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Influence of mixing method, speed and duration on the fresh and hardened properties of Reactive Powder Concrete

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HIGHLIGHTS

- A new four stage mixing method of producing RPC is proposed.
- The optimum mixing speed, for pan mixer is suggested, for producing RPC.
- The concept of change point to identify flowability of RPC mixes is introduced.
- An attempt to produce RPC using indigenous materials and conventional equipment's.

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ABSTRACT

Production methodology of Reactive Powder Concrete (RPC) is not clearly established yet, as several parameters have a varied influence on the resulting fresh and hardened properties of RPC. Even for the same composition, the fresh and hardened properties differ significantly by changing mixing method, mixing speed and mixing time/duration. The present investigation is an attempt to study the effect of mixing method, speed and duration, on the fresh and hardened properties of RPC. The study also deals with the microstructure investigation of RPC mixes. Results indicate that improved mixing techniques prove beneficial in enhancing fresh and hardened properties of RPC. Mixing speed and duration also have significant effect on the fresh and hardened properties of RPC. Higher mixing speed and longer mixing duration decreases flow and strength characteristics of RPC. Microstructure analysis reveals that higher mixing speed and longer mixing duration increases percentage of pores in RPC, leading to reduced fresh and hardened properties.

1. Introduction

Reactive Powder Concrete (RPC) is an emerging cementitious construction material which is characterized by its superior properties like high compressive strength, flexural and tensile strength with addition of fibers. The microstructure of RPC is more dense and homogeneous compared to normal concrete. RPC due to its superior performance has provoked many construction practitioners throughout the world in its application to special civil engineering structures, nuclear power plants, petroleum plants, municipal, marine and military uses. The other projects like, roof of stadium, long span bridges, space structures, blast resistance structures, high pressure pipes and isolation and containment of nuclear waste, RPC has been utilized for such specialized applications throughout the world [1]. The ultra-high mechanical performance of RPC, reduces thickness of concrete members leading to large savings in both materials and costs. Owing to its high compressive resistance, precast structural elements can be fabricated in slender form to enhance aesthetics of structure. RPC possesses good durability due to its low porosity nature and dense microstructure [2]. RPC construction requires low maintenance costs in its service life [3].

Lack of good quality coarse aggregates, in many parts of the world has been hindering the production of very high performance concrete. Strength of concrete is highly dependent on the interfacial transition zone between coarse aggregate and cement paste in a normal concrete. The coarse aggregate particles present in the interfacial transition zone are weaker than surrounding mortar. These particles crush before mortar phase, besides the presence of transition zone between the coarse aggregate and mortar matrix, which is the source of micro cracks in concrete reducing the strength and durability [4]. To overcome this problem, research efforts have continued in concrete technology leading to the

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development of RPC, which is coarse aggregate free as against normal concrete, also known as Ultra-High Performance Concrete (UHPC). This is relatively new generation of concrete produced as an ultra-dense mixture of water, Portland cement, silica fume, fine quartz sand, quartz powder, superplasticizer and steel fibers.

High strength and high performance materials have an increasing trend in structural applications in the last few decades. The demand for high strength construction materials is the reason for the development of RPC. The concept of Reactive Powder Concrete was first developed by P. Richard and M. Cheyrezy. RPC was first produced in the early 1990s by researchers at Bouygues laboratory in France [5]. RPC is coarse aggregate-free, as against that of the ordinary concrete. Instead of coarse aggregate, fine powders such as silica sand and crushed quartz, with particle sizes ranging from 45 to 600 μm are used in producing RPC. In fact, it is rather a mortar than an original concrete mixture [6]. RPC was developed with dense microstructure and reduced defects such as pores and micro-fractures, due to which superior performance of ultra-high strength can be ensured [7]. The RPC mixtures are optimized at the nano and micro scales to provide superior mechanical and durability properties compared to conventional and high performance concretes. The quality requirement of RPC is achieved through: limiting water-to-cementitious ratio to less than 0.20, optimizing particle packing, eliminating coarse aggregate, and implementing special curing regimes. Short fibers are added to enhance the tensile and flexural strength, ductility, and also toughness. The RPC mixtures are designed to have flow in the desirable range of 180–220 mm and compressive strength ranging from 120 to 800 MPa based on mix proportion and the temperature of the heat treatment applied before and during its setting [8].

To achieve the desired strength of RPC, well-chosen raw materials, high speed mixing equipment's and correct procedure are conventionally required, which makes it expensive to meet the demand of large-scale production. Therefore, it is of utmost importance, to propose an appropriate procedure to obtain the high strength RPC using locally available materials with normal mixing equipment's and adopting improved mixing techniques in addition to conventional curing, to produce RPC economically.

The earlier researchers have adopted varied mix proportions for production of RPC throughout the world. Some of the researchers have also shown that particle packing model bears a significant effect on the development of RPC [9,10]. Besides the optimization of RPC composition and special handling and curing methods, full exploitation of the performance of RPC requires consideration as regards to actual production guidelines and mixing procedures. Till now the application of RPC has been restricted due to the lack of production guidelines and lack of mixing procedure knowledge hindering the production of RPC in a large scale. Limited research work on production of RPC is carried out by some of researchers, in which RPC was produced by using high speed vacuum mixer and by application of pressure and heat simultaneously, on fresh samples to achieve higher strengths. Type of mixer used has a large influence on the mixing efficiency and uniformity of RPC mix. Generally in most research works, Hobart mixer or mortar mixer was used for production of RPC, which facilitates two speeds, such as low speed at 140 RPM and high speed of 285 RPM. Earlier studies also used inclined mixer, single axis mixer, ring mixer and planetary mixer to produce RPC [8,11,12]. From literature, it is learnt that output from large capacity mixer has considerable difference in workability and also in engineering properties when compared to RPC mix produced with high speed mortar mixer. However, whether this type of mixer is suitable for mixing RPC of low water-to-binder ratio of high cement content calls for further investigation.

RPC production consists of multiple and closely interrelated steps, including batching, mixing, consolidation, finishing and curing. Each step of the process makes a unique contribution to the quality of final RPC mix. The quality of concrete depends on the production methodology and homogeneous output mix at the end of the mixing process. However, there are no standard tests to determine the homogeneity of concrete. Generally homogeneity of concrete is evaluated indirectly by workability of fresh concrete mix, density of concrete, air content and compressive strength.

To the best of our knowledge there are no systematic studies as reported in literature on production of RPC, where the factors such as sequence of mixing, order of constituents loading and different methods of mixing have been researched along with their influence on the properties of RPC. In most of the published research work, various authors have followed their own method of mixing with different mixing speeds and mixing time as per their research limitations.

Production of RPC with high fluidity is a major task. However in the RPC with high fluidity, the role of superplasticizer is very important, due to low water-to-cement ratio and high fine content. An efficient application of superplasticizer including its optimum dosage, the proper addition time to the materials and finally the mixing time of all ingredients plays an important role to maximize the superplasticizer effects on concrete paste resulting in highest fluidity [13]. Incidentally an efficient application of superplasticizer including its optimum dosage, the proper addition time of the materials and percentage of dosage with water or without water addition needs a further clear understanding in the production of RPC. Limited studies have been carried out on the effect of superplasticizer addition at different stages of mixing in the production of RPC. The effective methods of adding superplasticizer to have good flowability of RPC mix have not been given much attention. Furthermore, step wise addition and the effect of adding superplasticizer at early stage of mixing or delayed addition of superplasticizer effects on fresh properties of RPC is needed. The early addition of superplasticizer may improve the flowability of RPC when time is a limiting parameter in production of RPC. On other hand, delayed addition of superplasticizer may be beneficial to enhance the fluidity of RPC mix when time of mixing is not a constrained parameter in the production of RPC. Further, stepwise addition of water during mixing, has not been studied yet in detail, in the production of RPC.

Generally RPC need more mixing time because of dissimilar raw ingredients, compared to ordinary concrete. And also, it consists of higher paste volume, lower w/c ratio, usage of large surface area ingredients and application of high superplasticizer content. The mixing time has a significant effect on the properties of RPC; the mixing time is defined as the time elapsed between the loadings of first constituents to the final discharge of the concrete. RILEM took another approach defining, mixing time as, time between the loading of all constituents and the beginning of concrete discharge, it includes solid constituents can be added at various stages of the loading period: during dry mixing, after water is added, after second period of mixing. Both definitions for time of mixing are acceptable [14]. The increased mixing time induces stiffening of the mix, i.e. consistency change or slump loss. Increase in the mixing period of concrete prior to discharge, particularly in hot weather concrete, results in temperature rise, which accelerates the cement hydration and causes loss of moisture due to evaporation, leading to increase in slump loss [15]. Later it also affects the hardened properties of concrete. The associated effect of prolonged mixing exhibits insufficient water for mixing, higher rate of evaporation and higher rate of hydration than expected.

Johanson [16] varied mixing time and measured the homogeneity of concrete by fresh and hardened properties. The results of the study indicated that a longer mixing time increases the homogeneity of concrete up to a point. After that the homogeneity of concrete depends strongly on the type of mixer and constituents of the mix.