EFFECT OF STEEL FIBRES ON MODIFICATION OF MECHANICAL PROPERTIES OF STRUCTURAL LIGHTWEIGHT CONCRETE

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Abstract:

In comparison to ordinary concrete (NWAC) of the same strength class, lightweight concrete (LWAC) is characterized by lower mechanical properties. Incorporating fibers into concrete matrix it is possible to enhance these properties. In the paper the influence of steel fibres on compressive strength, flexural strength, tensile splitting strength, modulus of elasticity as well as stress-strain relation of structural lightweight concrete with sintered fly ash aggregate is discussed. The level of concrete density (ca1600 and ca1700 kg/m^3), compressive strength (ca 45 and ca 55 MPa) and dosages of fibres (30, 45 and 60 kg/m^3) were considered as variables in the research programme. As a result of research it turned out that the addition of steel fibres are more effective in improvement of mechanical properties of LWAC in comparison with NWAC.

Keywords: lightweight concrete, mechanical properties, steel fibres

1 Introduction

Specific properties of lightweight aggregate, caused by its high porosity, are the reasons of different mechanical properties of structural lightweight aggregate concrete (LWAC) in comparison to normal-weight one (NWAC). Lightweight aggregate concrete of the same strength class as ordinary concrete is characterised by less density (up to 2000 kg/m^3), better thermal insulation, higher shrinkage (even more than 50%), lower shear, flexural and tensile strength (respectively about 5 to 25%, 20 to 55% and 20 to 40%) and lower modulus of elasticity (about 25 to 50%). Nevertheless structural LWAC is described by better structure homogeneity due to much better adhesion between porous aggregate and cement matrix as well as their comparable modulus of elasticity. Therefore the stress-strain relationship is more linear and appearance of cracking is much later (about 85 to 90% of maximum load). This is advantageous for better durability of structural lightweight concrete. On the other hand the better composite homogeneity is responsible for more brittleness of LWAC and therefore it is destroyed in more sudden and explosive way, and its fracture parameters are more disadvantageous [1,2,3].

Incorporating steel fibres into lightweight concrete it is possible to enhance some of above properties. Generally this type of fibres is added to concrete to minimize its susceptibility to cracking and to improve its mechanical properties such as: flexural, tensile and shear strength, fatigue strength, impact resistance, freeze and thaw resistance, abrasion resistance and fracture characteristics [4,5]. It also reduces volume changes, although this additive is never applied only for this reason. Steel fibres in amount of up to usually applied dosage of 2% by volume generally affect neither compressive strength nor

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modulus of elasticity. But there are also some exceptions in subject literature [6,7,8] which deny this. The effectiveness of steel fibres in modification of composite properties depends on their type, content as well as concrete type. It is supposed that this effectiveness may be more advantageous in the case of lightweight concrete, because of its lower tensile strength and lower modulus of elasticity. Unfortunately in comparison to NWAC there is not so much information on the effect of steel fibres on LWAC properties. The problem is additionally complicated by a huge assortment of lightweight aggregate, which properties vary in a considerable wider range in relation to normal aggregate, therefore they give incomparable results [7,8,9,10].

2 Experimental program

The aim of an investigated research programme was to check the influence of steel fibres addition on mechanical properties of structural lightweight concrete, such as: compressive strength, tensile splitting strength, flexural strength, modulus of elasticity and stress – strain relationship. These properties were tested after 28 and 365 days of curing.

Two series of lightweight aggregate concrete varying with density and strength were made. The concrete composition is presented in Table 1. As lightweight aggregate (LWA) sintered fly ash of 4-8 mm diameter was used. The aggregate Pollytag is the most suitable LWA, available on the national market, for structural lightweight concrete of higher strength. Before the use lightweight aggregate was initially moistened up to 17 % by mass. Such a procedure protected concrete mixture from workability losses or/and excessive cement paste consumption due to considerable absorption of water from cement paste by aggregate. Fine aggregate was natural sand, cement was CEM I 42,5 R. As steel fibres Dramix with hooked ends and length of 50 mm and a diameter 0,75 mm was applied. Contents of steel fibres were assumed as: 0; 0,4; 0,6; 0,8% by volume. Dosage of superplasticizer was set to achieve constant mixture consistency of about 13 – 15 s according to VeBe method. Therefore superplasticizer content was dependent on water to cement ratio of cement matrix as well as on steel fibres content.

Tab. 1 Composition of the concrete

	Components kg/m^3							
series	**IS**				**IIS**			
symbol	**I**	**IS1**	**IS2**	**I3**	**II**	**IIS1**	**IIS2**	**IIS3**
steel fibres	0	30	45	60	0	30	45	60
cement	345	345	345	345	446	446	446	446
LWA	765	765	765	765	700	700	700	700
sand	414	414	414	414	458	458	458	458
water	190	190	190	190	164	164	164	164
superplasticizer	0,0	0,0	0,7	1,4	3,6	3,6	4,0	4,5

After mixing all concrete components, various types of specimens, suitable to considered tests, were moulded. The number and types of specimens made for the tests are given in Table 2. All specimens were demoulded after 24 hours and during next 27 or 364 days until the test they were stored in standard conditions: in temperature of 20 ± 2 ^{o}C and humidity of 95 ± 5%.

Tab. 2 Types of specimens and test methods

test type	specimen type	dimensions [mm]	numbers
compression	moulded cube	150 x 150 x 150	2 x 5
	moulded cylinder	ϕ 150/300	5
	drilled cube	100 x 100 x 100	3
splitting	moulded cube	150 x 150 x 150	5
	drilled cube	100 x 100 x 100	3
three-point bending	moulded beam	100 x 100 x 500	2 x 3
modulus of elasticity	moulded cylinder	ϕ 150/300	5
σ – ε relationship in compression	moulded cylinder	ϕ 150/300	5

Fig. 1 Measurement equipment for σ – ε relationship and modulus of elasticity.

All strength tests as well as density tests were carried out according to suitable European Standards. However because of lack of such standards for modulus of elasticity and stress – strain relationship, these tests were conducted on the basis of some national requirements and own procedures. The range of stresses for cyclic loading and deloading, in order to assess the modulus, was from 0,1 up to 0,3 of concrete strength. The measurement apparatus, presented in fig. 1, consisted of 3 sensors of displacement, a force sensor, an amplifier for the force sensor, a measurement set with 4 channels (input) and a converter transforming signals from the set to the digital form. The measurement apparatus was connected with PC, which allowed to current control of stresses and corresponding strains. The same equipment was used to test σ – ε relationship. The frequency of measurements was 5Hz and the rate of loading was constant (0,05 MPa/s).

3 Results

Due to differences in water-cement ratios and volume proportions between lightweight aggregate and cement matrix (mortar) for both series, plain concretes achieved essentially different densities (1580 and 1710 kg/m^3 respectively for I and II concrete) and strength ($f_{cm,cube\ 28}$ amounts to 39,0 and 47,5 MPa respectively for I and II concrete).

Incorporation of steel fibres into concrete caused the density increase adequate to the addition content. Effects of applied steel fibres on the other considered concrete properties are discussed below.

3.1 Compressive strength

The assessment of the influence of steel fibres on compressive strength turned out to be dependent on specimen type. In the case of standard cubes the effect is not visible. Compressive strength tested on cubes both after 28 days and 365 days did not change practically with increasing steel content. However cylindrical specimens gave a certain difference. Incorporation of the highest fibres content (60 kg/m^3) into lightweight concrete resulted in compressive strength increase of 9% and 11% respectively for series IS and IIS.

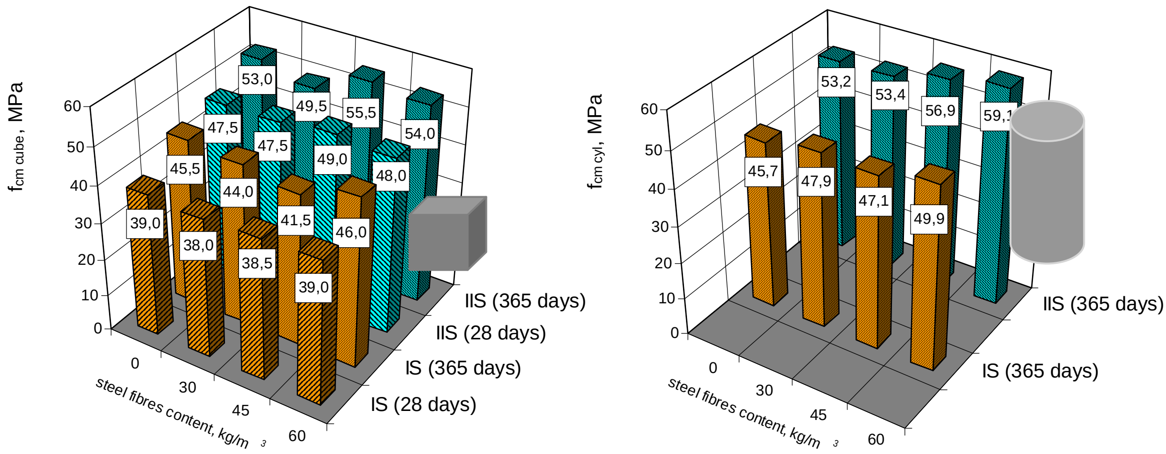

Fig. 2 Mean compressive strength for lightweight aggregate concrete.

There are two possible explanations of such a tendency, which may simultaneously occur. The first one is different mechanisms of fracture in compression for these two types of standard specimens. The range of friction effect of steel platens in testing machine is much bigger in the case of cubes, which characterised smaller slenderness than cylindrical specimens. As a result these two types of specimens show a different cracking pattern during their destruction in compression. The second mechanism is connected with different direction of moulding in relation to the direction of specimen loading. In the case of cubes these two directions are perpendicular to each other, for cylinders they are parallel. The last situation is more favourable to distribute fibres during specimen consolidation in more advantageous aligment to bridge propagating cracks.

3.2 Tensile splitting strength

As it can be visible in fig.3, addition of steel fibres improved tensile splitting strength. The effectiveness of this improvement evidently is dependent on fibre content and cross section of test specimen. Therefore in the case of standard cubes with side length of 150 mm the maximum strength increase was only 16% and 19% respectively for IS and IIS concrete series. However when smaller specimens (100 mm cubes) were used this increase was much higher and for the maximum fibres content (0,8% by vol.) it was as much as 46% and 73%.respectively for IS and IIS concrete series. These results confirm a special sense of application of this type of fibres to thin-walled elements. As a result of incorporation of fibres into lightweight aggregate concrete the ratio of splitting tensile strength to compressive strength became higher that means the decrease of brittleness of concrete. This ratio f_t/f_c specified on 150 mm cubes at 28 days changed on average from 0,07 for plain concrete only to 0,08 for concrete reinforced with 60 kg/m^3. Nevertheless, assuming the lack of essential increment of tensile splitting strength with time, the same factor assessed on 100 mm cubes would change in much wider range (from 0,07 up to 0,13).

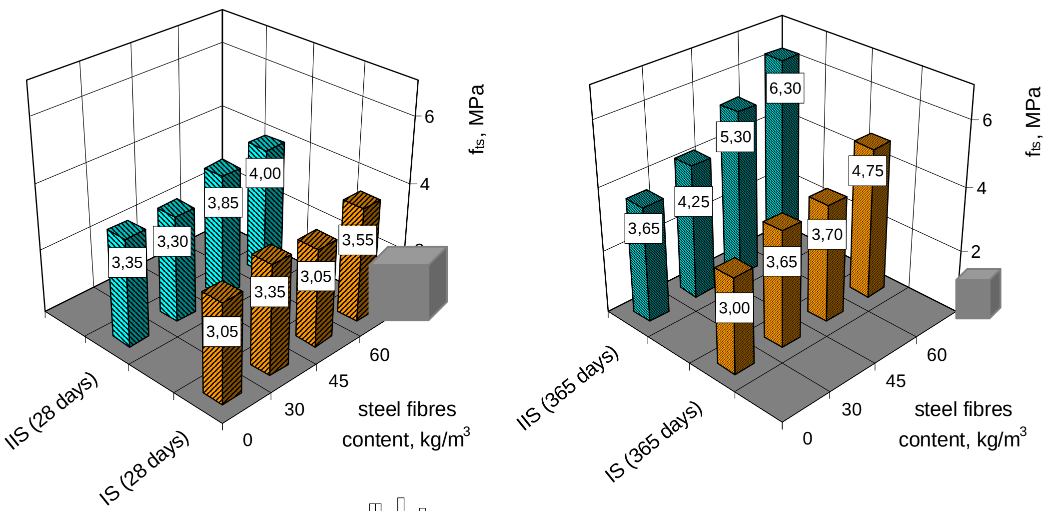

Fig. 3 Mean tensile splitting strength of lightweight aggregate concrete.

It should be noted that results of tensile splitting tests are characterized by relatively high dispersion, which is typical for this type of test. Nevertheless in the case of fibres concrete the results dispersion was even more considerable. This fact my be explained by random distribution and random alignment of fibres on the path of a decisive crack which determinates destruction of a specimen.

3.3 Flexural strength

Just as tensile splitting strength, flexural strength is also affected by the addition of fibres content. But the strength increment in this case is much more visible. After 28 days of curing for concrete series IS it was 49% and for concrete series IIS it was as high as 61%. In opposite to compressive strength, the farther increase of flexural strength values of plain as well as reinforced concrete was not observed. Therefore the results after 365 days of curing are almost the same as after 28 days (fig.4). Maximum fibres content caused improvement of the ratio of flexural strength to compressive one f_f / f_c on average from 13% up to 20%, which is much more effective in comparison to normal-weight concrete.

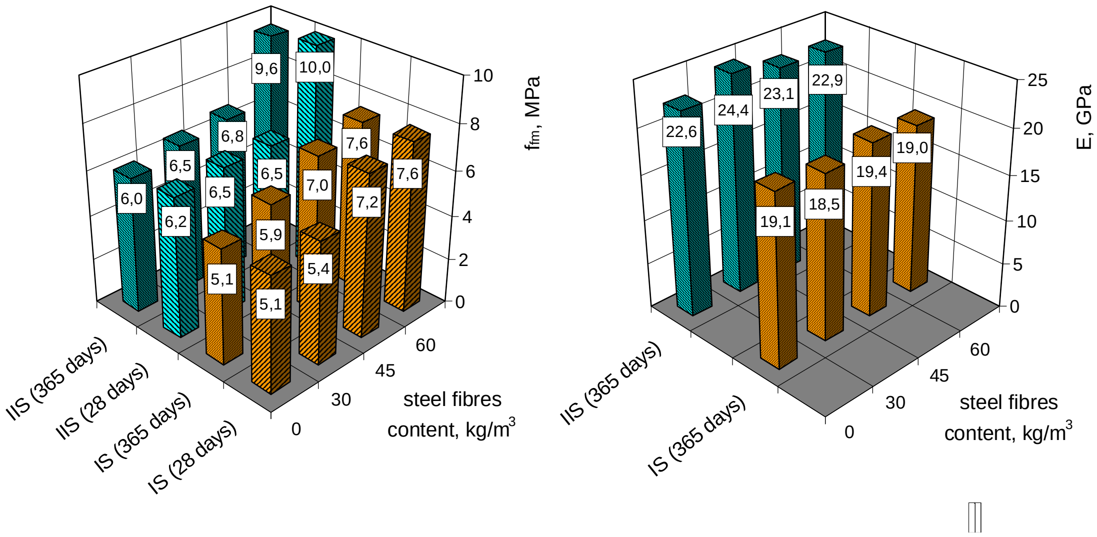

Fig. 4 Mean flexural strength and modulus of elasticity for lightweight aggregate concrete.

Analogically as in the case of tensile splitting strength, flexural strength test dispersion was higher for concrete with fibres depending on probability of fibre location in right position in the middle of a test beam, where the destructive cracking occurs.

3.4 Modulus of elasticity

Because of lower modulus of elasticity of porous aggregate, researched aggregate concrete are characterized by ca 45% lower Young's modulus in comparison to normal weight concrete of the same strength class. The achieved values are dependent on both concrete strength and density, therefore they are higher for concrete series IIS.

Assessing the influence of steel fibres on modulus of elasticity of lightweight concrete, the lack of such an influence in both concrete series should be stated (fig. 4). Despite incomparably higher Young's modulus of steel, the fibre content, which was as low as up to 0,8% by volume, was not able to improve the modulus of the composite. Considering the special role of steel fibres in crack bridging, the lack of the effect of fibres on modulus of elasticity of lightweight concrete is clearer. In the range of stresses, in which the modulus is tested, researched concrete, because of their perfect structural homogeneity, did not show cracking. Therefore in this range fibres could not fulfil their main role. The best confirmation of this mechanism is course of stress-strain relationship.

3.5 Stress – strain relationship

In pre-peak stage the effect of fibres is hardly visible. Both plain concrete as well as ones reinforced with steel fibres indicate strongly linear stress – strain relationship with exactly the same slope for a given concrete series. For plain concrete the linearity is hold up to ca 95% of maximum concrete stress. In the case of reinforced concrete this range is a little bit lower (up to ca 85%) because of higher concrete strength, improved by fibres crack bridging and taking part in stress transfer, which was discussed in 3.1. As a result of fibres incorporation strain corresponding to maximum stress is much higher. It changes from ca 2,5 mm/m for plain concrete to ca 3,0 mm/m for concrete with maximum fibres content.

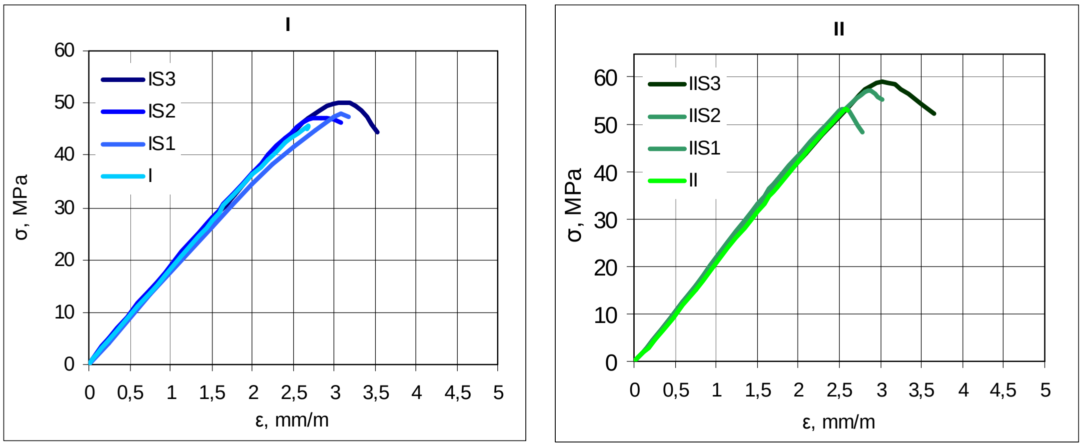

Fig. 4 Mean stress-strain relationship for lightweight aggregate concrete.

In post-peak stage of stress-strain relationship the influence of steel fibres is more considerable. It should be noted that plain concrete was practically characterized with lack of descending part of the chart. This is a proof of ideally brittle nature of tested lightweight concrete. Addition of steel fibres resulted in enhancement of concrete deformability after achieving maximum stress. Therefore for concrete with the highest steel content of 0,8 % by volume maximum strain was as high as 3,7 mm/m. Nevertheless even the lowest fibre content of 0,4 % by volume resulted in complete elimination of sudden explosive fracture.

4 Conclusions

Incorporation of steel fibres in amount of up to 60 kg/m^3 (0,8% by vol.) into structural lightweight concrete yielded essential enhancement of its mechanical properties, such as: tensile splitting strength, flexural strength and deformability in post-peak stage of uniaxial compression. In comparison to normal-weight concrete, benefits of steel application for mechanical properties increment were even more advantageous for lightweight concrete, because of their higher brittleness. Since the enhancement of the properties was more pronounced in the case of series IIS, characterised by higher strength. Steel fibres, even at their low content 30 kg/m^3 (0,4 % by vol.), eliminated completely the sadden and explosive nature of lightweight concrete fracture.

The influence of steel fibres on compressive strength was not so pronounced and turned out to be dependent on a specimen type. Slight strength increase was observed for standard cylinders, but in the case of cube specimens no steel effect occurred.

Steel fibres did not modify modulus of elasticity of tested lightweight concrete. This lack of fibre influence may be explained by relative low steel content and excellent concrete homogeneity resulting in fact that concrete usually works in uncracked state under load.

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