Research Article

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Impact of reinforcement on shrinkage in the concrete floors of a residential building

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Abstract: The type of floor in a building object results from the serviceability requirements, technical possibilities, and costs of its implementation. Concrete screeds constituting the structural layer of the floor can be made without reinforcement, with dispersed reinforcement, or reinforced with meshes of various materials. Due to the large surface dimensions, concrete screeds are susceptible to scratches as a result of occurring strains, service loads and unevenness of the floor. There are detailed recommendations on how to make floors, and on the materials used. However, the conditions in which floors are made often differ from those recommended. The article presents the results of measured strains on the surfaces of three screeds constituting the floor layer in a residential building. The screeds, which were made in identical environmental conditions, differed in the type of reinforcement used: steel mesh, dispersed polypropylene fibres, fibreglass mesh. In addition, strain measurements were carried out on concrete and fibre-reinforced concrete specimens made of the mix used to make the screeds. The results allowed the assessment of the effectiveness of the reinforcement used, the impact of environmental conditions on the values, and the analysis of differences in the course of strains in real elements and the specimens.

Keywords: concrete screed, concrete shrinkage, fibre-reinforced concrete, reinforcing mesh, laboratory specimens

1 Introduction

The basic elements of floor finishing in building rooms are concrete floors, which, depending on the purpose of the object, may be the final finishing layer (e.g. industrial floors with appropriate abrasion or chemical resistance, etc. in rooms of various purposes) or a construction layer for finishing layers (in residential buildings or public buildings) [1–4]. Concrete screeds in residential buildings are made in wet or dry technology [2, 5–7]. Cement or anhydrite binder is most commonly used. The choice depends on the type of room (dry or exposed to moisture) or location in the building (on the ground, on the structural layer of the floor slab) [5]. The planned solution of floor layers may also be relevant. Factors affecting the choice of floor screed are, therefore: the subfloor, the type and distribution of thermal and moisture insulation, the planned presence of underfloor heating installations, etc. Implementing guidelines specifying the rules for the correct implementation of floors include: the method of preparing the floor, determining the upper level of the screed, distribution and manner of expansion joints, division into technological sections (applies to large surface floors, e.g. in hall facilities), preparation of the mixture in accordance with the recipe, correct application of mixture (adequate to current conditions during works - mainly thermal) and proper care in the first hours and days of binding and then hardening of the mixture used [6–9]. In any case, the screed should be designed and constructed so that it is protected against steam and water penetration [10]. It should be mentioned here that the most important recommendations cited above for the correct execution of floors are not always met in practice [11, 12]. This applies most often to floors made in small residential buildings. Concrete floor screeds, which are not particularly important from the point of view of structural reliability, are often made in residential buildings without due diligence. This may be the result of insufficient knowledge of contractors and deficiencies in supervision, which results from the assumption that the effects of poor performance are not associated with large losses and do not threaten safety in use. Despite the fact that damage to floors very rarely leads to a direct

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threat of a major failure, they can in the long run reduce the serviceable parameters of the building and reduce its durability. Faulty floor construction, which causes discontinuities (cracks) and unevenness of the screed layer, is visible during the building's operation and leads to its damage, and consequently to the need for repair [12, 13]. The main reason for the appearance of cracks in concrete screeds (apart from excessive loads) is the shrinkage of concrete. This occurs both during setting (chemical and plastic shrinkage) and hardening of concrete (shrinkage due to drying) [14–18]. The shrinkage resulting from the setting and hardening processes during the cement hydration process cannot be completely inhibited or radically limited and is, in practice, irreversible. In contrast, contraction resulting from excessive drying can be reduced by proper care of young concrete [14, 15, 18–22]. It is recommended that shrinkage strains in concrete screeds do not exceed the order value $0.4 \div 0.5$ mm/m [6, 7, 11, 23].

Therefore, the floor implementation method should be considered at the design stage. In order to achieve sufficient efficiency and durability of the floor, while minimizing the complexity of workmanship, it is necessary to take into account the various solutions currently available. Taking into account the possibility of errors arising from improper preparation of the mixture (including no plasticizing admixtures), performance errors and inadequate care, as well as the unforeseen impact of environmental conditions (mainly temperature and humidity), reinforcement is used, which significantly reduces shrinkage and excessive cracks and displacement of self-dilated concrete floors in this way [11, 24, 25]. Nowadays, reinforced steel mesh (with different diameters and bar spacing), dispersed fibres (mainly steel and polypropylene, or less often basalt) or fibreglass mesh are used as reinforcement for floor screeds [24–28]. The effectiveness of these solutions can vary. Therefore, it is advisable to directly compare the effectiveness of the solutions used in comparable conditions and at the same time.

With this in mind, tests were planned in a detached residential building in three adjacent rooms with similar area and shape of horizontal projection. Each room had a

different type of screed reinforcement. Screeds were made at the same time and with the same quality of workmanship. This article presents the research results (partly discussed in the conference paper [25]) enabling direct comparison of the effectiveness of chosen types of reinforcement applied in floors. The analysis of test results and assessment of the impact of reinforcement used on the size and course of shrinkage from the day of screed application to the initial phase of their exploitation are presented. In addition, parallel laboratory measurements were carried out on specimens made of the same concrete mixture that was used to make the screeds.

2 The scope and method of research

Screeds of the floor on the ground, made in a detached residential building in three adjacent rooms, were tested. The floor consists of the following elements: a finished concrete layer with a thickness of 7 cm, expanded styrofoam boards with a thickness of 15 cm, two layers of an insulating foil, C12/15 concrete with a thickness of 10 cm, as well as a sand and gravel bed with a thickness of 20 cm (Figure 1). The CEM I 32,5R Portland cement was applied on concrete floors, as well as sand and water. The following components were used per 1m^3 of concrete mix: cement 250 kg, sand 1300 kg, and water 100 l. Coarse fraction aggregates and plasticising admixtures were not used.

The following reinforcement was used in three separate rooms:

- in the first room (R-S) steel welded reinforcing mesh with 10×10 cm holes and 1×2 m size, made from $\varnothing 3$ mm rods was used,
- in the second room (R-PF) BauCon polypropylene fibres $\sim 0.9 \text{ kg/m}^3$ (fibre length $l_w \approx 12$ mm, diameter $\varphi \approx 38 \mu\text{m}$, having a straight shape) were used,
- in the third room (R-G) reinforcement mesh made of Fola glass fibres 40×40 mm, 50 linear metres was used.

Figure 1: Arrangement of floor layers.

Figure 2: Pictures of performed construction works: a) room R-S (steel mesh reinforcement), b) room R-PF (reinforced with polypropylene fibres), c) the room R-G (fibreglass mesh reinforcement).

Concrete screeds were made at the end of October in a closed building, which had a direct effect on the conditions of the concrete mixture setting. The setting and maturing period took place in the first days at a relatively low ambient temperature, *i.e.* in the range of about $7\div 10^{\circ}\text{C}$ with average humidity above 80% (precipitation). Increased humidity caused the mixture to dry slowly, which was a positive factor because the screeds did not require additional care during this period. The method of the screeds' implementation in individual rooms is shown in Figure 2.

For strain measurement a mechanical extensometer was used. The benchmarks (measurement bases) were glued immediately after hardening and sufficient drying of the screed surface (necessary due to the effect of the adhesive). This was possible on the third day after laying the floors. The first measurement was made on the fourth day, then measurements continued to be recorded of shrinkage strains at intervals appropriate to the age of the concrete: in the first week of measurements daily, for the next three weeks every two days, and later at intervals of about $7\div 10$ days, also taking into account the guidelines contained in the instructions [29].

The location of measurement bases in individual rooms is shown in Figure 3 in orange.

At the same time, part of the concrete mixture used to make the screeds was used to prepare specimens. Two types of specimens were prepared at the construction site: concrete specimens (Sp-C) and concrete specimens with randomly dispersed polypropylene fibres (Sp-PF). In total,

Figure 3: Sketch of the placement of measurement benchmarks (dimensions in centimetres): a) room R-PF, b) room R-G, c) room R-S

8 specimens for laboratory tests were made: 4 concrete specimens and 4 fibre-reinforced concrete specimens, including one larger sample - size $100 \times 100 \times 300$ mm (Sp-C-I, Sp-PF-I) and three smaller samples - size $50 \times 50 \times 100$ mm (Sp-C-II, Sp-PF-II). Strains were measured on each of the four side walls of the specimens. These measurements

were carried out in parallel with the measurements of the screeds.

Demec extensometers, manufactured by W.H. Mayes & Son were used for the measurements. On screeds and the specimens Sp-C-I and Sp-PF-I the extensometer 100 mm base was used (extensometer constant: 0.79×10^{-5}), while for measurements of the specimens Sp-C-II and Sp-PF-II a 50 mm base extensometer was used (extensometer constant: 1.60×10^{-5}). The shrinkage was measured with an accuracy of 0.002 mm.

During the measurements (each time just before the next measurement) the temperature of the tested surfaces and the ambient humidity were recorded. The temperature was measured with a non-contact infrared thermometer with a range of $-50^{\circ}\text{C} \div 380^{\circ}\text{C}$ and a tolerance of $\pm 0.5^{\circ}\text{C}$. Ambient humidity was measured using a wireless weather station MONSUN 3540 (measurement range $20 \div 90\% \pm 5\%$).

3 Results and analysis

The results of strain measurements on the screed surfaces in the examined rooms are presented below in the form of diagrams in Figures 4a-c and Figure 5. Figure 4 presents graphs of strain changes (measured over 310 days) recorded on individual measurement bases in each room, as well as the average of these measurements.

The graphs show that the most even increase in strains (independent of the base and direction of measurement) was recorded in room R-PF (in which polypropylene fibres were used). The largest dispersion of the strain values measured in this room occurred on the last day of measurements and was equal to $\epsilon = 0.3 \div 0.55\%$. The maximum relative difference between the measured strain and the average value on that day was $\sim 32\%$. In other rooms, i.e. R-S and R-G (in which steel mesh and fibreglass mesh were used, respectively), the observed dispersion of results was greater. In R-G room (fibreglass mesh used) the largest dispersion of results was recorded on the 126th day of measurements and it was equal to $\epsilon = 0.24 \div 0.57\%$, and the maximum relative difference from the average value that day was $\sim 35\%$ (respectively on that day in room R-PF was noted $\epsilon = 0.26 \div 0.36\%$, and in room R-S: $\epsilon = 0.15 \div 0.47\%$). However, in room R-S (steel mesh used) the largest spread of results was recorded (similar to room R-PF) on the last day of measurements, and it was $\epsilon = 0.33 \div 0.84\%$, while the maximum relative difference from the mean value on that day was $\sim 42\%$ (respectively on that day in room R-G was recorded $\epsilon = 0.46 \div 0.66\%$).

(a)

(b)

(c)

Figure 4: Graphs of strain changes on screed surfaces in each room: a) room R-S, b) room R-PF, c) room R-G

Observation of the course of changes in the size of strain increments shows that regardless of the type of reinforcement used, the rate of strain increase was not constant throughout the entire period. Clearly larger strains of each screed occurred during the first 140-150 days from the start of measurements. In the following days, until the end of the study, i.e. until day 310, the increases were smaller. The average value of strains after 150 days was the lowest in room R-PF and amounted to $\epsilon = 0.38\%$. In other rooms, the value of strains on that day was, respectively: in room R-S $\epsilon = 0.41\%$ and in room R-G, $\epsilon = 0.46\%$. The average

Figure 5: Graphs of average strain increases on the screed surface in individual rooms together with graphs of humidity and temperature changes

strain value after another 160 days (on the last day of measurements) was also the lowest in room R-PF, $\epsilon = 0.44\text{‰}$ and in the others: R-S, $\epsilon = 0.49\text{‰}$ and R-G, $\epsilon = 0.54\text{‰}$, respectively. From this follows the well-known conclusion regarding changes in the size of shrinkage strains in concrete as a function of time, that the largest strains of screeds occur within the first 140-150 days of their execution. However, the amount of strain can be limited to varying degrees. The most effective of the reinforcement used turns out to be polypropylene fibre - it reduced the final strains by about 0.1‰ in relation to those in the floor reinforced with fibreglass mesh and by about 0.05‰ in relation to those in the floor reinforced with steel mesh. However, in the initial period (at the floor strain level to approximately $0.15\text{--}0.20\text{‰}$), the reinforcement in the form of steel mesh turned out to be the most effective.

Figure 5 presents graphs of average strains on floor surfaces determined from measurements in the three tested rooms and the parameters recorded in parallel: ambient humidity and temperature of the tested surface. The above data allowed the estimation of differences in shrinkage size depending on the reinforcement used, as well as the analysis of the impact of changes in environmental conditions on the increase in strains. On this basis, one can notice a change in the rate of strain increase resulting from the impact of the temperature change after switching on the heating (about the 98th day of measurements). After about 140 days, one can clearly see the change in growth dynamics of the measured strains mentioned earlier. From this moment, the decrease and stabilization of indoor air humidity is also visible.

In general, the results obtained show very similar trends in strain as a function of time on all tested surfaces in three rooms with simultaneously recorded changes in temperature and humidity. However, the values of strain increments differ significantly. The lowest shrinkage in-

crease in the first three months after concreting (up to the 104th day of measurement) was recorded in room R-S (where a steel mesh was used). It probably also resulted from the fact that in the first days after preparing the screed, the temperature in this room was about $1\div 2^{\circ}\text{C}$ lower than in other rooms, which slowed the setting and drying of concrete. At humidity above 80% in the initial stage of concrete maturation, even swelling was noted. As mentioned above, the initial difference in the value of strains in the R-S room compared to the strains measured in the R-PF and R-G rooms was maintained for the first four months of measurements. Then the shrinkage in the R-S room began to increase faster than in the other rooms.

Changes in ambient humidity very clearly affected the values of recorded strains. In the first 21 days after making the screeds, the humidity did not fall below 60% (repeated measurements indicated $\text{RH} > 80\%$), which clearly limited the shrinkage, causing periodic return changes of systolic strains. Only a longer period of reduced humidity after setting the concrete (between the 25th and 46th day of measurements) influenced the acceleration of concrete drying and a gradual increase in strain. Significant changes in the increase of shrinkage strains began after the 98th day of measurements, i.e. from the moment of turning on the heating and increasing the temperature by $\sim 10^{\circ}\text{C}$, which at the beginning clearly accelerated the drying process. In the following days, until the measurements were completed, the humidity remained more or less constant, $\sim 65\%$. During this time, it is clearly seen that even small changes in humidity, by 5–8%, had an impact on the size of the shrinkage (Figure 5).

Simultaneously with measurements in the residential building, shrinkage strains were measured on concrete and polypropylene specimens made of the same concrete mixture that was used to make the screeds. It allowed a comparison of the course and values of strains measured on the surface of screeds and free strains measured on specimens. Figure 6 presents the average results of measurements on four walls of each type of samples: Sp-C-I, Sp-PF-I, Sp-C-II, Sp-PF-II together with measurements of humidity and temperature in the laboratory room.

The strains of the specimens after just a few days reached a value of $\epsilon = 0.45\text{‰}$, which after a direct comparison with floor strains shows the desirability of using reinforcement and its positive impact on shrinkage reduction. Although the final strains of the floors ($\epsilon = 0.44\div 0.49\text{‰}$) and specimens ($\epsilon = 0.47\div 0.57\text{‰}$) are comparable, their reduction is clearly visible (especially in the case of fibre concrete floors). The analysis of shrinkage in concrete and fibre-reinforced concrete specimens showed that the addition of fibres had little effect on the changes in the value

Figure 6: Graph of average increases in shrinkage strain measured on laboratory specimens along with graph of humidity and temperature changes

of shrinkage strains. In the specimens Sp-C-I, Sp-PF-I (dimensions $100 \times 100 \times 300$ mm) it was almost identical (although, in the case of these specimens, the results are less reliable, because only one specimen of each type was tested). In the specimens Sp-C-II, Sp-PF-II (dimensions $50 \times 50 \times 100$ mm) it can be seen that in the first days of measurements the values of shrinkage strains were also similar, but after about 14 days from concreting the strain values in the specimens with the addition of fibres were slightly lower than in concrete specimens (by about 8%).

The influence of specimen size on the obtained results is also noticeable. In the first 21 days of measurements, a smaller increase of strains was observed in the Sp-C-I, Sp-PF-I specimens than in the Sp-C-II and Sp-PF-II specimens. However, in the following days, until the end of the measurements, strains in these larger specimens turned out to be higher, reaching, on the last day of measurement, values $\epsilon = 0.53\%$ (Sp-C-I) and $\epsilon = 0.56\%$ (Sp-PF-I), while in smaller specimens $\epsilon = 0.50\%$ (Sp-C-II) and $\epsilon = 0.47\%$ (Sp-PF-II) were noted.

As indicated above, the course of shrinkage strains in specimens Sp-C-II, Sp-PF-II was characterized by faster growth in the first days after concreting. As early as on the 14th day of measurements the strains reached values that were measured in the Sp-C-I, Sp-PF-I specimens only seven days later. In the following days, however, the shrinkage increased slightly, and the final values of the shrinkage strains, measured on the 310th day of test, were $\epsilon = 0.466\%$ (Sp-PF-II) and $\epsilon = 0.504\%$ (Sp-C-II).

It can be assumed that the observed changes in the course and values of shrinkage strains resulted from both the size of the specimens and the way they were made, which had a direct impact on the loss of water during the setting and hardening of the concrete mixture, on which the amount of shrinkage depends. In the first days after

Figure 7: Graph of average increases in systolic strains measured on laboratory specimens and screed with polypropylene fibre reinforcement

concreting, the water loss in the Sp-C-II and Sp-PF-II specimens (of smaller volume) was faster than in the Sp-C-I and Sp-PF-I specimens, and this resulted in a faster increase in strains. Subsequent changes in strain increases (associated with drying of hardened concrete) could have resulted from the way specimens were made. All specimens were moulded in-situ without vibrating. The mixture was compacted by hand. For this reason, a mixture of larger specimens (Sp-C-I and Sp-PF-I) may be less compacted than smaller specimens (Sp-C-II and Sp-PF-II). Differences in condensation of the mixture may have caused a different degree of water evaporation at the moment of systolic strain.

The next graph (Figure 7) summarizes the course of shrinkage strains measured on fibre-reinforced specimens (Sp-PF-I and Sp-PF-II), which were left in the laboratory and on screeds with polypropylene fibre reinforcement (R-PF). Analysis of the course of the charts indicates a clear diversity of the strain values in two types of specimens in relation to those measured on the screed surface during the first four months of measurements, which (also taking into account previous charts with marked humidity and temperature values) are also clearly dependent on changes in humidity and ambient temperature.

4 Conclusions

The tests allowed to assess the effectiveness of the reinforcement used in concrete floors and to determine the impact of environmental conditions on the size and course of strains in real elements and specimens.

1. Based on the results obtained, the most effective of the types of reinforcement used in terms of

shrinkage reduction (and also due to the ease of making the screed) was reinforcement in the form of polypropylene fibres. The final strains in the floor with dispersed reinforcement were about 0.1‰ smaller than in the floor reinforced with fibreglass mesh and about 0.05‰ smaller than in the floor reinforced with steel mesh.

2. The reinforcement in the form of dispersed polypropylene fibres increased the homogeneity and isotropy of the floor layer, which was indicated by the smallest dispersion of results obtained in the R-PF room.
3. Fibreglass mesh was the least effective in reducing shrinkage among the three types of reinforcement used in the screeds.
4. Studies have confirmed that environmental conditions, *i.e.* humidity and ambient temperature, have a significant impact on the size of the shrinkage. In the initial period of concrete maturation, the low temperature in the building slowed down the drying process, which at ambient humidity above RH = 80% affected the inhibition of shrinkage and even concrete swelling. However, the abrupt increase in temperature (as a result of starting heating) significantly influenced the increase in the rate of strain increase.
5. The increase in shrinkage measured on fibre concrete specimens was much faster than shrinkage in the building, which was mainly due to less favourable ambient conditions - higher temperature and low humidity in the laboratory room, as well as small dimensions of the samples in relation to the size of the floor surface.
6. Comparison of the shrinkage value measured on non-compacted concrete and fibre-reinforced concrete specimens indicated a slight reduction in shrinkage due to the use of polypropylene fibres.
7. The specimen sizes had an impact on the measured strain values.

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