INVESTIGATION OF ULTRA HIGH PERFORMANCE FIBER REINFORCED CONCRETE UNDER IMPACT LOADING

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ABSTRACT. In order to study the influence of the ultra-high performance fiber reinforced concrete (UHPFRC) beams on impact performances. Impact analysis was conducted on varying percentage of fiber in concrete beams having 35MPa and 140MPa compressive. The targets beam of dimension 100mm×100mm with 500 mm of length is studied. The beams were subjected to an impact of rectangular impact or weighing 50kg. The impact or were modelled by ANSYS V18.0 Design Modular to drop height range between 500 mm to 2000 mm. Impact resistance of UHPFRC beams at different velocities and varying percentage of fibers had been find out analytically. The results thus obtained from numerical investigation in finite element code ANSYS are presented in terms of deformation, stress, strain, energy absorption capacity and damage pattern due to the drop impact are discussed.

Keywords: UHPFRC, Impact Loading, ANSYS Workbench V18.0, RHT Concrete Damage Model.

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INTRODUCTION

Terror attacks against civilians continued to increase worldwide. Ordinary concrete, which is the most widely used construction material, is however vulnerable to the extreme loadings caused by impacts and blasts. This vulnerability is due to the brittle nature of concrete under tension, which results in poor energy absorption capacity and sudden collapse shortly after the formation of first-cracking. Many studies have been performed to overcome the brittle nature of concrete by adding discontinuous fibers into the brittle cementitious matrix; this strategy has proven to be one of the most promising and simplest methods. In particular, ultra high performance fiber reinforced concrete (UHPFRC), which was developed in the mid-1990's, has recently been considered as a material applicable for structures subjected to these types of extreme loadings, due to its excellent mechanical strength and energy absorption capacity.

UHPFRC is a relatively new generation of fiber cementitious composites which has been developed to give significantly higher material performance than other concrete classes. UHPFRC exhibits outstanding mechanical and durability properties. Such properties include ultra compressive strength exceeding 120 MPa, enhanced tensile strength exceeding 8 MPa, ductility, flexibility, toughness, dimensional stability, durability, impermeability, corrosion resistance, abrasion resistance, and aggressive environment resistance. Such superior properties have been achieved through the use of an optimized combination of materials which include cement, fine sand, micro silica, high-range water reducing admixture (HRWRA), a very low water content, and fibers.

Low-velocity, high-mass impact loading conditions with velocities up to 10 m/s is the most common impact scenarios for civil engineering structures. Typical low-velocity impact scenarios include transportation structures subjected to vehicle collisions, and offshore structures subjected to ice and/or ship impact. Additionally, loading arising from natural hazards such as earthquakes and tornadoes are also related to low-velocity impact. Several experimental investigations at the material level have demonstrated that UHPFRC exhibits excellent dynamic properties. However, analytical investigations on the dynamic response of UHPFRC structural members (that is, beams and slabs) are limited. Additionally, most of available data in literature are related to extreme loading conditions, such as blast loading and high-velocity impact simulation using shock tube testing. In summary, all these investigations confirmed that UHPFRC shows improved performance and superior damage control properties under extreme load conditions compared to conventional concrete.

Therefore, some researchers currently regard it as a promising material for innovative structures subjected to severe loading conditions such as impact, shock, and explosive loadings.

The application of UHPFRCs to civil infrastructures, especially those subjected to impacts or blasts, is still limited because of the high cost and relatively low workability of the materials. Most UHPFRCs contain high fiber volume contents between 2 and 6%, which generally increase the cost and decrease the workability of the composites. Consequently, it is important to minimize the volume of steel fibers for the practical application of UHPFRC, without sacrificing the high resistance to impacts or blasts. To reduce the volume of steel fibers added for tensile strain hardening behaviour, without sacrificing the high impact or blast resistance of the final concrete, various approaches have been developed as follows: (1)

maximizing the packing density of the matrix, thus increasing the physical or chemical bond strength between the fibers and matrix; (2) utilizing deformed steel fiber geometries to generate mechanical interfacial bond strength ; and (3) adding nano materials to provide nano-level reinforcement.

Several studies have reported the high impact and/or blast resistance of various commercial UHPFRCs at both material and structural performance levels. The mechanical properties, including the compressive strength, tensile strength, and fracture energy, of with 6% steel fibers and with 5% steel fibers were sensitive to the applied strain rates, compact reinforced composites, another type of UHPFRCs contains 6% steel fibers; under impact loads, CRC produced a flexural strength and toughness twice and four times higher, respectively, than those of normal fiber-reinforced concrete (FRC). In addition, columns of UHPFRC containing 4-6% steel fibers produced very high blast resistance by reducing the maximum displacement, enhancing the damage tolerance, and eliminating secondary blast fragments. UHPFRC panels or slabs with 2-6% steel fibers have shown high ductility, limited permanent deformations, and substantial energy absorbance without fragmentation under blast loads.

LITERATURE REVIEW

Habel Katrin et al (2008) presented an experimental and analytical (*ANSYS*) study of rate-dependent *UHPFRC* behaviour. The results of this study showed that multiple cracking was observed in the high moment region and final fracture occurred by fibre pull-out in one localized bending crack at the center of the specimen.

T. Yua et al. (2010) proposed a modified plastic-damage model within the theoretical framework of the Concrete Damaged Plasticity Model (CDPM) in ABAQUS for the modeling of confined concrete under non-uniform confinement. The modifications proposed for the CDPM include a damage parameter, a strain-hardening/softening rule and a flow rule, all of which are confinement-dependent, and a pressure dependent yield criterion. The proposed model can also be very usefully exploited in FE models to investigate the behaviour of confined concrete in various forms of columns to develop a better understanding of structural behaviour and to develop design methods for practical use.

Thomas Borrvall et al. (2011) were presented the RHT model in LS-DYNA together with sample data input and an application example. Because of the general interest of this model they believed that this will be a motivated contribution to the available set of concrete material models in LSDYNA. The post-yield and post-failure behaviours are characterized by strain hardening and damage, respectively, and strain rate effects is an important ingredient in this context. Furthermore, the pressure is governed by the Mie-Grune is equation of state together with a p-α model to describe the pore compaction hardening effects and thus give a realistic response in the high pressure regime.

Bindiganavie Vivek et al (2012) concluded that under impact loading, Carbon Reinforced Concrete (*CRC*) is capable of dissipating much higher energy compared with conventional *FRC* with polymeric or steel fibre. *CRC* is an Ultra High Performance Concrete (*UHPC*) with a compressive strength around 200 MPa and splitting tensile Strength found to be around 20 MPa.

Haitham Al-Thairy, et al. (2013) presented a simplified analytical method to predict the critical velocity of transverse impact by rigid body on steel column under axial load using ABAQUS/Explicit. The parameters investigated included different levels of axial load (0, 0.3 0.5 and 0.7 of the column's design load), different section sizes, different boundary conditions, different impact locations and different column slenderness ratios (36.05, 51.5 and 76.9). The impact velocity ranged from 20 km/h to 80 km/h. They found that the agreement between the analytical and ABAQUS simulation results was very good.

Kamel S. Kandil et al. (2014) compared the comparison between the field test results for the slabs subjected to a 33.4 kg shot with the results of the explicit analysis using LS-Dyna. Explicit analysis using LS-Dyna model provides much better presentation than implicit analysis using ANSYS model. In implicit analysis, analysis is terminated due to convergence problems before reaching the peak blast reflected pressure. In explicit analysis, the analysis continues to the end of blast load. The maximum deflection at the center of plate for explicit analysis is much closer to experiment measurements than implicit analysis. Predicted damage patterns in LS-Dyna model are closer to experimental work than ANSYS model.

Anil Ozgur et al (2015) observed experimentally as well as analytically (*ANSYS*) that the highest no. of drops is obtained from the specimens supported on four sides, while the lowest no. of drops when slab supported on two adjacent sides. It was also observed that generally crack distribution concentrated at supported sides while fewer cracks are observed on the sides without supports.

Abhishek Rajput et al. (2016) found experimentally that ballistic limit of the reinforced concrete plates is increased 20%, 25% for 80mm, 100mm thicknesses respectively, when compared to plain concrete plates. Also Residual velocities for reinforced concrete plates are decreased when compared to plain concrete plates. Equivalent diameter was increases with decrease of the impact velocity till ballistic limit however at low velocity higher global deformation had been found when compare to higher velocity for the same specimen. spalling of the impacted concrete plate were almost equal at different velocities however scabbing were increase with decrease of the velocities till ballistic limit of the specimen. Due to the incorporation of reinforcement in the concrete plates there is very huge decrease in the scabbing however when striking velocity of the projectile is low then scabbing in the rear face of the concrete plate is high for plain concrete plates and as well as reinforced concrete plates. It is also found that pressure wave propagation is very slow due to confinement of concrete so cracks were very small while in case of plain concrete cracks were wide and long.

Anil Ozgur et al (2016) obtained experimentally that the smallest cracks formed on the test specimen's manufactured using Engineered Cementitious Concrete (*ECC*) and the largest cracks formed on the test specimens manufactured using low strength concrete. For the numerically simulated specimens, analytical results are in good agreement with the measured results in terms of maximum displacement and load values.

H. Othman et al. (2016) conducted experimental investigation to address the advantage of using UHPFRC in low-velocity impact resistance structures and to investigate the effect of steel reinforcement ratio and fiber volume content on the impact behaviours of UHPFRC plates. The UHPFRC plates exhibited superior performance with regard to damage control characteristics under low-velocity impact loading conditions when compared to reinforced concrete plate cast with HSC concrete. Under repeated impact tests, all UHPFRC plates, regardless of the fiber volume dosage and/or steel reinforcement ratio, reached the target cumulative residual displacement of 65 mm and only bending cracks were observed without any significant punching shear cracks. Increasing the fiber content showed great improvement of the dynamic properties of the UHPFRC plates, resulting in reduced peak deflection and residual displacement at same impact loads and an overall increase in the specimen ability to sustain increased impact energy capacity before failure.

M.A. Iqbal et al. (2016) concluded that the concrete with 20% induced prestress offered highest ballistic limit followed by the concrete with 10% induced prestress and non prestressed concrete respectively. Ballistic experiments have been carried out on prestressed concrete targets of different magnitudes of induced initial stress and the results have been compared with non prestressed concrete targets. Finite element simulations have also been conducted on a commercial finite element code employing HJC model for concrete and JC model for reinforcement.

Waseem F. K. Al-Muqdadi et al. (2016) described modelling of reinforced concrete slabs under impact loading using finite elements. The crack patterns at the bottom face of all slab specimens was found to be in very good agreement when compared with those of the tests. Similar crack patterns, damage and failure process of specimen were found through the comparison between the analysis and the experiment. The punching shear failure of impacted slabs was very well predicted in the analysis. The analytical results show that the damage of slab under impact loading can be efficiently reduced by adding traditional shear stirrups.

Yao Xiao et al. (2016) investigated that similar crack patterns, damage, and failure processes of specimens were found through the comparison between high loading- rate testing and impact testing for reinforced concrete slab. Both longitudinal and transverse reinforcements are effective in enhancing the maximum strength of specimens. The experimental results show that the damage of slab under both high-rate and impact loadings can be efficiently reduced by adding shear stirrups.

Abhishek Rajput et al. (2017) have been carried out the experiments and numerical simulations for studying the ballistic performance of plain, reinforced and prestressed concrete targets of thicknesses 60 and 100 mm against 0.5 kg ogive nosed steel projectile. The ballistic resistance for a given thickness and type of concrete increased with the decrease in incidence velocity of projectile. The increase in the ballistic resistance with the decrease in projectile velocity was most prominent in prestressed concrete followed by reinforced and plain concrete respectively. The numerical results accurately reproduced the residual projectile velocities and also witnessed the highest ballistic resistance offered by prestressed concrete followed by reinforced and plain concrete.

Yao Xiao et al. (2017) found that the damage of slabs under low-velocity impact increases with increasing impact energy. The change of mass and drop height of impactor do not affect the slab damage so much as long as the impact energy is fixed. Compared to the flat nose shape impactor, the hemispherical nose shape impactor can cause penetration on RC slabs with relatively small impact energy but requires more impact energy to cause punching shear failure on them. In addition, more impact energy is required to fail RC slabs when the diameter of impactor increases. Results from the finite element analysis show that an increase in any of concrete strength, diameter of impacted area, and slab thickness can effectively boost the energy capacity of a lightly reinforced concrete slab, whereas the effect of longitudinal reinforcement ratio was limited.

Jian Liu et al. (2018) numerically investigated the effects of steel wire mesh reinforcement on reactive powder concrete (RPC) targets subjected to high-velocity projectile penetration at the striking velocities ranging from 539 to 1000 m/s based on a computer program called LS-DYNA. They found, the addition of steel wire meshes in RPC targets is of great significance to enhance its capacity to resist the high velocity projectile penetration regarding the depth of penetration (DOP), localized and crater damages also the energy absorption capacity of steel wire meshes is very sensitive with its tensile strength and volumetric fraction in RPC targets.

COMPUTATIONAL MODEL

The UHPFRC targets and the rectangular impactor (weight 50kg) were modelled in ANSYS V18.0. Initially the plan dimensions of the targets, 100mm× 100 mm with length 500mm, were modelled.

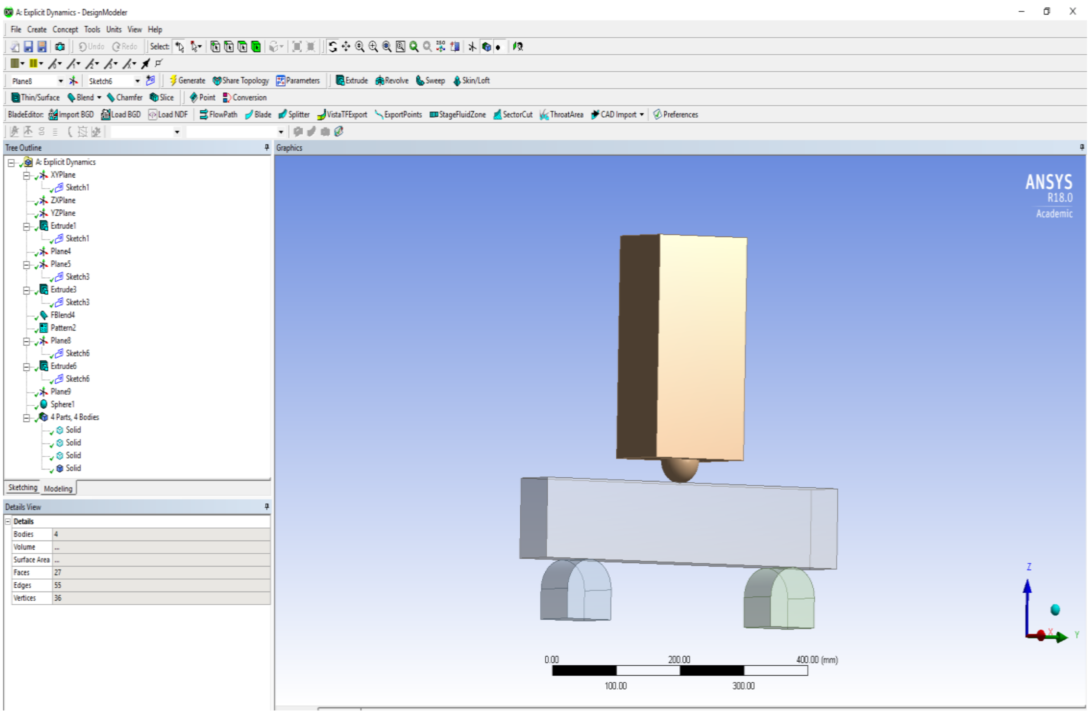


Figure 1 Geometry model of Beam specimens

In Table 1and Table 2 summary of the properties of the material model used for steel supports, steel impactor and RHT concrete material model are given.

Table 1 Material model properties of steel supports and steel impactor

NAME	UNITS	STEEL SUPPORTS AND STEEL IMPACTOR
Density	Kg/m^3	7800
Poisson’s ratio	None	0.3
Young’s Modulus	MPa	210000
Bulk Modulus	MPa	166670
Shear Modulus	MPa	76923

Table 2 Material model properties for RHT concrete model

NAME	UNITS	NSC	UHPFRC
Density	Kg/m^3	2314	2520
Poisson's ratio	None	0.20	0.20
Specific heat	J/(kgC)	654	
Compressive Strength (fc)	MPa	35	140
Tensile to compressive strength (ft/fc)	None	0.1	0.1
Shear strength to compressive (fs/fc)	None	0.18	0.18
Intact failure surface constant A	None	1.6	1.6
Intact failure surface exponent N	None	0.61	0.61
Tens./Comp. Meridian ratio Q2.0	None	0.6805	0.6805
Brittle to Ductile Transition BQ	None	0.0105	0.0105
Hardening Slope	None	2	2
Elastic Strength/ft	None	0.7	0.7
Elastic Strength/fc	None	0.53	0.53
Fracture Strength constant B	None	1.6	1.6
Fracture Strength constant m	None	0.61	0.61
Compressive strain rate exponent α	None	0.032	0.00909
Tensile strain rate exponent □	None	0.036	0.0125
Maximum fracture strength ratio SFMAX	None	1E+20	1E+20
Use cap on elastic surface	None	Yes	Yes
Damage Constant D1	Non	0.04	0.04
Damage Constant D2	None	1	1
Minimum strain to failure	None	0.01	0.01
Residual shear modulus fraction	None	0.13	0.13
Shear Modulus	MPa	11200	
Polynomial EOS			
Parameter A1	MPa	35270	35270
Parameter A2	MPa	39580	39580
Parameter A3	MPa	9040	9040
Parameter B0	None	1.22	1.22
Parameter B1	None	1.22	1.22
Parameter T1	MPa	35270	35270
Parameter T		200	
P-alpha EOS			
Solid Density	Kg/m^3	2750	2750
Porous Soundspeed	m/s	2897	3242
Initial Compaction Pressure Pe	MPa	18.37	93.30
Solid Compaction Pressure Ps	MPa	6000	6000
Compaction Exponent n	None	3	3

NUMERICAL SIMULATION

The simulation for predicting impact performance of ultra high performance fiber reinforced concrete beams with varying percentage of fibers and different velocities ranges from

3.13m/s to 6.26m/s were carried for drop weight impact simulation, performed in ANSYS/Explicit.

RESULTS AND DISCUSSION

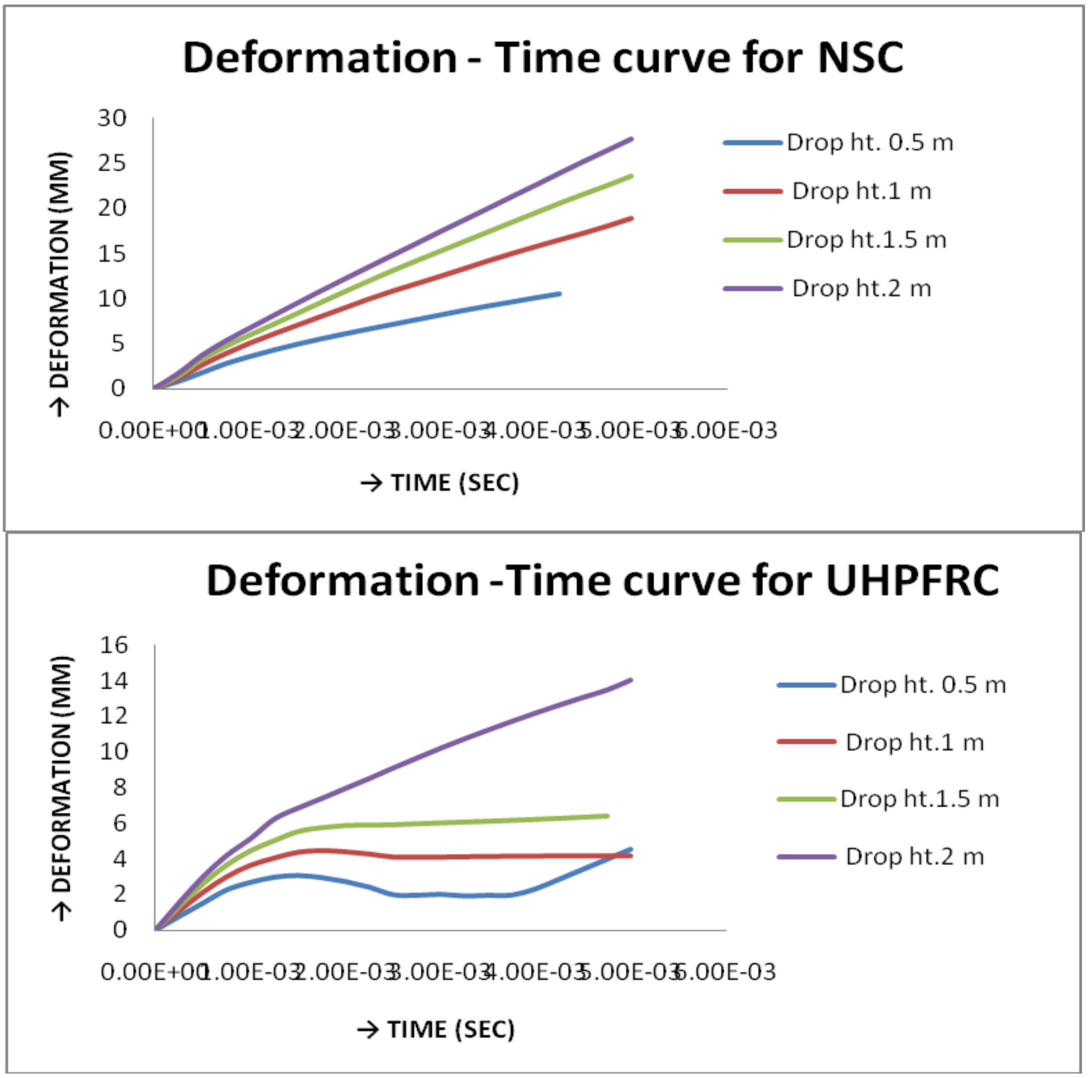


Figure 2 Deformation-time curve for the NSC and UHPFRC under different drop height

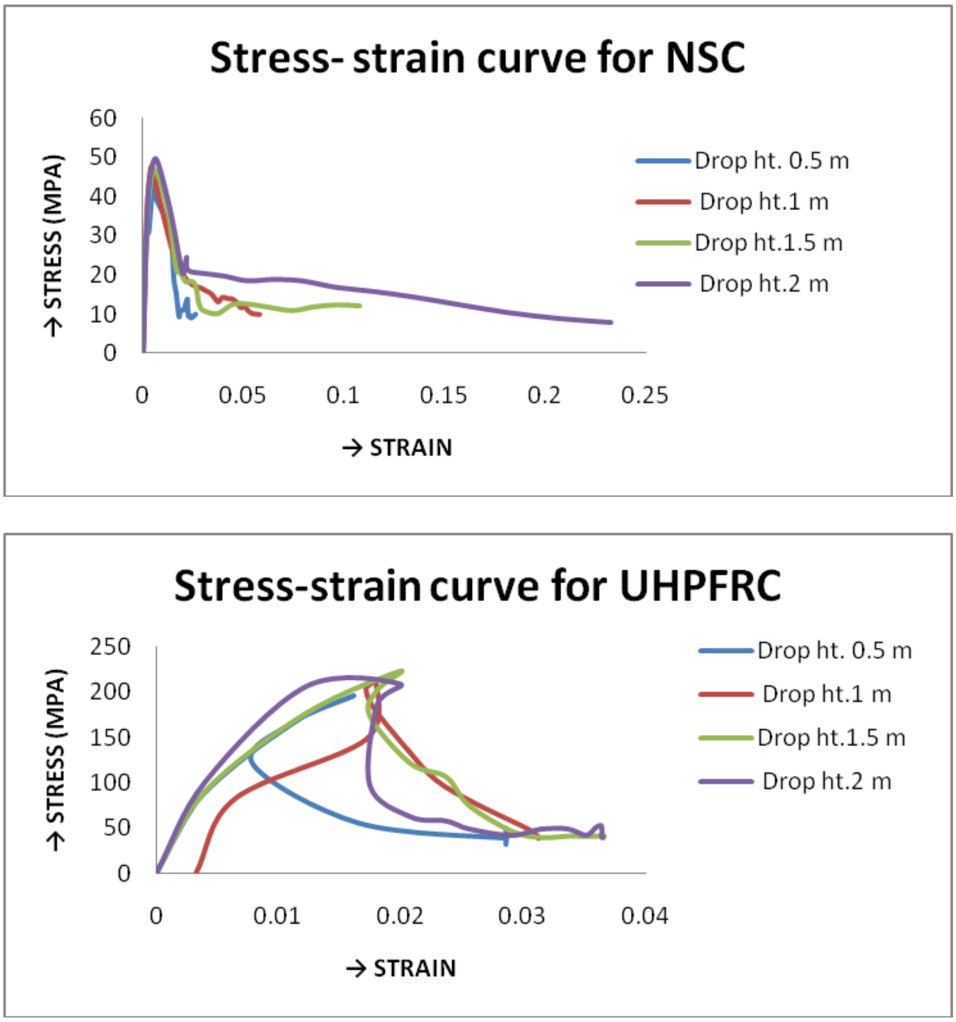
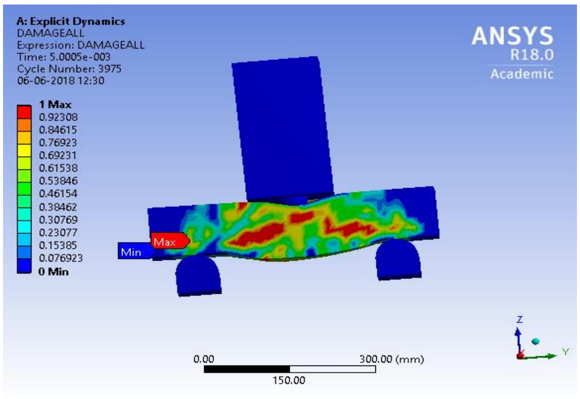
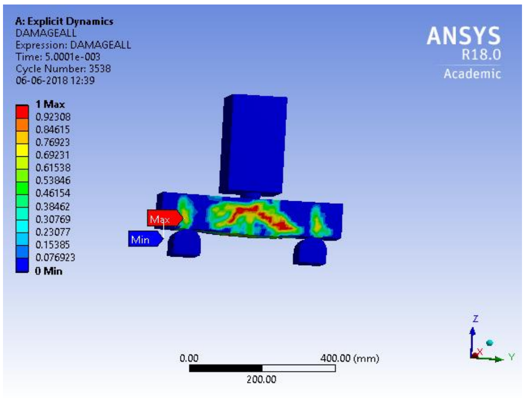


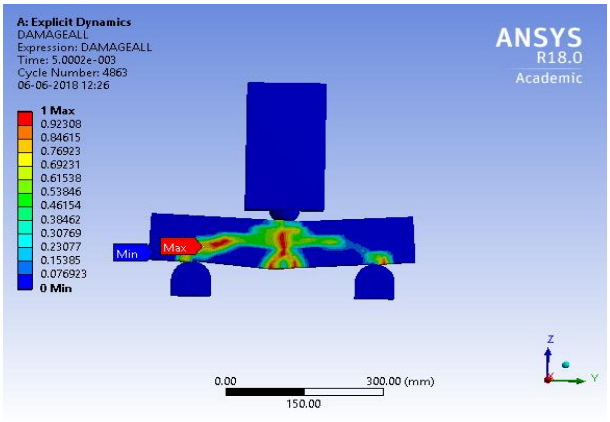
Figure 3 Stress-strain behavior for NSC and UHPFRC beams under different drop height



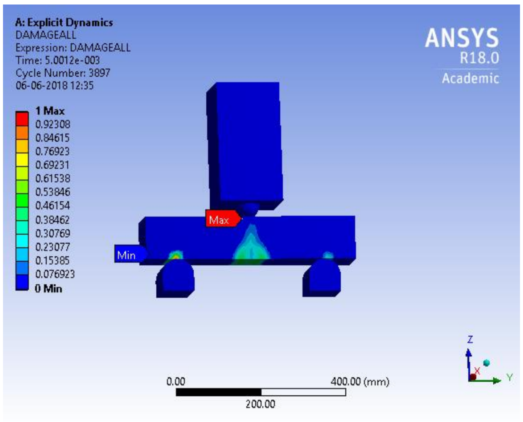
a. Falling ht. from 0.5 m



b. Falling ht. from 2 m

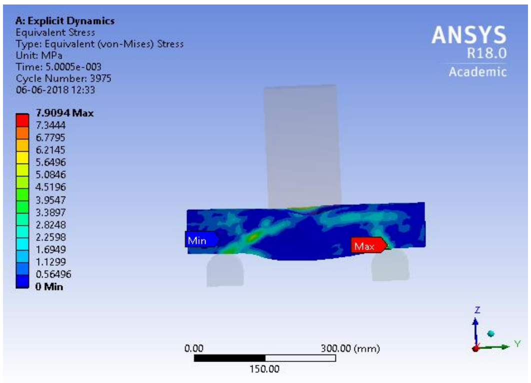


c. Falling ht. from 0.5 m

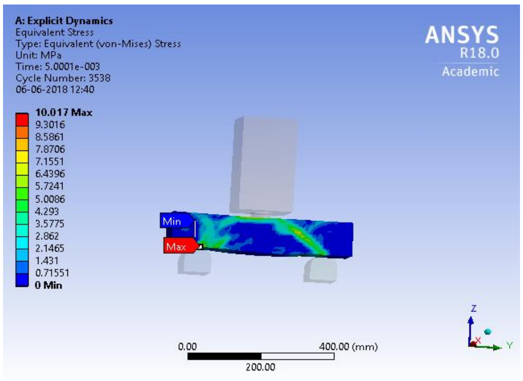


d. Falling ht. from 2 m

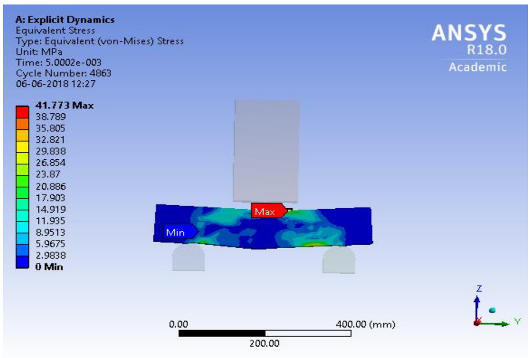
Figure 4 Damage pattern of NSC (fig 4a & fig.4b) and UHPFRC (fig. 4c & fig. 4d)



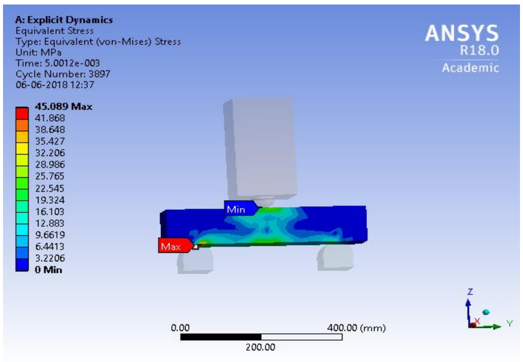
a. Falling ht. 0.5 m



b. falling ht. 2 m



c. Falling ht. 0.5 m



d. Falling ht. 2 m

Figure 5 Equivalent Stress behavior of NSC (fig. 5a & fig. 5b) and UHPFRC (fig. 5c & fig. 5d)

CONCLUSIONS

The impact response of UHPFRC beams was numerically investigated. Based on the numerical investigations the following conclusions are drawn.

i. The UHPFRC beams exhibited superior performance with regard to damage control characteristics under low velocity impact loading conditions when compared to normal strength concrete.
ii. Among the two NSC and UHPFRC investigated, it appears that the deformation under impact loading increases with increasing the drop height.
iii. The energy absorption capacity under impact loading increases only for UHPFRC, on the other hand, a reduction in the energy absorption capacity was noted as the severity of impact velocity was increased.
iv. The result show that the peak stresses of the NSC and UHPFRC of 2 m drop height was more than the peak stress of 0.50 m drop height for simply fixed condition.

This study demonstrates that the advantageous properties of UHPFRC over NSC under impact loading.

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