Experimental Research of Non-Autoclaved Concrete with Unconventional Reinforcement

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Abstract. Foam concrete is classified as a lightweight concrete. It is a cement mortar in which air-voids are entrapped by a foaming agent. Its practical application is mainly limited to non-structural material. For many years, the application of foam concrete has been limited to backfill of retaining walls, insulation of foundations, roof tiles and sound insulation. However, in the last few years foam concrete has become a promising material also for structural purposes. When the marginal loads are reached, all of alveolar concrete, included foam concrete, is destroyed without previous deformations. So, the main condition for the safe and reliable foam concrete use in structure elements is to increase its strength characteristics for short and long loads. Span constructive elements of foam concrete are performed as usual, reinforcement is ensured by a steel armature of a smooth or periodic profile. Experimental and theoretical research of comprehensive light concrete span elements and other types of reinforcement, their use in the methods of calculation, such as constructions with unconventional reinforcement, are not explored and used enough. One way to solve the problem is to replace conventional reinforcement by unconventional one (for example, organic or biological materials, different kinds of mesh). The results of experimental research of foam non-aerated concrete elements, the features of their work under the load are presented in this article. In this article, methods of increasing the strength of non-autoclave foam concrete using secondary waste are proposed. The results were compared with the results of tests of unreinforced elements.

1. Introduction

General application and the growing use of cellular concrete in construction works is possible owing to constant experimental research and experience gained from the construction practice [1, 2, 3]. In addition to gas concrete, the most popular is foam concrete. In order to form a foam concrete cellular structure, a suspension with foam can be used where cement usually serves as a binding material. As a building material, foam concrete indicates an increase of strength in time, like other types of cement-based materials [4].

Cellular concrete is used mainly for constructing external and internal walls, including partition walls in building facilities. Such concrete can also be used for thermal insulation of roofs, lofts, floors and for sound insulation of reinforced concrete ceilings [5, 6]. Foam and gas concrete components are light and eco-friendly and have good thermal and acoustic insulation properties. Furthermore, they are easy to
process, they can be easily cut, drilled, milled, etc. Cellular concrete is commonly used owing to the above-mentioned features and also for its relatively low price.

The disadvantage of cellular concrete is material brittleness. Therefore, research is made to find methods of reinforcing its structure. Now, currently known research covers primarily homogeneous cellular concrete without reinforcement or reinforced with a metal core and polypropylene or metal fibres [7]. The use of alternative reinforcement, e.g. elastic rope reinforcement or rigid reinforcement of biological or organic origin [8, 9] or different types of mesh [10], has not been sufficiently well studied and described. As regards non-metal fibres made of waste or recycled materials, there are certain, yet not entirely confirmed assumptions. The article presents results of compressive strength tests of non-autoclaved foam concrete reinforced mainly with waste of biological and organic origin. At present, these materials are not often used for building purposes. However, use of such cheap materials (often waste materials) would lead to a significant reduction of material cost and improvement of the natural environment.

2. Presentation of test and analysis results

D600 non-autoclaved foam concrete was applied in the presented studies. A mixture of foam concrete was prepared on the basis of formulations and technologies of a foam concrete manufacturer in Lviv and produced by this company (‘Pianobeton Lwów’). The foam concrete was made in accordance with the classic procedure. First, a concentrate of a foaming agent and water was mixed to obtain a work foaming solution. This solution was then put into a foam generator in which foam was made with a compressor. The remaining amount of water was added to a mixture of sand and cement. Before adding the foam to the prepared mixture, it is necessary to make sure that the water-cement ratio is at least 0.38. A low value of the water-cement ratio of the mixture may cause it to take water necessary for chemical reactions directly from the foam. This will result in its partial destruction, i.e. a decrease of the volume in a foam concrete mixture. When mixing, the optimal water-cement ratio should range from 0.4 to 0.45.

35 samples in the form of 100x100x100 mm cubes from one foam concrete mixture were used for the tests. The cubes were reinforced with shreds of a linen or polyamide cord, strips cut out of PET bottles and strips from residues of glass fibre plaster mesh resistant to an alkali environment. This stage of the tests was focused on determination of the compressive strength of foam concrete reinforced mainly with waste materials of biological and organic origin. Other tests of foam concrete (e.g. for absorbability, shrinkage) are scheduled for the next stage, if satisfactory results of the strength tests are obtained.

![Figure 1. Preparation of cubes for tests.](image)

A specific number of all types of fibres (figure 1) were put into individual cells of a specially prepared wooden mould which was then filled with a prepared foam concrete mixture. By mixing with a hand mixer for 5-8 minutes, it was possible to achieve uniform saturation with fibres for each sample. After mixing, excessive foam concrete was removed from the surface with a spatula which was also used to smoothen the surface. The moulds with samples of reinforced and non-reinforced concrete were stored for 28 days in a closed room at 15 to 20°C, constant humidity and atmospheric pressure.
The compressive strength of reinforced and non-reinforced foam concrete samples was determined with a P-10 laboratory press (figure 2).

![Figure 2. Compressive strength test of the cubes.](image)

In order to examine the effect of the type of non-metal fibres on mechanical properties of generated foam concrete, the samples were combined into separate groups. The first group – seven non-reinforced concrete samples. The second group – four samples reinforced with shreds of a linen cord of 5, 10, 15 and 20 mm in length with a fibre volume fraction of 1000 g/m³. The remaining groups of samples were also reinforced with shreds of a polyamide cord, 2 mm wide strips cut out of used wide PET bottles and 5 mm wide strips from residues of glass fibre plaster mesh resistant to an alkali environment (figure 3).

![Figure 3. Non-metal fibres and their length.](image)

According to the methodology of the experimental research [11], a load of the samples was applied continuously at speed ensuring a static increase of stress in the sample until its complete destruction. The beginning of a significant increase of line deformations of the sample at a constant external load was taken as a breaking load. Results of the experimental research are shown in tables below.
Table 1. Results of tests of samples for different lengths of non-metal fibres (fibre volume fraction of 1000 g/m³).

| Sample number | Fibre material       | Fibre length, mm | Critical load, F, kN | Sample compressive strength, fₖ, MPa |
|---------------|----------------------|------------------|---------------------|-------------------------------------|
| 1…7           | -                    | -                | 11.94               | 0.1194*                             |
| 8             | Linen cord           | 5                | 15.63               | 0.1563                              |
| 9             | 10                   | 13.42            | 0.1342              |
| 10            | 15                   | 14.11            | 0.1411              |
| 11            | 20                   | 15.63            | 0.1563              |
| 12            | Polyamide cord       | 5                | 15.17               | 0.1517                              |
| 13            | 10                   | 15.48            | 0.1548              |
| 14            | 15                   | 14.10            | 0.1410              |
| 15            | 20                   | 11.45            | 0.1145              |
| 16            | Strips cut out of PET bottles | 5 | 10.71 | 0.1071 |
| 17            | 10                   | 14.56            | 0.1456              |
| 18            | 15                   | 14.42            | 0.1442              |
| 19            | 20                   | 13.83            | 0.1383              |
| 20            | Strips from glass fibre mesh | 5 | 13.92 | 0.1392 |
| 21            | 10                   | 12.76            | 0.1276              |
| 22            | 15                   | 14.28            | 0.1428              |
| 23            | 20                   | 12.12            | 0.1212              |

* selected average value

On the basis of the results, graphs were drawn up to present the dependence of the compressive strength of foam concrete reinforced with non-metal fibres [12] on their length (figure 5) for the constant fibre volume fraction of 1000 g/m³.

The analysis of the graphs indicates that:

- using 5 mm long fibres (figure 4a) cut out of linen and polyamide cords and strips from glass fibre mesh, an increase of the strength of non-autoclaved foam concrete from 16% to 30% was achieved in comparison to non-reinforced samples. Linen cord reinforcement proved to be the most effective, whereas strips cut out of PET bottles reduced the strength of the foam concrete samples by 10%;
- all types of 10 mm long non-metal fibres (figure 4b) improved the compressive strength of non-autoclaved foam concrete from 7% to 30%. The best result was achieved with polyamide cord reinforcement;
- an improvement of the strength of non-autoclaved foam concrete from 18% to 20% was observed for all types of 15 mm long non-metal fibres (figure 4c);
- when reinforcing foam concrete with a 20 mm long fibre (figure 4d), the best result was achieved with a linen cord fibre. The strength increase was 31%. PET bottle strips improved the strength of foam concrete by 16%. For reinforcement provided by glass fibre mesh strips and a polyamide cord, there was no expected improvement of the compressive strength of foam concrete.
Figure 4. A change of the compressive strength of non-autoclaved foam concrete depending on the type of materials of non-metal fibres and for different lengths: a) 5 mm; b) 10 mm; c) 15 mm; d) 20 mm.
Figure 5. A change of the compressive strength of non-autoclaved foam concrete reinforced with different types of non-metal fibres depending on the fibre length, a) linen cord; b) polyamide cord; c) PET bottle; d) glass fibre mesh.
Observed changes of the compressive strength of non-autoclaved foam concrete depending on the length of fibres at their constant fibre volume fraction (1000 g/m³, figure 5) are interesting. On the basis of the analysis of the results, the following was stated:

- the greatest increase of the compressive strength of foam concrete reinforced with a linen cord fibre in comparison to a non-reinforced sample (by 31%) (figure 5) is obtained for 5 mm and 20 mm long fibres and the lowest increase (12%) – for 10 mm long fibres;
- when using polyamide cord reinforcement (figure 5b), the best result was achieved for 5 mm and 10 mm long fibres. The strength increase was 27% and 30% accordingly, in comparison to non-reinforced samples. Further increase of the fibre length resulted in a decrease of the strength of foam concrete. The strength of the sample reinforced with 20 mm long fibres was lower than that of the non-reinforced sample;
- when reinforcing foam concrete with strips cut out of PET bottles (figure 5c), the increase of the strength of foam concrete was 16% to 22% in comparison to non-reinforced samples, however, only with regard to fibres of 10 to 20 mm in length. The compressive strength of foam concrete reinforced with 5 long strips was lower than that of non-reinforced concrete;
- the most optimal lengths of fibres for strips from glass fibre mesh are 5 mm and 15 mm (figure 5d), for which the strength increase was 17% and 20% accordingly, in comparison to non-reinforced samples. Reinforcement of foam concrete with 10 mm and 20 mm long strips improved the strength by max 7%.

Another group includes three samples reinforced with 10 mm long linen cord fibres with a fibre volume fracture of 750, 950 and 1150 g/m³. The remaining groups of samples were reinforced with polyamide cord fibres, 2 mm wide strips cut out of used PET bottles and 5 mm wide strips from residues of glass fibre plaster mesh resistant to an alkali environment (figure 2).

**Table 2.** Results of the experimental research of samples for different non-metal fibre content (fibre length 10 mm).

| Sample number | Fibre material       | Fibre content g / m³ | Critical load, F, kN | Sample compressive strength, f_c, MPa |
|---------------|----------------------|----------------------|----------------------|--------------------------------------|
| 24            | Linen cord           | 750                  | 11.48                | 0.1148                               |
| 25            |                      | 950                  | 10.73                | 0.1073                               |
| 9             |                      | 1000                 | 13.42                | 0.1342                               |
| 26            |                      | 1150                 | 9.45                 | 0.0965                               |
| 27            | Polyamide cord       | 750                  | 10.72                | 0.1072                               |
| 28            |                      | 950                  | 10.93                | 0.1093                               |
| 13            |                      | 1000                 | 15.48                | 0.1548                               |
| 29            |                      | 1150                 | 13.48                | 0.1348                               |
| 30            | Strips cut out of PET bottles | 750 | 14.42                | 0.1442                               |
| 31            |                      | 950                  | 14.56                | 0.1456                               |
| 17            |                      | 1000                 | 14.56                | 0.1456                               |
| 32            |                      | 1150                 | 12.50                | 0.1250                               |
| 33            | Strips from glass fibre mesh | 750 | 11.89                | 0.1189                               |
| 34            |                      | 950                  | 13.75                | 0.1375                               |
| 21            |                      | 1000                 | 12.76                | 0.1276                               |
| 35            |                      | 1150                 | 14.85                | 0.1485                               |

Figure 6 presents graphs of the change of strength of samples depending on their non-metal fibre content. 10 mm long non-metal fibres were used for the tests.
On the basis of the presented graphs, it was stated that the optimal reinforcement volume fraction of linen and polyamide fibres is 1000 g/m$^3$ (figure 6a, figure 6b). A similar result was achieved for foam concrete reinforced with fibres cut out of used PET bottles (figure 6c). For reinforcement of foam concrete made of glass fibre mesh, the optimal fibre volume fraction should be at least 750 g/m$^3$ (figure 6d).

3. Final conclusions

1. It was confirmed that non-metal fibres cut out mainly from waste or recycled materials can be used to improve the compressive strength of non-autoclaved foam concrete.
2. The following types of non-metal fibres were proposed: shreds of a linen or polyamide cord, strips cut out of used PET bottles and strips from residues of glass fibre mesh.
3. Such non-metal fibres improve the compressive strength of non-autoclaved foam concrete from 7% to 25% on average.
4. Among the tested materials, linen and polyamide cords are best as non-metal fibres used to reinforce foam concrete. The most optimal length of such a fibre is 15 ± 3 mm.
5. The best results were achieved for the fibre volume fraction of non-autoclaved foam concrete samples amounting to 1000 ± 50 g/m$^3$.
6. Using fibres from waste and recycled materials to improve the compressive strength of non-autoclaved foam concrete is very important. In particular, to some extent, the use of PET bottles for this purpose is one of the solutions of the problem of their recycling or disposal.

The obtained results are qualitative. For quantitative determination of the effect of the proposed types of non-metal fibres on a change of strength parameters of non-autoclaved foam concrete, further research is required. Samples of foam concrete reinforced with a different content of biological or organic materials are to be tested at subsequent stages of the research, etc. Other features of foam concrete are also planned to be examined, e.g. absorbability, shrinkage, frost resistance.
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