TESTING OF FOAM CONCRETE FOR DEFINITION OF LAYER INTERACTING WITH SUBSOIL IN GEOTECHNICAL APPLICATIONS

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Abstract: Today's production of foam concrete (FC) has become more suitable for various types of applications due to the usage of new additives and improved technology. One typical application of foam concrete in Europe is the creation of a sub-base layer of the floor of multi-storey buildings, where thermal and noise insulation functions are required. The main advantage of foam concrete production is its unlimited variety of desired properties, which must be properly balanced for a specific application and its interacting structure. Produced FC can have unit weight from 300 to 900 kg.m-3, compression strength from 0.4 to 12 MPa, elasticity modulus from 1200 to 2500 MPa and coefficient of thermal conductivity from 0.15 to 0.30 W.m-1K-1. Thanks to these properties, FC can be used for the construction of foundation slabs of passive houses, as a sub-base layer of industrial floors and as a filling material of narrow excavated shafts. As for concrete, reinforcement can improve tensile properties, but due to corrosion, iron bars or nets must be replaced by special material bars, nets, geogrids or geotextiles. For the mentioned type of structures and loading of FC layers, the importance of laboratory and in-situ testing is crucial. This article presents laboratory tests of one of the selected parameters, which is flexural strength of FC in various unit weights, and demonstrates a significant improvement of strength when non-woven geotextile and mesh type reinforcement was used. Use of geotextile at the bottom part of samples increased flexural strength from 30 to 60%, mesh reinforcement can have doubled basic flexural strength. Crack propagation with respect to time was also observed during tests in order to compare the results of reinforced FC with no reinforced layer.

Keywords: Flexural strength, Foam concrete, Geotextile, Reinforcement

1. INTRODUCTION

The successful cooperation between academic and private sectors brings new possibilities for the use of progressive and multifunctional materials, which foam concrete (FC) is without any doubt.

The aim was to verify the usage of FC of various bulk densities as a subbase layer for industrial floors, foundation structures or pavements, thereby providing the investor with benefits in terms of cost savings, improved subbase homogeneity and increasing durability with favorable thermal properties.

Utilization of the FC is dependent on the relevant investigation of material properties. For the design of the above-mentioned structures, estimation of some mechanical characteristics is important, especially the compressive and flexural strength or modulus of elasticity.

Considering the loading mechanism of such a layer in the horizontally situated and vertically loaded structure, the flexural strength can be the limiting factor. Paper presents the bend testing using 4-point flexural test and possible ways how to improve this important parameter for the definition of layers of foam concrete.

2. FOAM CONCRETE

Foam concrete (FC), as a mixture of cement, water, additives, and technical foam, has been in principle well known for more than 30 years. It is a building material with good mechanical properties, low thermal conductivity, suitable for simple or even technological treatments. Foam concrete contains closed void pores that allow achieving a low bulk density with a low material requirement of raw materials. Thanks to its properties, it is usable as a replacement of conventional subbase layers of the floors, the pavements or as a part of the foundation structures of passive buildings [1-4]. Mixture composition of foam concrete can be prepared for the production of various bulk densities. Our special mixing machines can produce FC of the dry bulk density of 300, 400, 500, 600 and 700 kg.m⁻³. For each density of foam concrete, simple names are used FC300, FC400, FC500, FC600 and FC700. For the application in the industrial floors, foam concrete layer is equipped with non-woven geotextile (GTX-N) at the bottom. Nowadays the foam concrete with densities 300 -400 kg.m⁻³ is most often used as a floor leveling layer of administrative and residential buildings.

Realized researches show that its utilization in various densities [3] and strength [5] can be much wider. The conventional subbase layer of aggregate can be replaced with the layer of the foam concrete FC with the corresponding density.

2.1 Mechanical Characteristics

Mechanical characteristics are necessary inputs of the structural analysis. In order to provide the required parameters, a series of material tests have to be performed. Measured parameters of the foam concrete are listed below.

2.1.1 Compressive strength

In contrast to the fill materials for the subbase layers, the foam concrete is capable of bearing the compressive load. The compressive strength of the FC depends on the formula based upon required bulk density. Time-dependent propagation of the compressive strength for bulk densities 500, 600 a 700 kg.m⁻³ is plotted in Fig. 1.



Fig. 1. Time dependence of compressive strength of the foam concrete.

For all bulk densities, 3-day's compressive strength reaches a minimum of 50% of the 28-day's compressive strength.

2.1.2 Flexural strength

The significantly higher tensile strength of the foam concrete is an advantage in comparison to the granular materials used for the subbase layers. A 4-point flexural test is usually performed to measure the flexural strength of the hardened concrete and this method is also suitable for the simple foam concrete. Preliminary tests show that 3-day's tensile strength reaches a minimum of 50% of the 28-day's flexural strength similar to compressive strength.

Flexural strength of non-reinforced FC can further be improved by the geotextile (GTX-N) at the bottom face of the layer. Geotextile is a regular part of the final subbase layer design. To achieve a further increase of the flexural strength, additional reinforcement can be added. The influence of the reinforcement will be presented in this paper.

2.1.3 Elasticity Modulus and Poisson's ratio

Elasticity modulus is a crucial parameter for the design of the floor or foundation slabs and their interaction analysis, [6-8]. In practical design, a multi-layered subbase compound usually requires the substitution of the particular materials with the homogenous and isotropic half-space, which is described by the modulus of subgrade reaction or the modulus of elasticity. The dependency on the modulus of elasticity and the bulk density is plotted in Fig. 2.



Fig. 2. Modulus of elasticity vs. bulk density of foam concrete.

Poisson's ratio is determined during compressive stress at a defined stress level up to 68% of the final compressive strength. Typical values of Poisson's ratio of the foam concrete FC 500 are presented in table 1.

Table 1. Poisson's ratio of foam concrete FC 500

Compressive stress [kPa]	472	708	944	1180
Poisson's ratio [-]	0.11	0.20	0.24	0.33

2.2 Reinforcement of Foam Concrete

The principle of reinforcement of FC is similar to conventional concrete. Reinforcing elements are bars, meshes or fibers or their combinations. The contribution of the reinforcing elements in the foam concrete is most noticeable at the tensile loading of the layer when brittle materials like foam concrete or regular concrete bear only a limited amount of tensile forces. In practical design, tensile forces are usually borne by the reinforcing members. The tests of the flexural strength presented in this article were aimed at the contribution of the reinforcement to the mechanical properties of the foam concrete. The first step represents the geotextile at the bottom of the foam concrete as a permanent part of the design. Despite its low tensile strength and high ductility, geotextile structure together with the fresh foam concrete creates a reinforced layer at the bottom and

causes a larger flexural strength. In opposite to the classic concrete or crushed gravel layer, liquid foam concrete leaks into a geotextile structure between fibers and creates a high interaction mechanism.

Use of additional reinforcement elements brings another increase of the flexural strength and overall roughness, which is a phenomenon observed at the concrete reinforced with the dispersed fibers. When tensile failure occurs, the resistance of the specimen still increases as the activation of the reinforcement takes place. Because our main goal was to utilize the FC in the subbase layer, reinforcement by meshes was considered. Preliminary flexural tests aimed at the foam concrete formula improvement show a significant increase of the flexural strength using basalt meshes. Standard steel meshes have to be installed with some covering layer of the concrete to restrict the negative impacts of environment and concrete itself. Basalt meshes are non-corrosive and dielectric and no covering layer is required. Mesh can be placed right on the geotextile without distance elements. Liquid FC leaks through the mesh openings right to the geotextile and creates a composite structure "FC-GTX-mesh".

2.3 Reinforcement Types

Preliminary flexural testing was aimed at the selection of the appropriate reinforcing elements. The main criterion was the highest possible peak flexural strength achieved with particular reinforcement type.

2.3.1 Geotextiles

After first tests, it was obvious that even nonwoven separation geotextile (GTX-N) can cause an increase of the flexural strength. But the overall contribution of the stiffer geotextiles does not correspond to the higher stiffness and cost. Exclusion of the woven geotextiles was the next step when only regular non-woven geotextile of separation and filtration function was used, with area weights from 200 to 500 g.m⁻². Further tests show that geotextile with the weight of 200 g.m⁻² is almost comparable with heavier geotextiles in terms of flexural strength contribution, besides the lower costs, so it was selected as geotextile layer for the flexural tests presented in this paper.

2.3.2 Basalt mesh reinforcement

Foam concrete is similar to the conventional concrete in some ways and its reinforcement by basalt mesh (rods of basalt fibers arranged in net) is one of the suitable for them. Application of FC is aimed rather on the subbase layers and extensive reinforcement is not required. Plate load tests performed on the 22 cm layer of the FC at the insitu testing field of the University of Zilina show about 20% increase of the measured modulus of elasticity when basalt reinforcing mesh was used. Following those findings, several specimens for the flexural testing were prepared with this type of reinforcement. Except for the meshes, reinforcing bars can be used but their application in the foam concrete is not suitable at the moment because of the loading mechanism of the subbase laver made from the foam concrete. Mesh structure creates a uniformly reinforced structure during the "leak in" process with higher flexural strength and roughness in opposite to the distinct bars with a significantly higher stiffness when interaction mechanism between reinforcement and softer surrounding foam concrete needs to be verified.

2.3.3 Combined reinforcement

Combigrid as a combination of the biaxial bonded geogrid and non-woven geotextile was also tested. Surprisingly, the flexural strength was lower than with the geotextile alone. Reason for this phenomenon is the flat shape of the geogrid with the relatively smooth surface of the ribs. This imperfection disturbs the "composite effect" of the FC and the geotextile. Usability of the combined reinforcement thus depends on the ability of the composite system "foam concrete-combined reinforcement" to provide a sufficient interaction level between particular elements of the system.

3. A FLEXURAL TEST OF FOAM CONCRETE

The flexural test provides values of the modulus of elasticity of bending or flexural strength. Usually, a 3-point or 4-point flexural test can be used. Preparation of the specimen and the test procedure itself are simple but the results can be affected by the specimen irregularities, loading geometry or strain rate. This mechanism of loading takes place in two-dimensional horizontal structures such as slabs or layers in the floor, foundation or pavement structures [1, 3, 4]. Tensile or flexural strength becomes a crucial parameter of the particular material in the design. Hardened foam concrete is very similar to the conventional hardened concrete, so flexural test simulating real load conditions can be adopted to determine the flexural strength of the test specimen [9]. A 4-point flexural test was performed with the FC beams of the selected bulk density.

3.1 Test Geometry and Specimens

Test specimens were prepared in accordance with the standards for the flexural testing of the

conventional concrete, [9]. Nominal dimensions of the beam were $d_1 = d_2 = d = 100$ mm and L = 400mm. The span of the supports was l = 300 mm. Distance of the loading pins was d = 100 mm (Fig. 3). Force is distributed from the hydraulic cylinder through spreader to the loading pins. The load cell is situated at the connection of the cylinder and the spreader.



Fig. 3. The geometry of the flexural test.

Flexural strength f_{cf} for the 4-point bending test is calculated as follows:

$$f_{cf} = \frac{F \cdot l}{d_1 \cdot d_2^2} \tag{1}$$

Each specimen was created in the form with the open upper surface. When the foam concrete was poured out to the form, the upper surface was leveled after a few hours. The beam was then removed from the form after 3 days and it was covered by a foil to avoid the extensive evaporation that can cause a deprivation of the strength. The foil was removed right before the test which took place 28 days after the specimen creation. Geotextile was placed on the bottom of the form when basalt mesh was used, it was placed directly on the geotextile (Fig. 4).



Fig. 4. Basalt mesh on geotextile in the form.

3.2 Foam Concrete Parameters

A total of four mixtures of foam concrete were prepared for the testing. Each mixture is represented by the nominal bulk density which is given by the corresponding formula. Nominal bulk density is the density of the dry specimen while normal density during the test is the density of the specimen with some moisture content. Nominal and average normal bulk densities during the test calculated from 3 measurements on the 28-day's beams are in table 2.

Table 2. Bulk densities of the foam concrete

Туре	FC 300	FC 400	FC 500	FC 600
Average density (kg.m ⁻³)	397	522	584	735

3.3 Reinforcement Parameters

Non-woven separation geotextile Geofiltex 63/20 was used in the first step of reinforcing. Parameters of the geotextile are shown in table 3.

Table 3. Parameters of geotextile Geofiltex 63/20

Parameter	Value
weight (g.m ⁻²)	200
tensile strength (kN.m ⁻¹)	
- longitudinal direction	12.0
- transversal direction	7.5
ductility (%)	
 longitudinal direction 	75
- transversal direction	115
dynamic puncture resistance (mm)	14
static puncture resistance (N)	1 400
material type	PP

Basalt reinforcement was represented by the composite mesh ORLITECH ® MESH [10] made from rods located in mutually perpendicular directions connected in the node by a special mass. Rods are crafted from basalt fibers with the resin binder (Fig. 4). Parameters of the basalt mesh are shown in table 4.

Table 4. Parameters of the basalt mesh

Parameter	Value
weight (g.m ⁻²)	360
rod distance (mm)	100×100
rod diameter (mm)	3
tensile strength (MPa)	1 300
modulus of elasticity (GPa)	47
ductility at maximum force (%)	2.5

3.4 Test Procedure

The specimen was placed in the test apparatus according to the scheme in Fig. 3. After initial "zero" loading involving the weight of the spreader, the loading began with the rate of 5 to 8 kg.s⁻¹. The test ends when maximum loading force is achieved at the total failure of the specimen. In the case of reinforced FC, the force may still increase as the full activation of reinforcement takes place.

4. RESULTS AND DISCUSSION

Three specimens of each combination of bulk density and reinforcement were tested. Typical propagation of the test for one specimen is plotted in Fig. 5.



Fig. 5. The load/time dependency propagation of selected flexural tests, a) plain FC, b) FC with GTX, c) FC with geotextile and mesh.

The increase of the bulk density is proportional to the increase of the flexural strength. The behavior of the specimens is similar across the bulk densities. Average flexural strength for the particular bulk density and the reinforcement is plotted in Fig. 6.

4.1 Time Dependence Behavior of Reinforced FC

Fig. 7 shows a direct comparison of the load/time dependency for the reinforced and non-reinforced specimen of FC 400. When peak loading was achieved, the tensile stress rapidly dropped to "zero" values in case of the plain foam concrete. On

the contrary, tensile strength raised again after some drop, when cracks occurred in case of reinforced FC.



Fig. 6. Flexural strength of the tested FC mixtures.

Drop after first cracks is more evident at the specimen with geotextile only, while the after-crack increase of tensile stress is much larger at the specimen with both geotextile and mesh.



Fig. 7. Propagation of the load/time dependency for the FC400 with various reinforcements.

Confirmation of plotted behavior can be seen at the investigation of specimens after testing. In the case of plain FC, a simple vertical crack occurs approximately in the middle of the specimen (Fig. 8a). Cracks appear very quickly and the damage of the specimen is almost instant. In the case of the geotextile, multiple cracks take place in lines intersecting the positions of loading pins (Fig. 8b).

After the initial break, geotextile activates and the specimen behaves as a viscoelastic element. Extended tensile load at the bottom is accompanied by the compressive load at the top of the specimen. Total break takes place when breakage of the compressed part occurs together with the loss of connection between the geotextile and the FC. Added basalt mesh induced another set of cracks related to the mesh ribs (Fig. 8c). These cracks are inclined from the center of the loading zone and end at the edge points where transversal mesh ribs are located. Overall behavior till the total breakage of the specimen is similar to the geotextile reinforcement.

4.2 Interaction of FC Layer with Subsoil

Use of reinforcement elements with a good level

of mutual interaction significantly increases available flexural strength and some level of flexural roughness can be achieved. This allows utilizing the post-crack part of the flexural strength similar to the conventional concrete with dispersed fibers. This is particularly advantageous for interacting structures where relatively higher deformations are allowed.



- Fig. 8. Failure mechanisms of the FC specimens, a) plain foam concrete,
 - b) foam concrete with geotextile,
 - c) foam concrete with GTX and mesh.

There are several points that still need to be considered for further research to obtain real interaction of the FC layer with subsoil. These include the influence of structure/FC layer/subsoil stiffness ratio, geometry and load type (static/dynamic), time dependence behavior of FC layer with subsoil, shear interaction on contact areas, etc. These parameters must be verified by measurements on real structures or physical models, not only by numerical analyses.

5. CONCLUSION

Presented tests were aimed at the flexural strength testing as a crucial parameter for the design of the subbase layer of the several structures. Results show that normal flexural strength of FC can be further increased by the reinforcing elements such as geotextile alone or combination of the geotextile and the basalt reinforcing mesh. Addition of the geotextile contributes 30% to 60% increase of the first-crack flexural strength in comparison to the plain foam concrete. The additional mesh could rise basic flexural strength twice the time.

An increase of roughness is observed at the reinforced specimens. This means that final flexural strength at total breakage can be higher than first-crack flexural strength. Post-crack part of the flexural strength is then available similarly to the conventional concrete reinforced with the dispersed fibers. That opens up the opportunity for further research using experimental and new computational approaches. Based on these laboratory experiments, characteristics of the FC layer can be established, and the material model can be formulated, which describes stress-strain behavior of FC layer interacted with subsoil.

6. ACKNOWLEDGMENTS

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