UNIVERSITY GRANTS COMMISSION

EXECUTIVE SUMMARY FOR MAJOR RESEARCH PROJECT

Title of the Project

Study on Influence of Industrial by –Products on Modified Reactive Powder Concrete (MRPC)

Name of the Principal Investigator

Dr. K. ARUNACHALAM

Professor and Dean (Academic Process)

Name of the Co – Investigator

Mrs. M. VIGNESHWARI

Assistant Professor

THIAGARAJAR COLLEGE OF ENGINEERING

MADURAI – 625015

TAMILNADU

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INTRODUCTION

Concrete is a commonly used structural material for the construction of infrastructure facilities throughout the world. The upper limit of compressive strength for materials that can be used in commercial applications continues to be pushed higher and higher. The low flexural and tensile strength of concrete has a number of undesirable consequences for its performance as an effective building material. In developing countries, concrete is used in greater extent than that of the structural steel. Also maintenance and repair of concrete structure is a growing problem involving significant expenditure. Over the past decade, some research works have been conducted to examine the effect of cementitious materials that can achieve a higher mechanical performance. One of the breakthroughs was the development of High Performance Concrete (HPC) which can provide a compressive strength of 50 to 100 MPa (Washer et al., 2004). A new generation of Ultra High-Performance Concrete (UHPC) named Reactive Powder Concrete (RPC) has been developed by Bouygues in France in the mid 1990s. It has a typical compressive strength of 150 to 200 MPa, which is four times that of Normal Strength Concrete (NSC). Strength with up to 810 MPa has also been recorded (Richard and Cheyrezy, 1995; Semioli, 2001; Cyr and Shah, 2002). This new type of concrete is recognized as a revolutionary material that can provide a combination of ultra-high strength, high ductility through the inclusion of short steel-fibre reinforcement and excellent durability (Richard and Cheyrezy, 1995; Gao et al., 2005; Shaheen and Shrive, 2006; Wong et al., 2007).

REACTIVE POWDER CONCRETE

The composition of RPC is coarse aggregate-free which differs from that of ordinary concrete. Instead, fine powders such as quartz sand and crushed quartz, with particle sizes ranging from 45 to 600 µm are used. In fact, it is rather a mortar than an original concrete mixture because there is no coarse aggregate. The term “reactive powder” reflects the fact that all the powder components in RPC react chemically following casting: cement by conventional hydration; silica fume through pozzolanic reaction with the resulting calcium hydroxide; quartz sand by providing dissolved silica for the formation of further Calcium Silicate Hydrate C-S-H gel; crushed quartz to alter the CaO/SiO_2 ratio and favour the formation of tobermorite and xonotlite when RPC is subjected to heat treatment or setting pressure (Lee and Chisholm, 2005; Cheyrezy et al., 1995).

The basic principle to improve the concrete properties is for reducing the inherent weaknesses of normal concrete, such as micro cracks and capillary pores (Ma and Schneider, 2002). The ultra high mechanical performance of RPC can be explained by

- Enhancement of homogeneity of RPC by the elimination of coarse aggregates. It was suggested that the maximum size of ingredients of RPC should be less than 600 μm (Richard and Cheyrezy, 1995)
- Enhancement of compacted density by optimizing the granular mixture (Richard and Cheyrezy, 1995)
- Enhancement of microstructure by heat treatment after hardening (Richard and Cheyrezy, 1995)
- Improved matrix properties by addition of pozzolanic admixtures, i.e. silica fume (Ma and Schneider, 2002) and
- Improved matrix properties by reducing water-to-binder ratio (Ma and Schneider, 2002).

Despite these attractive properties, RPC has not yet received wide attention in India. Its utility is nil in India, because of non availability of sufficient experimental data regarding the performance of RPC. It is also still in research stage which needs lot of experimental works. The basic objective of this research is to remove some of the barriers to the adoption of RPC technology in India by developing a kind of experience with its production. The high amount of cement in RPC, 900-1000 kg/m^3 and very high Silica Fume (SF) content, 150-250 kg/m^3 (10-30% by weight of cement) cause not only the high cost in RPC but also some drawbacks when sustainable development is considered [Richard and Cheyrezy 1994; 1995; Bonneau *et al.* 1996; Aitcin 2000]. The production of cement increases the emission of CO_2 gas, which impacts on global warming and heat of hydration which may cause shrinkage problems. In this respect, using the mineral admixtures can be an attractive alternative.

Silica fume with an extreme fineness and high amorphous silica content becomes an essential constituent in RPC because of its physical (filler, lubrication) and pozzolanic effects. Thanks to its exceptional characteristics and properties, the presence of SF explains its contribution to the mechanical properties and durability of RPC's [Long *et al.* 2002]. As a result, the limited available resource and the high cost of SF constrain its application in modern construction industry, especially in developing countries. For these reasons, it gives a motivation for searching for other materials with similar functions to substitute SF partially or fully in producing RPC. Mineral admixtures can be a feasible solution to overcome these problems in RPC. Also the use of expensive materials such as ground quartz and steel micro fibers that are not locally available also increases the cost.

PRESENT STUDY

In the proposed research work, it has been planned to produce RPC using micro silica materials obtained by using agricultural and industrial wastes. This research work aims at replacing cement and silica fume with Juliflora ash and Rice Husk Ash (RHA) respectively. The quartz sand will be replaced by steel slag and Ground Granulated Blast furnace Slag (GGBS) as replacement for quartz sand. Also, industrial waste fibers such as scraps from lathe etc.will be used instead of steel micro fibers. The RPC so produced will be economical and paves the way for effective utilization of theabove-mentioned waste materials which otherwise have huge environmental impact. The main objective is to evaluate the mechanical properties of RPC produced using agricultural and industrial wastes and to investigate the key factors of mix design through series of experiments, as a systematic or standard mix design is not available for RPC. The aim of this research is to develop design method by replacing the constituent of RPC with the locally available agricultural and industrial waste products and to assess the mechanical and durability properties of RPC. Experiments to assess the compressive strength, split tensile strength, flexural strength, failure modes, stress strain behavior, shrinkage characteristics and durabilityproperties will be undertaken to understand the behavior of so produced Modified Reactive Powder Concrete (MRPC).

OBJECTIVES

The present investigation focuses on the development of Modified Reactive Powder Concrete (MRPC) by utilizing the agricultural and industrial wastes. The objectives of the present investigation are given below:

- To understand the microstructure of RPC so as to assess what results to such a high strength and high performance nature
- To develop the mix design procedure for RPC
- To explore the production process of RPC utilizing locally available materials in this region
- To include industrial and agricultural wastes in the production of MRPC
- To use industrial waste fibers like scrap from lathes, steel wire from wire winding industry etc., in the production of MRPC
- To examine the durability aspects under aggressive environmental conditionand shrinkage characteristics of MRPC
- To investigate the mechanical and structural behaviour of the produced MRPC in order to make it available for practical applications in construction industry

METHODOLOGY

- Developing a mix design based on particle packing model
- Utilizing the agricultural and industrial wastes by replacing the components of RPC
- Investigating the influence of agricultural and industrial waste materials in mechanical properties such as compressive strength, split tensile strength, flexural strength, stress – strain behaviour under different curing regimes ofMRPC

- Examining the microstructure development of the RPC at a low w/b ratio
- Assessing the durability performance of MRPC under various aggressive environmental conditions
- Results and Discussions

LITERATURE REVIEW

Pierre Richard & Marcel Cheyrezy (1995) discussed about the development of an ultra-high strength ductile concrete designated as Reactive Powder Concrete (RPC), was made possible by the application of certainbasic principles relating to the composition, mixing and post-set heat curing of the concrete. They found that the compressive strength of RPC 200 was more than 218 MPa at 90^{o}C curing and RPC 800 requires the application of pre-setting pressure and heat-treatment at 250^{o}C and RPC 800 could only be used for production of pre cast elements.

Nguyen Van Tuan et al. (2011) investigated the effect of RHA on the hydration and microstructure development of RPC and compared with a control sample made with SF. The addition of RHA increases the degree of cement hydration in RPC at the later ages, which may be caused by the porous structure of RHA and the uptake of water in this pore structure results in a kind of internal curing of RHA modified mixtures. The favorable effect of RHA on cement hydration was found to be stronger than that of SF. A significant pozzolanic reaction of RHA results in a reduction of the porosity of RPC at 28 and 91 days. The compressive strength of RPC containing RHA can reach at least 175 MPa and 185 MPa at 28 days and 91 days respectively. The compressive strength of the sample made with RHA after 7 days was higher than that of the control sample made with SF.

HalitYazıcı et al. (2013) investigated the mechanical properties (compressive and flexural strength) of RPC under autoclave curing and compared with standard water curing condition. Test results indicated that autoclave curing pressure, temperature and duration are very significant parameters for the mechanical performance of RPC. The compressive strength values of these high performance composites exceeded 200 MPa after autoclave curing. Silica fume increased the mechanical performance of RPC significantly underboth curing regimes. The morphology of C–S–H was generally changed to a fibrous structure by higher pressure, temperature and increasing autoclave duration periods.

Caijun Shi et al. (2015) analyzed the hydration and microstructure of Ultra High Strength Concrete (UHSC) with cement – silica fume-slag binder. Flow ability, compressive strength, hydration and microstructure of UHSC were investigated. Flow ability of UHSC increased from 110 to 190 mm as the silica fume content increased from 0 to 22%. Compressive strength of concrete increased from 108 MPa to 125 MPa when the silica fume content increased from 0% to 15%.

MATERIALS USED

The materials used for producing RPC include Portland cement, silica fume, quartz flour, fine quartz sand; Polycarboxylate based Super Plasticizer (SP), steel fibers and water. The Ordinary Portland Cement of 53 grade, quartz sand of size ranging from 600µm to 150µm and the crushed quartz flour with an average diameter of 10µm were used. SF with an extreme fineness and high amorphous silica content is an essential constituent in RPC because of its filler and pozzolanic effects which is partially replaced with RHA. The brass coated steel micro fibers of 6 mm long and 0.12 mm diameter with the aspect ratio of 50 and the tensile strength of 2600 MPa were used.

TESTS ON UHSC

In this study, Cement and Silica Fume were partially replaced with Juliflora Ash (JFA) and Rice Husk Ash (RHA) in the production of RPC. The cement replacement was in the range of 10%, 20%, 30% and 40% of its weight and silica fume replacement was in the range of 10%, 20%, 30%, 40% and 50% of its weight. The Steel Slag (SS) and

Ground Granulated Blast furnace Slag (GGBS) were used as partial replacement materials for quartz sand and the replacement was in the range of 10%, 20%, 30%, 40% and 50% of its weight for SS and it was in the range of 20%, 40%, 60%, 80% and 100% of its weight for GGBS. Also, the Steel Scrap Fibres(SSF) from lathes were used as replacement material for steel micro fibers and the replacement was in the range of 0.5%, 1%, 1.5% and 2% of volume of concrete. The effect of JFA, RHA, SS and GGBS on the mechanical and durability performance of RPC was ascertained for two different curing regimes (standard water curing and steam curing). Tests were conducted using three specimens for each mix designation and the average values were taken into account as per the respective IS code specifications.

SUMMARY OF THE FINDINGS

This study is aimed at investigating experimentally the feasibility of utilizing Juliflora Ash (JFA) and Rice Husk Ash (RHA) as partial substitute for cement and silica fumerespectively; Ground Granulated Blast furnace Slag (GGBS) and Steel Slag (SS) as replacement for quartz sand and Steel Scrap Fibres (SSF) as replacement for steel fibers by ascertaining the mechanical and durability properties. The following are the conclusion from the present study.

- The optimum content of silica fume is 30% by weight of cement and water - binder ratio is 0.14 of RPC based on the mechanical performance of MRPC.
- Steam curing seems to be beneficial than the normal curing because the reactivity of amorphous silica increases under this regime.
- It was observed that specimens were not split into separate pieces when tested due to the inclusion of steel fibers indicating gradual and ductile failure.

1. Replacement of cement with JFA

- Test results showed that RPC containing Juliflora ash has satisfactory mechanical and durability performance up to 10%replacement.

- The percentage increase in compressive strengthandsplitting tensile strength of 5% and 10% replacement of cement with juliflora ash compared to control RPC is 8% and 3 % after 28 day water curing. This increase in strength may due to the pozzolanic effect of the concrete.
- The water absorption, porosity and sorptivity values of MRPC with Juliflora ash increases when the replacement level is more than 10%. This may be due to increase in the pores of the concrete.

2. Replacement of silica fume with RHA

- 30 % replacement of SF with RHA shows higher compressive strength, splitting tensile strength, flexural strength and axial load carrying capacity than the other mixes. Though there is reduction in strength at 40% and 50% replacement compared to 30% replacement, still it is higher strength than the control concrete
- Replacement of SF withRHA leads to the reduction in porosity and chloride ion penetration and excellent resistance to aggressive environmental conditions such as acidic and marine environment. This characteristic is found to increase as the percentage replacement increases with best performance at 50% replacement.
- MRPC with RHA at 50 % replacement of silica fume showed the lowest corrosion rate in both water and steam curing.
- The results show that RHA can be used asa partial replacement material for silica fume to produce RPC.

3. Replacement of quartz sand with GGBS

- The replacement of quartz sand with GGBS at 20% shows higher strength and durability performance than other proportions.
- When the GGBS content increases beyond this percentage, it leads to increase in pores and lower packing density which is evident from the SEM

analysis of the mix proportions. This increase in pores for higher GGBS proportion may be due to lower water binder ratio.

- GGBS can be used as a partial replacement material for quartz sand to increase the strength of RPC; also use of GGBS which is an industrial waste reduces the cost of manufacturing of RPC.

4. **Replacement of quartz sand with steel slag**

- Steel slag at 40% replacement of quartz sand achieved higher compressive strength, splitting tensile strength and flexural strength than the other combinations.
- Steel slag at 50% replacement of quartz sand has lesser percentage of water absorption, porosity and chloride ion penetration than the other combination levels.
- The drying shrinkage percentage has lesser results at 40% replacement of quartz sand with steel slag than the other replacement levels.
- The steel slag in RPC enhances the durability properties by refining its pore structures and it exhibits very low water permeability due it is homogenous and dense microstructure.

5. **Replacement of steel fibers with steel scrap fibres**

- The combination of steel scrap with steel fibers will improve the properties of RPC compared to the RPC without fibers. The optimum percentage of steel scraps is 1.5%.
- MRPC with steel scraps at 0.5%, 1.0 % and 1.5 % replacement of steel fibers gave higher compressive strength, splitting tensile strength and flexural strength than the concrete without fibers under steam curing.
- The percentage of water absorption, porosity and sorptivity values of MRPC with steel scraps at all the replacement levels were within the codal provisions.

The utilization of agricultural wastes such as JF and RHA and industrial wastes such as GBBS, Steel Slag and Steel Scrap Fibres improves the strength and durability performance of MRPC. Hence without affecting the strength and durability, these wastes can be utilized in MRPC, thereby reducing the manufacturing cost and the environmental problems associated with it.

Publication - Journals

1. M.Vigneshwari, **K.Arunachalam**, A.Angayarkanni, "Replacement of silica fume with thermally treated rice husk ash in Reactive Powder Concrete", Journal of Cleaner Production, Elsevier Publication, vol.188, pp. 264-277, 2018. Impact Factor – 5.715

Publications - Conferences

1. **Dr.K.Arunachalam**, Ms.M.Vigneshwari and Mr.A.Rajasekar, "Prosopis Juliflora Ash as an admixture in Reactive Powder Concrete" in the "National Conference on Energy and Environment" organized jointly by IIT Madras and The Coimbatore District Small Industries association, held at CODISSIA Trade Fair Complex, Coimbatore held on 16^{th}& 17^{th} September 2016.
2. R.Sutharsan and **M.Vigneshwari** (2016), "DUCTAL CONCRETE USING INDUSTRIAL WASTE FIBRES" Proceedings National Conference On Latest Emerging Trends & Sustainable Development of Civil Engineering, Bannari Amman Institute of Technology, Sathyamangalam, Tamilnadu, 23^{rd} March 2016
3. Gayathri A, and **Vigneshwari M**, (2016), "Mix proportion for Reactive Powder Concrete", International conference on Concrete Vision for Humanity (ICCVH), 18^{th}, March, 2016, Renganathan Engineering College, Coimbatore.

Final Report Assessment / Evaluation Certificate
(Two Members Expert Committee Not Belonging to the Institute of Principal Investigator)

It is certified that the final report of Major Research Project entitled "Study on Influence of Industrial by – Products on Modified Reactive Powder Concrete (MRPC)" by Dr. K. Arunachalam, Professor, Department of Civil Engineering, Thiagarajar College of Engineering, Madurai 625 015, has been assessed by the committee consisting the following members for final submission of the report to the UGC, New Delhi under the scheme of Major Research Project.

Comments/Suggestions of the Expert Committee:-

1. Dr. P. Jayabalan, Professor of Civil Engineering, National institute of Technology, Trichy- 620 015.

The report of Major Research Project entitled "Study on Influence of Industrial by – Products on Modified Reactive Powder Concrete (MRPC)" by Dr. K. Arunachalam, Professor, Department of Civil Engineering, Thiagarajar College of Engineering, Madurai 625 015 was assessed by me and it has been observed that the topic of the research is more relevant in the current scenario and the findings are very useful. The objectives mentioned in the research proposal were achieved successfully. The results were published in peer reviewed journal with high impact factor. In this study, the silica fume replaced with agricultural wastes (Rice Husk Ash) has enhanced the mechanical and durability properties. The addition of steel fibers improved the flexural performance of RPC. Also the corrosion resistance properties of concrete were studied using advanced corrosion monitoring techniques and the results revealed the superior performance of RPC. The overall outcome of the research project is very good. The reports are as per the UGC guidelines.

2. Dr. K. Mahendran, Professor & Director, Centre for Rural Technology, Gandhigram Rural Institute deemed to be University, Gandhigram

The report of the MRP project was assessed by me and it has been found that the outcome of the research on the development of RPC is very interesting and useful to the society. The objectives mentioned in the proposal were fulfilled. The results have been published in peer reviewed International Journal with good impact factor. The various locally available industrial and agricultural wastes were utilized in this project without affecting the strength and durability performance of the concrete. Hence the utilization of waste in RPC reduces the manufacturing cost and the environmental problems due to dumping of the wastes.

Overall outcome of the project is very good. The reports are as per the UGC guidelines.

Name & Signatures of Experts with Date:-

Name of Expert	University/College name	Signature with Date
1. Dr. P. Jayabalan, Professor	National Institute of Technology, Trichy – 620 015	Dr. P. JAYABALAN, Professor, Department of Civil Engineering, National Institute of Technology, Tiruchirappalli - 620 015. 4/5/19
2. Dr. K. Mahendran, Professor	Gandhigram Rural Institute, Dindigul – 624 302	DIRECTOR, RURAL TECHNOLOGY CENTRE, GANDHIGRAM RURAL INSTITUTE, GANDHIGRAM - 624 302, DINDIGUL (DT). TAMILNADU 4/5/19

It is also certified that final report, Executive summary of the report, Research documents, monograph academic papers provided under Major Research Project have been posted on the website of the University/College.

(~~Registrar~~/Principal)

Seal

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PRINCIPAL
Thiagarajar College of Engineering
MADURAI - 625 015