UTILISATION OF UHPFRC IN STRUCTURES OF VACUUM INSULATED CONTAINERS

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Abstract

Vacuum insulated containers are usually made of steel or plastic structures. The structure made of UHPFRC, which consists of two containers with 70 mm gap between them is presented in the paper. The small experimental container was designed to test the thermal insulation parameters of the vacuum tank. It is insulated by vacuum and also by reflection layer to hold medium temperature stable for a long period of time. The structure was designed at SUT in Bratislava and the container was made of UHPFRC prepared by TBG – Metrostav, Prague. The long-term thermal tests being executed in Kysucké Nové Mesto - Slovakia. The results of the material tests and the results of structural performance of the container are described in the paper.

Keywords: UHPFRC, vacuum insulated container, formwork, casting process

1. Introduction

Nowadays, the insulation for thermal energy storage is not as good as it should be. One reason for this is the higher investment cost for better insulation. Nevertheless, most of the recent studies show that the thermal losses of long-term storage have been underestimated. Therefore, recent research studies have focused on vacuum-insulated thermal storage. There are two common concepts with regard to the use of vacuum insulation for thermal storage. An evacuated double vessel filled with pearlite or with vacuum insulation panels. Both the insulation concepts are based on the Knudsen effect. Thus, the thermal conductivity is lowered by a factor of 6–10, when compared with the conventional insulation materials. Both the concepts are adoptions of the existing insulation applications. The filled double vessel tank is already being used for cryogenic storage for liquid gases. Furthermore, they are being used to insulate passive houses. However, the use of vacuum insulation for thermal energy storage causes different problems due to higher temperature differences and moisture. Nevertheless, vacuum insulations are a promising solution for small thermal long-term storage. This paper presents the vacuum-insulated thermal tank made of UHPFRC.

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The structure of the inner and outer container is introduced in part 2 and characteristics of UHPFRC are presented in part 3.

The whole structure of the vacuum insulated thermal tank was designed in frame of the project: Development of methods for structure of thermal vacuum insulated containers – (Vývoj metód konštrukcie akumulačných vákuových nádrží - in Slovak).

2. Intelligent Energy Supply System

Efficient and cost effective energy usage for households and buildings was designed as a comprehensive system to optimize energy consumption. It is a flexible and adaptable system with option to choose energy source, to store energy or to use stored energy. The system can choose between energy sources, because it is connected to several different energy sources. It uses the most cost effective available energy source, several energy sources simultaneously to cover peak loads, also with option to store cheap energy and with possibility of seasonal storage. (Fig. 1).

The crucial point of the system is "a vacuum insulated container" made of special concrete with an anti-gas diffusion layer and an anti-radiation layer.

The physics of heat transfer through insulation materials is well known. Overall heat transfer can be divided into three major processes: the heat transfer due to gas conductivity; the heat transfer through the solid of the core and the heat transfer via radiation. The lowest heat transfer via gas conductivity can be achieved by a perfect vacuum. Therefore, a vacuum can reduce the thermal conductivity of the most traditional insulation materials.

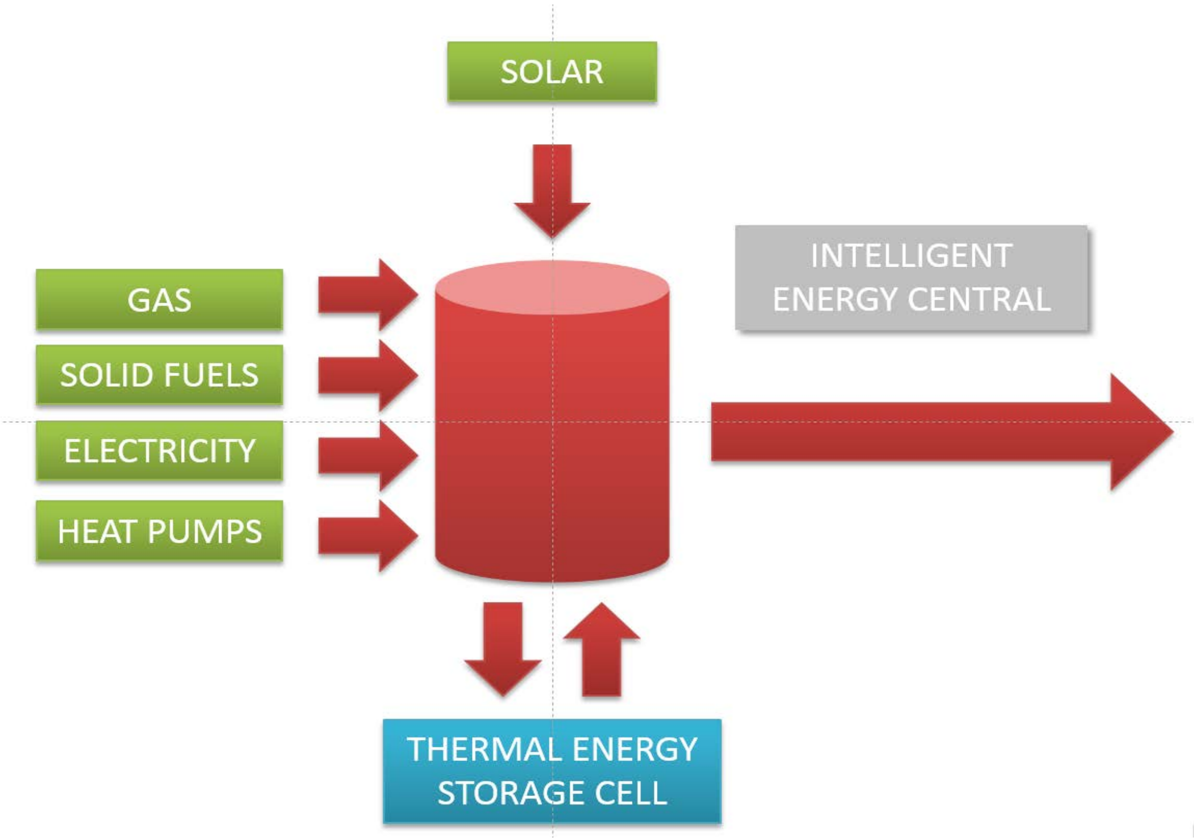

Fig.1 The high density thermal energy storage cell

3. Structure of the Storage Cell

The experimental storage cell consists of two containers. Both are made of structural concrete with 40 mm thin walls and 70 mm gap between both parts of the tank (Fig. 2). An inner surface of the smaller container and outer surface of the bigger container are covered by 1 mm thin steel plate as an anti-gas diffusion layer. Also special openings for input and output of special thermal medium and wider opening for vacuum pump are located in the top cover.

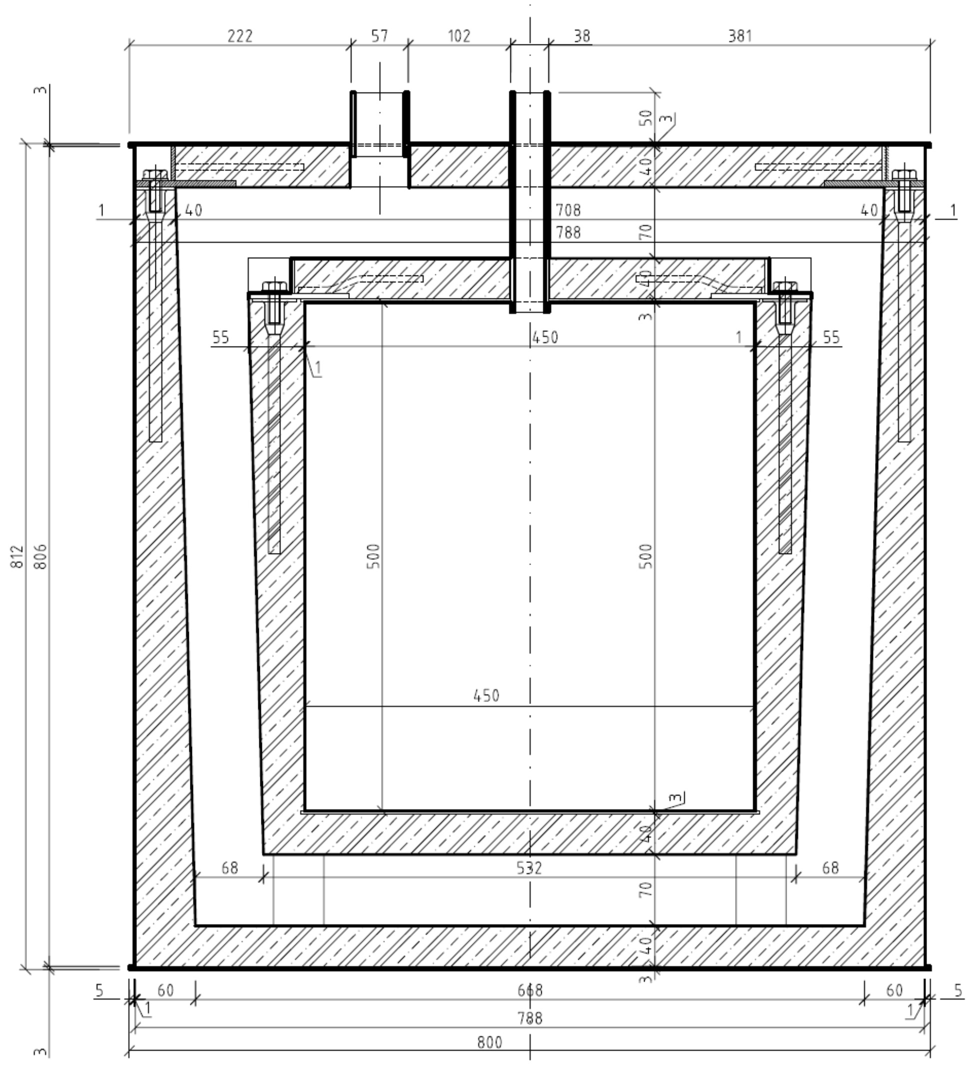

Fig.2 The scheme of the experimental storage tank

The thin steel layer of outer container is reinforced by horisontal and vertical ribs Fig.3. These were necesary for the time of concreting. As it was mentioned above the walls are made of structural concrete UHPFRC reinforced only with fibres. By the theoretical assumption of vacuum between two containers there are stresses about 100 kPa with precondition of atmospheric pressure of the thermal medium inside smaller container. Comming from these asssumption and possible strengths of UHPFRC the thicknees of the container walls was designed 40 mm.

Fig.3 Outer part of the container

Fig.4 Inner part of the container

Fig.5 Completed container

All parts of containers were filled with UHPFRC in Prague using a special made mould used for both containers.

4. UHPFRC composition and parameters

The UHPFRC composition for containers was based on the composition used for footbridge in Čelákovice [1]. New composition for container was optimized for daily-based production on usual concrete plant. There were used common types of aggregate (D_{max} 8mm), cement and admixtures. This allows producing UHPFRC whenever it is needed, without changing materials in silos. A disadvantage of this change is in a slight reduction of compressive strength and dry bulk density. A water/cement ratio was 0,21. The compressive strength development is shown in Fig. 6. The compressive strengths vary between 135 and 165 MPa at the age of concrete 28 days and between 146 and 176 MPa at 90 days, in dependence on the type and size of the testing specimen.

UHPFRC for container is reinforced exclusively by steel fibres. The amount of fibres is similar as that used for the footbridge (i.e. about 160 kg/m^3). Flexural strength was measured on small beams (160x40x40 mm) and on larger beams (700x150x150 mm). The splitting tensile strength was measured on cubes 150x150x150mm. The results of the performance in tension at the age of concrete 28 days are shown in Fig.7 and 8.

The measured values show that the smaller specimens provide higher strength in compression and in tension as it was already shown in [2]. Fig 8 shows very small scatter of flexural strength measured on 6 beams subjected to 4 point bending.

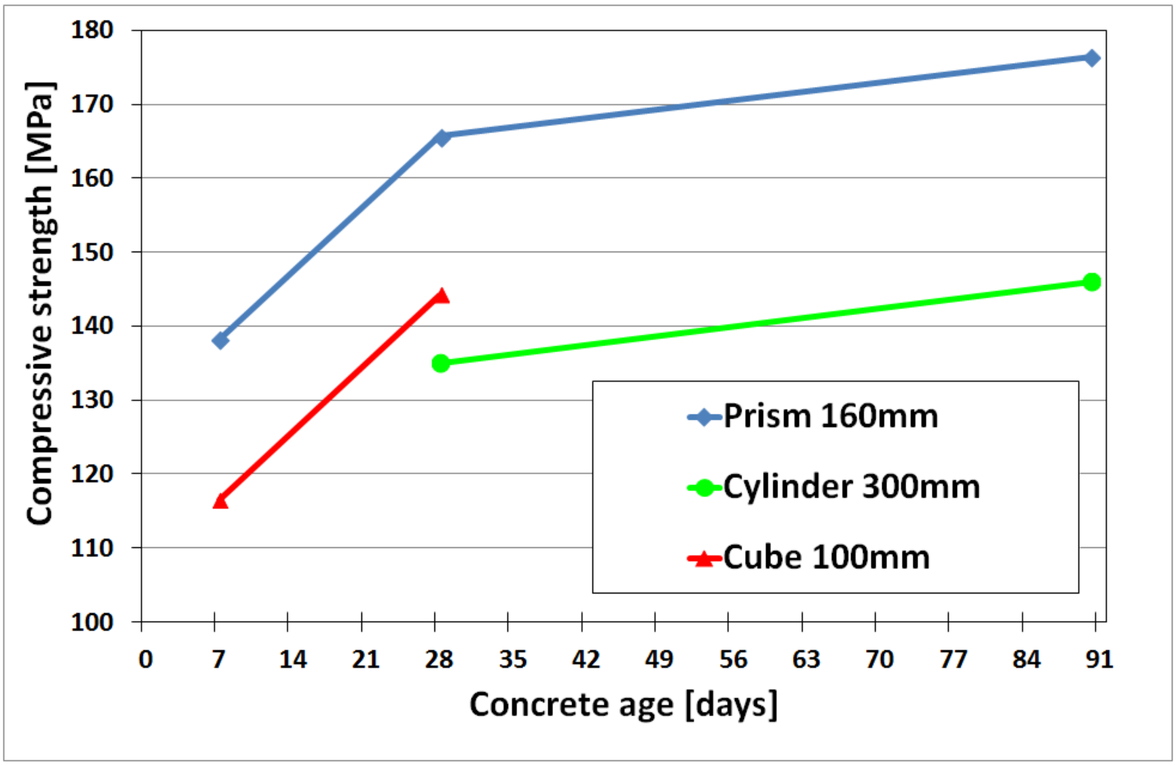

Fig. 6 Compressive strength in dependence on the age of concrete and on the type of the testing specimen

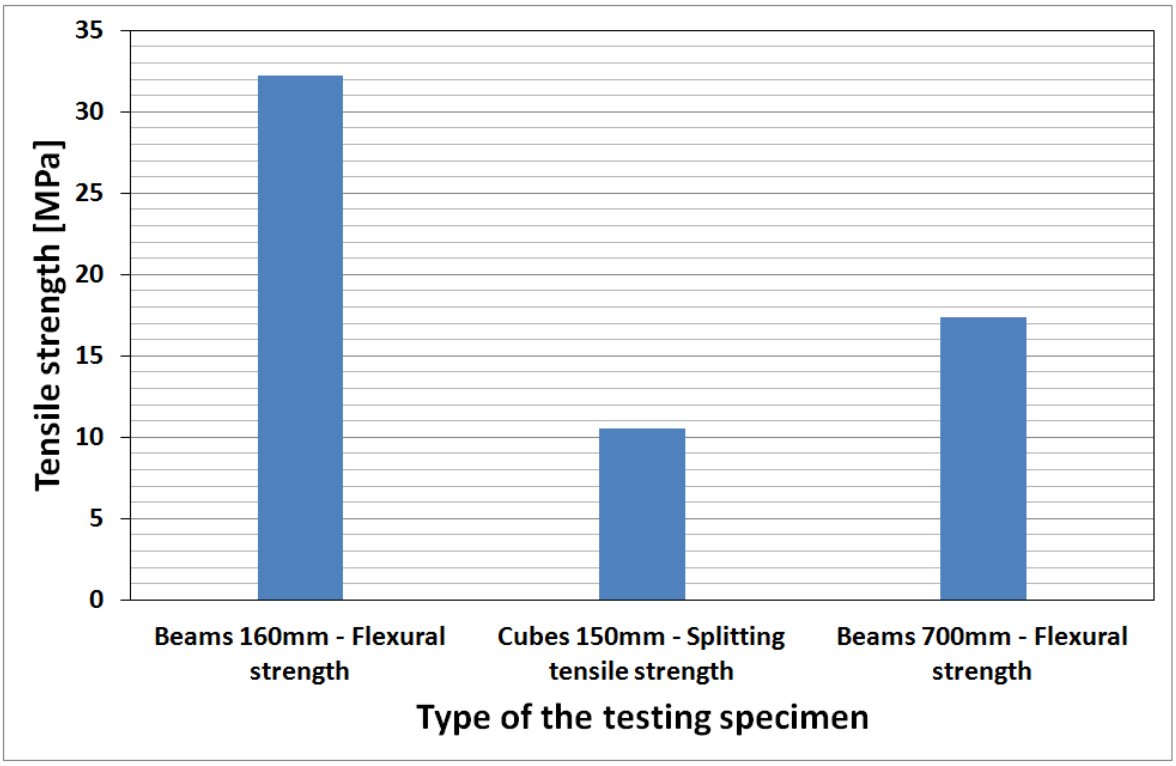

Fig. 7 Tensile strength in dependence on the age of concrete and on the type of the testing specimen (28 days)

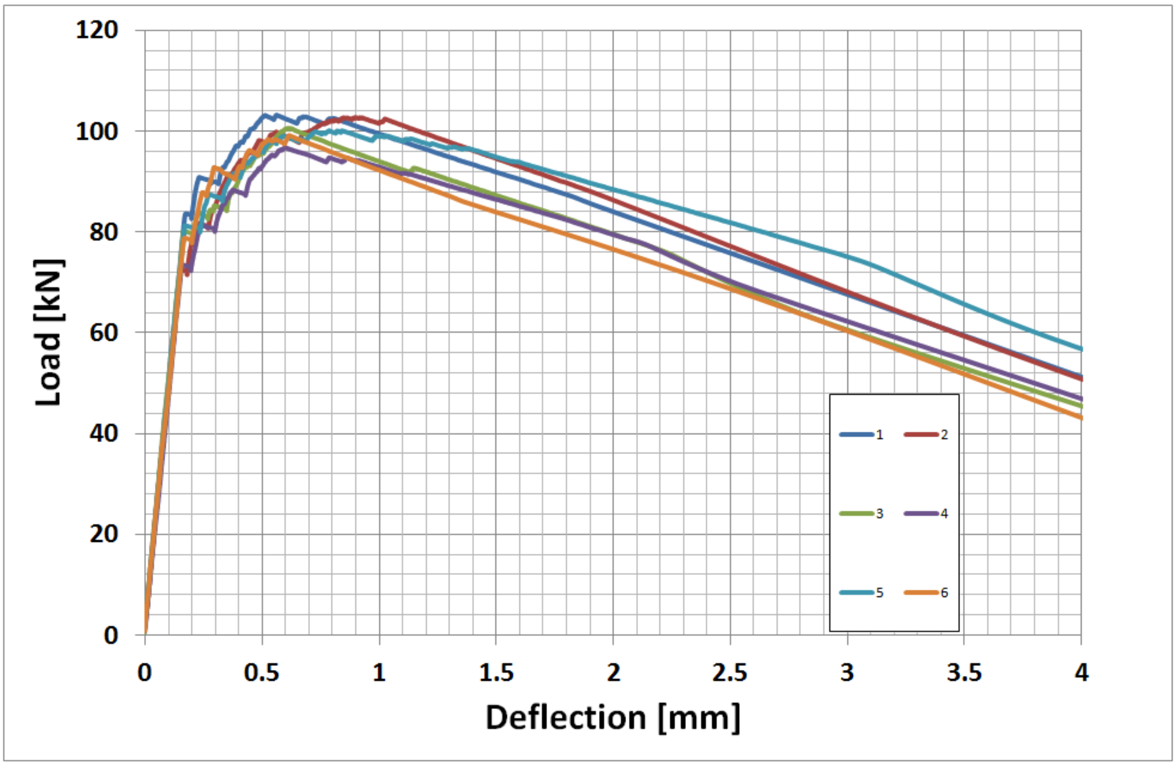

Fig. 8 Load deflection curves – 4 point bending test, beams 700 mm

5. Conclusions

The structure of vacuum insulated containers made of UHPFRC, which consists of two containers with 70 mm gap between them is presented in the paper. A medium situated in small container is insulated by vacuum and also by reflection layer to hold medium temperature stabile for a long period of time. The structure was designed at SUT in Bratislava and the container was made of UHPFRC prepared by TBG – Metrostav, Prague. The long-term thermal tests were realised in Kysucké Nové Mesto - Slovakia. The results of the material tests and the results of structural performance of the container are described in the paper.

The experiment showed that the UHPFRC represents an alternative material for production of the container. The concrete is able to carry the load of atmospheric pressure and allows the use of an expensive metal - stainless steel sheet only in a thin layer, which is sufficient to ensure the air tightness of the tank. The production is feasible and the excellent durability of the UHPFRC can contribute to the reliability of the proposed storage cell.

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