Development of Ultra High Performance Concrete for Resistance under High Strain Rate Impact

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ABSTRACT

Ultra-high strength concrete (UHPC) is a modern composite material with extremely good mechanical characteristics. Component materials and curing regimes significantly affect the properties of UHPC. For this reason, the influence of supplementary cementitious material (metakaolin) and curing regimes (accelarated curing) on the properties of UHPC has been analyzed. With advances in concrete technology, ultra-high performance concrete (UHPC) has become a new focus for researchers and the concrete industry. UHPC is characterized by high compressive strength and excellent durability properties resulting in lighter structures and longer life. Unlike conventional concrete, On the other side optimization of UHPC mix is also necessary to get the desired result. The optimized particle-packing allowed an increase in the concrete compressive strength leading to what was called Ultra-High-Strength Concrete (UHSC), and also an increase in the durability performance of concrete. Particle packing has been recognized to influence mechanical and durability properties of cementitious materials, which are generally favored by optimum packing density. An Ultra-High-Performance Concrete with an optimized particle packing by using a special selection of fine and ultrafine particles, low porosity and high durability. The use of a minimum content of fibers to guarantee a minimum degree of matrix ductility. Particle packing density is always playing an important role in the development of Ultra high strength concrete. In this study Puntke test was adopted to get the highest particle packing density of the cement and mineral admixture. Packing density test (water demand test) was performed on three binary mixture they were C+MK, C+SF, C+UFS. Among the three binary mixtures C+MK showed the highest packing density. C+MK further used to develop mixes. Optimization of mix designs was done by increasing or decreasing the percentage value of used material and further compressive strength test was performed on these trial mixes. Trial mix 13 showed the maximum compressive strength, because of more optimized mix design use in it. Influence of inert admixture and inert fillers were also investigated. For the simulation JHC model was adopted to analyzed the projectile impact.

INTRODUCTION

Concrete is the world`s most consumed construction material because of some high-five benefits which include easy availability of raw materials, easy casting and so on. But along with those advantages, there are some drawbacks and shortcomings rendering a reason for most of the structures like skyscrapers; bunker is not made with pure concrete. Still the material engineers, civil engineers and scientists are trying to uplift and enhance the properties lied within the matrix of the concrete mass. Among those efforts one of the listed attempt is development of Ultra High-Performance concrete (UHPC) and Ultra High-Performance Fiber reinforced concrete (UHPFRC) in structures. Requirement of a good concrete is now becoming a first preference of important structures. Good concrete is a sustainable building material, it is totally friendly towards the environment during its whole life span from its making to its destruction. It's also safe against the impulsive loading which become a very important aspect of safety. Requirement of safe and good concrete takes high to build high rising building, towers etc, these buildings are designed to resist the various natural as well as man-made load events, e.g. earthquake crash of plane now we have to also include the terrorist attacks. So structure should have the ability to resist the impact generated by any penetrating projectile, so it became necessary to examine the damage and after analyses design structure to show protection against the multiple projectile impact. To give the additional safety to important structure`s new high tech concrete like and UHFRC should take under practices. Concrete is an essential material used in concrete structures. It has also contributed to the development of the construction industry. It became the main axis of the construction industry over a hundred years ago, before the First World War broke out. This led to an increased interest in preserving human life and the safety of concrete structures. There has been also a great deal of interest in the impact resistance of concrete against conventional weapons. Petry began research on the impact resistance of concrete and developed the formula for evaluating it in 1910. Research on the impact resistance of concrete has been carried out since the First World War began, and the research continues in the present day. The importance of concrete structures has increased for over a hundred years, and safety-threatening factors have become more diverse. Concrete materials and structural design techniques have advanced a great deal in the academic field.

LITERATURE REVIEW

Tironi et al. studied the influence of different thermal treatments (i.e., different temperatures) and different durations on the activity index of high purity virgin kaolin with 98% kaolinite. Poon et al. [39] showed that the initial reactivity of MK in blended cement pastes is higher than that of silica fume or fly ash. Due to the high initial reactivity of cement paste with MK, the rate of compressive strength development is higher than cement paste containing silica fume. Curcio et al. [40] indicated that mortars containing MK had higher rate of strength development than that of silica fume. An increase in strength of 30% is obtained when cement is replaced with 10%15% MK. Partial substitution of cement with MK is found to enhance the compressive strength of concrete [41], [42]. However, both MK and silica fume contributes in strength development. MK is relatively cheaper than silica fume and may have greater application in high performance concrete. Siddique and Klaus [43] in his research showed similar results showing an increase in compressive strength and mechanical properties with the use of metakaolin in the mix. The research also found out that mixes made with partial replacement of cement by metakaolin reduces the effect of water penetration through capillary action, is more effective in resisting sulphate attack, reduces permeability of the mix and is more resistant to chemical actions. The incorporation of high reactivity metakaolin replacing 10-15 % cement can control alkali silica reaction.

Concrete is a brittle material and has very limited post-crack behavior with a sudden failure of the specimen. The steel fibers are incorporated into UHPC to bridge the gap between the cracks and enhance the ductility of the material [44]. **Richard et al**. [28] proposed that an economic optimum content of 13mm long and 0.15 mm diameter steel fibers is 2 %. In case of heat treatment the research suggested the use of much shorter fibers with length of 3mm. **Wille and Naaman [47]** carried out a detailed research on the fibers embedded in HSC and UHPC matrix they also investigated that by enhancing the bond between cementitious matrix and fibers through introduction of fine sand particles and metakaolin a bond strength of 20 MPa was achieved showing the high tensile behavior and ductility of UHPC with fiber reinforcement. According to Wu et al. [48] carried out a research to examine the effect of steel fiber content and shape on mechanical properties of concrete. The results showed that hooked end and crimped fibers had a much greater impact on the compressive and tensile strengths rather than the straight fibers. The incorporation of 3 % hooked and crimped fibers increased the compressive strength by 48 % and 59 % at 28 days as compared with straight fibers. The research also described the impact of fiber content on peak loads and showed that though the fibers doesn’t have a significant effect on the first crack strength. It greatly enhanced the peak load and peak deflection values. This explains the conversion of brittle behavior into ductile when incorporation of fibers occurs in UHPC. The toughness is largely increased giving a large area under the deflection curve. According to **Sahmaran and Yaman** smooth and small diameter steel fibers reduced the water amount required for workability of self-compacting high strength concrete. The increase in compressive strength was influenced by small dimensions and large fiber volume of fibers delaying the micro crack formation and preventing its propagation once they are formed. Wu et al. described that the incorporation of combination of macro and micro steel fibers can lead to tensile strain hardening behavior of the mix. The incorporation of fiber content from 2-5 % increased the compressive strength of specimen by 3.7 to 25 %, flexural strength increased upto 100 % and shear strength up to 260 % as compared with no fiber content Garas, Kahn, and Kurtis showed that the use of fibers can reduce the drying shrinkage by over 100 %. Wille, Joo, and Antoine showed that by using 1 % of high strength fibers, strain- hardening behavior of the mix can be established. The formation of multiple cracks during strain hardening behavior will lead to a high ductility

quartz filler and reactive admixtures reacts better when heat or pressure treatment is applied. Wu, Shi, and He [57] carried out a research to find out the effect of curing conditions on the mechanical properties of UHPC incorporated with SCMs. The study showed an increase in compressive and flexural strength when the mix was hot water cured than the mix, which was cured under standard conditions. Ibrahim et al. [31] found out that the 28 days compressive strength values were almost similar for mixes that were cured at 90ºC. The compressive strength values were more pronounced at high temperatures this probably was because of the high temperatures activating the quartz powder and other fillers which would act inert without heat treatment. The application of heat curing makes these fillers active by taking part in the hydration reactions resulting in longer C-S-H chains giving a denser microstructure and resulting in higher compressive strength. Bulvar [58] showed that the standard and hot water curing after 56 days has a less pronounced effect and the compressive strength gain rate decreases substantially. Zanni et al. [45] investigated the effect of heat treatment on UHPC. The results showed that the pozzolanic activity of quartz and silica fume depends on the temperature and duration of the curing procedure. From the pozzolanic activity of quartz as nothing was observed when treated for up to 8 hours, but there was a significant rise as the treatment was continued for more than 8 hours.

METHODOLOGY:

Ultra-high-performance concrete (UHPC) mixtures were developed using Ordinary Portland Cement as the primary binder along with supplementary cementitious materials, namely metakaolin (MK), silica fume (SF), and ultra-fine slag (UFS). Particle packing density was optimized using the Puntke water demand test on three binary binder combinations (C+MK, C+SF, and C+UFS). Among these, the C+MK combination exhibited the highest packing density and was therefore selected for further UHPC mix development. Fine aggregates, inert fillers, and a high-range water-reducing admixture were incorporated to achieve low porosity and adequate workability at a low water–binder ratio.

UHPC mix optimization was carried out through a series of trial mixes by systematically varying the proportions of metakaolin, inert fillers, and binder content. Specimens were cast and subjected to both normal water curing and accelerated curing regimes to evaluate the influence of curing conditions on strength development. Compressive strength tests were conducted at designated ages, and the results indicated that Trial Mix 13 achieved the highest compressive strength due to improved particle packing and optimized binder composition.

The influence of inert admixtures and fillers on matrix densification and strength enhancement was also investigated. Furthermore, the impact resistance of the optimized UHPC was analyzed numerically using the Johnson–Holmquist Concrete (JHC) material model. Projectile impact simulations were performed to study stress distribution, damage evolution, and energy absorption behavior, providing insight into the mechanical performance of UHPC under high-strain-rate loading.

Conclusions

From the study conducted, the following conclusions are drawn:

1. Packing density of particles is increasing as the amount of mineral admixtures and fillers are increased, which leads to increase in the specific surface area of the particle and also increase the water demand, but increase in water leads to increase the void use of super plasticizer is necessary to maintain the water demand.
2. In all the binary combinations, C+MK showed the highest packing density of 0.6 as compared to C+SF and C+UFS.
3. Result emphasized that the particle packing density is maximum when replacement was 30% with metakaolin, 17.5% with silica fume and 12% with ultra fine slag.
4. Puntke test gave a good correlation for achieving the maximum packing density of different

filler combinations resulting in maximum compressive strength.

5. It was found out that appropriate amount of supplementary cementitious materials (SCMs) can be used to replace cement. The replacement of cement by SCMs provides excellent compressive strength values. A maximum compressive strength of 106.56 MPa was observed when 30 % of the cement was replaced by metakaolin.
6. Case 4 has the most optimized percentage values with total cementitious material of 1300kg/m^3, optimum steel fiber percentage of 4%, w/c of 0.22, super plasticizer 4%, quartz powder of 30% of total volume of aggregate and quartz sand and natural sand are used 50% of remaining volume of aggregate.
7. The optimum amount of w/c ratio was found to be 0.22. Increasing the w/c ratio above 0.22 caused significant difference compressive strength values.
8. The impact of steel fiber on the compressive strength of the mixes was quite notable. In case 1 average compressive strength was increased from 34.25 MPa to 48.66 MPa when fiber dosage increased from 1.5 to 4%. In case 2 average compressive strength was increased from 41.94 MPa to 58.27 MPa when fiber dosage increased from 2.5 to 4%. In case 3 average compressive strength was increased from 51 MPa to 54 MPa when fiber dosage increased from 1.5 to 2%. Case 4 showed the highest average compressive strength of 93 MPa.

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