STATIC RESPONSE AND MODELLING OF IMPACT RESISTANCE OF UHPFRCC SLAB SPECIMENS

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Abstract

The demand for improved properties of the construction materials increase with time and the related design and construction codes are adapted in an analogous manner. UHPFRCCs represent a class of cement composites which have superior characteristics in terms of material properties. Their mechanical and fracture behaviour is substantially enhanced compared to other types of concrete. These materials have, however, a significant increase in cost over and above that of conventional and even High Performance Concrete and it is therefore appropriate to identify applications which will fully utilize their mechanical properties and performance characteristics. The aim of this study is to present the results on the development of an UHPFRCC, the experimental investigation of the quality and the behaviour of this material in a highly demanding application, such as the impact resistance of structures and finally the development of a Finite Element Analysis program which will form a basis for analysis of future field tests.

Keywords: Impact resistance, modelling, slabs, static response, UHPFRCC

1 Introduction

Ultra high performance fibre reinforced cementitious composites (UHPFRCCs) represent a class of cement composites which have superior characteristics in terms of material properties. Their mechanical and fracture properties are substantially enhanced compared to other types of concrete. With the advent of special processing methods and the use of high volume fraction of steel fibres, concretes of high compressive and tensile strength, as well as high energy absorption capacity have been reported. The produced materials are characterized by strain hardening and followed by tension softening due to localization of cracks.

2 Existing Knowledge

The basic principles in the selection of the constituent materials for the production of the UHPFRCCs are (Karihaloo et al., 2005 - Benson, 2003): (a) the enhancement of homogeneity by elimination of coarse aggregates, (b) the enhancement of compacted density by optimization of the granular mixture, i.e. microsilica improves the compacted density of the mix thereby reducing voids and defects, (c) the reduction of water/cement ratio and inclusion of superplasticizer ensures a workable mix, (d) the enhancement of the microstructure by post-set heat-treating, i.e. the silica fume and the quartz sand become highly reactive at these elevated temperatures, (e) the enhancement of ductility by incorporating small-sized steel fibres and finally, (f) the maintenance of the mixing and casting procedures as close as possible to existing practice for normal and high strength concretes. Application of post-set heat-curing appears to be an optional measure designed to enhance compressive strength but does not seem to have an effect on the flexural strength.

As described in authors' previous work (Nicolaides et al., 2012) it is possible to produce UHPFRCCs utilising the materials available in Cyprus. Developed mixtures have compressive and flexural strengths in the excess of 170MPa and 30MPa respectively, as well as modulus of elasticity in the range of 40GPa.

3 Static response of slabs

Once the optimum sand was selected, mixtures were prepared in order to cast slab-like specimens with dimensions 600x600x50 mm. Since UHPFRCCs are characterised from their unique high performance properties, such panels can be used as protective cladding to conventional concrete frames, guarding against high strain rate loads.

As a result, it is very important to study and understand their static response first. Note that the work presented here is a part of a research project studying the impact and blast resistance of such panels (Nicolaides et al., 2012). Each slab was equipped with strain gages and LVDTs to measure strain development and deflection under loading, respectively. All panels were tested in a 250 kN MTS servo-hydraulic actuator. Figures 1 and 2 show the experimental set-up.

Fig. 1 Experimental set-up for the static tests in UHPFRCC slabs.

Fig. 2 LVDTs arrangement for the static test.

During static loading all slabs have failed in tension, with fibres being the key factor in avoiding catastrophic punching failures in the studied specimen. Failures have been recorded between 52kN and 75kN with mid span deflections ranging between 3 and 5 mm, depending on the supports. Fixed supported specimens exhibited punching shear failures at high load values exhibiting extensive deflections. On the other hand, simply supported slabs failed in flexure at lower load values exhibiting less displacement. At failure, large cracks have been formed at the tension face of the slabs. Nonetheless, these cracks did not evolve to large through cracks, due to the bridging action of the fibres. Figure 3 shows the load-deflection results for two slabs tested with different supports.

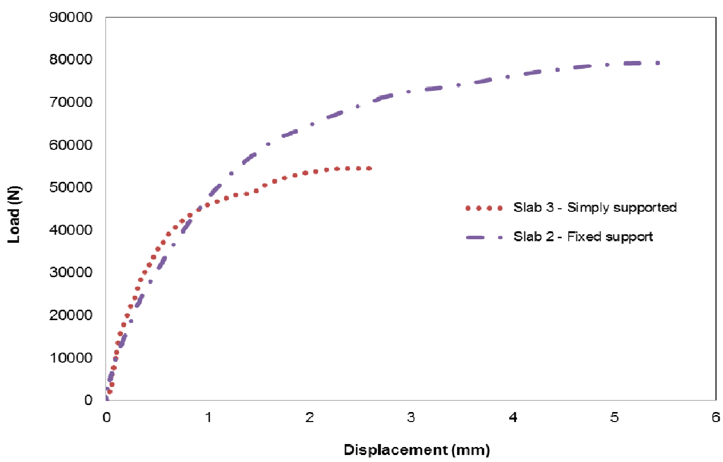

Fig. 3 Load-deflection curve for one of the slab specimens.

4 Modelling impact on UHPFRCC slabs

The work presented here is part of a European co-funded project investigating mechanical properties, static and impact resistance of UHPFRCC slabs. The impact tests have been designed to include high speed projectiles such as small/medium calibre bullets and anti-tank missiles. A numerical model was developed for the finite element analysis of UHPFRCC panels using AUTODYN (AUTODYN, 2005). However, it has to be noted that the developed model is just a preliminary attempt to model the complex phenomenon of subsonic projectile impact on composite panels.

The model will be calibrated once the first field test results will be available. For the requirements of the analysis, the RHT constitutive model was used. The adopted parameters for the simulation were based on the model proposed by Leppänen (Leppänen, 2006). Equation of state has been developed to correlate the pressure to density of the material while for the simulation of the projectile the 1006 Steel Johnson Cook constitutive model was used (AUTODYN, 2005). Since in practice high speed projectiles are going to be used, for the purposes of the simulation the initial velocity of the projectile was set to 295 m/s. For the simulation of the UHPFRCC panel, Smoothed Particle Hydrodynamics (SPH) Lagrangian mesh-free method was used while the projectile was simulated using Lagrangian mesh method.

In the present work six different 3D models were examined. Two different wall thicknesses of 50 mm and 100 mm were examined (volumetric elements) and steel plates (shell elements) were used for the strengthening of the front and the back side of the walls. In Table 1 the characteristics of the examined models are presented.

Table 1
Description of the examined models

Thickness of wall (mm)	Thickness of steel plate (mm)	Position of steel plate
50	-	-
100	-	-
50	1	Back side
50	1	Front and back side
50	5	Back side
50	5	Front and back side

The results of the analyses indicate that in both cases (50 mm and 100 mm thickness) when UHPFRCC slab was examined with not any additional steel plates, the structure was completely damaged (Figure 4) while when steel plates were placed in the front and the back side of the slab the damage was considerable reduced (Figure 5).

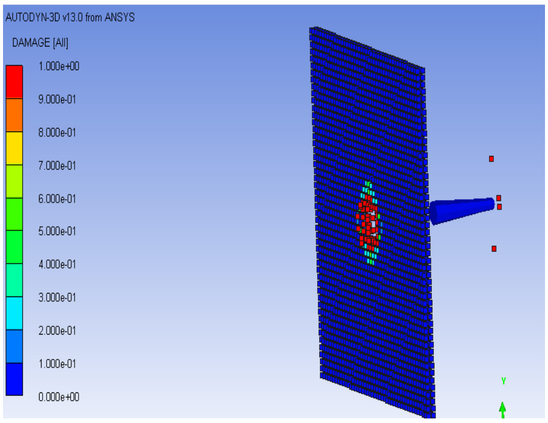

Fig. 4 Impact on the slab without the existence of steel plates

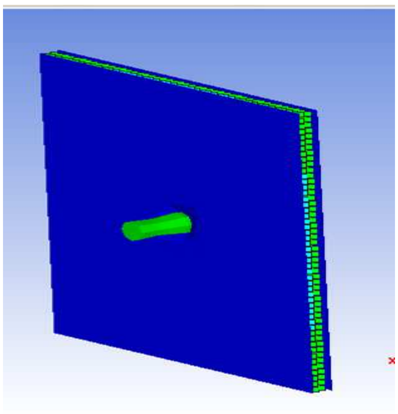

Fig. 5 Impact on the slab that has steel plates as additional reinforcement.

The results indicate that the UHPFRC wall can reduce the speed of the projectile and this reduction was higher for the thicker wall (100 mm), as expected. It is very important to note that the model simulates the properties of the material under impact with an arbitrarily selected projectile. Once the field tests will start the type and speed of projectile will be calibrated in the code, with respect to the obtained field measurements. With regards to UHPFRC energy (Figure 5), the highest values were observed for 100 mm walls and this value was reduced for thinner walls (50 mm). Further reduction was achieved with the application of steel plates.

5 Conclusions

The results from the current study showed that mode of failure under static loading in UHPFRCC slabs can vary depending on the type of support. Using fixed supports the load carrying capacity of the element increases and finally fails under punching shear with extensive deflection. Simply supported slabs exhibited less load carrying capacity failing in flexure. Additionally, a preliminary model has been developed in order to simulate the complex phenomenon of high speed projectile impact on UHPFRCC slabs. The model will be used and calibrated further once the field tests on impact will commence.

Acknowledgement

The authors would like to express their sincere gratitude to the Republic of Cyprus, the Cyprus Research Promotion Foundation (RPF) and the European Regional Development Fund, for funding the research project entitled “Mix Design, Mechanical Properties and Impact Resistance of Ultra High Performance Fibre Reinforced Cementitious Composites” (Contract: ΤΕΧΝΟΛΟΓΙΑ/ΥΛΙΚΑ/0609(ΒΙΕ)/01).

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