [8].

6. Conclusion

Type of chosen aggregate is a very important component for well-designed concrete. Quality and ingredients of this aggregate depend on many variables [12]. Unfortunately, in the Central Pomerania, the granulometric composition of aggregate deposits, in about 70%, corresponds to sand [19]. This is why the attempts of using fine sand have been present since 1970's [13, 15]. Using steel fibres in sand concretes allows to reduce enormous waste sand dumps. Fine aggregate concretes containing steel fibres, are characterized by limited shrinkage value, in relation to elements made from both fine aggregate concrete and plain concrete. Creep rate for analyzed fine aggregate concretes containing steel fibres is also lower than for plain concretes having similar strength parameters [3].

Deflections of fine aggregate beams containing steel fibres obtained from the research significantly differ from values determined by EC2 [8]. Experimental crack width values are on the maximum level of 0.1 mm, what is acceptable under EC2 [8]. Analyzing these serviceability limit states of beams one should remember that the amount of of used fibres did not exceed 0.5%. This may indicate that such a small amount of fibres in fine aggregate concrete beams may cause real improvement of their functional properties [17, 22].

Undoubtedly using composite materials in construction elements is becoming more and more popular [16, 17]. The idea of using steel fibres in concrete mix based on waste aggregate seems to be a good idea [5] corresponding to the, so called, environmental sustainability. Lack of normalized methods enabling to analyze construction elements prepared from composite materials yet still remains a problem. Of course there exist studies on this matter [3, 20, 23] which, however, are not yet included in EC2 [8]. It could probably change after Model Code 2010 [20] is taken into account.

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Badania długotrwałe belek fibropiaskobetonowych na bazie kruszywa odpadowego

Streszczenie

W artykule opisano badania fibropiaskobetonów na bazie kruszywa odpadowego. Jako zbrojenie rozproszone zastosowano dwa rodzaje włókien stalowych w ilość nieprzekraczającej 0,5% objętościowo. W badaniach określono podstawowe właściwości zaproponowanych fibrobetonów takie jak: wytrzymałość na ściskanie, rozciąganie przy rozłupywaniu czy też moduł sprężystości. Jednak główny nacisk badawczy położono na określenie stanów granicznych użytkowalności badanych belek z uwzględnieniem cech relogicznych (tj. skurczu i pełzania) użytych fibrokompozytów.

Słowa kluczowe:
piasek odpadowy, włókna

Keywords:
waste sand, fibres