Experimental Investigation on Rock Filled Self-Compacting Concrete

[1]Arun Raja L. and [2]Dr.M. Shahul Hameed
[1]Assistant Professor, Department of Civil engineering, P.S.R. Engineering College, Sivakasi, India
[2] Dean (Research) & Professor, Department of Civil engineering, P.S.R. Engineering College, Sivakasi, India

Abstract — **Rock-filled concrete (RFC) was developed in China mainly for large-scale concrete construction. The distinctive casting procedure of RFC makes it highly dependent on the filling capacity of self-compacting concrete (SCC). This study investigated two of the most controversial issues regarding Rock Filled Concrete (RFC)- the filling performance of SCC and the large interface between SCC and rocks. These issues were examined through an experimental setup designed to stimulate SCC flow in rock skeleton. The slump cone, L-Box, J-Ring, and V-Funnel tests were carried out on the fresh Self Compacting Concrete with the EFNARC guidelines. After each mix proportion, specimens were casted and cured for 28 days in water and compressive strength and split tensile values were determined. The result show that the strengths found better for SCC with Rock filled concrete**

*Keywords:***Rock filled, SCC, Fresh concrete properties, Strength**

I. INTRODUCTION

Rock-filled concrete (RFC) is a type of concrete developed by Tsinghua University in 2003. It has been used in more than 40 projects in China, most of which are large-scale concrete construction projects in hydraulic engineering. On the basis of the technology of self-compacting concrete (SCC), the construction process of RFC involves two major steps: (1) filling in-situ formwork with large-scale rocks (grain size N30 cm) that pile on one another under gravity, and (2) pouring fresh SCC into the pre-packed rock skeleton to fill the voids between rocks and produce a consolidated concrete structure [1]. The application of large-scale aggregates presents many advantages, such as less cement usage, less deformation, less hydration heat, no vibration, faster construction speed, and less CO2 emission. Nonetheless, these advantages come with concerns, among which the most controversial are (1) whether SCC can effectively fill the spaces between aggregates and (2) whether the large interfaces between SCC and rocks will become a weak part and threaten the strength and durability of RFC. The capacity of SCC to pass through obstacles and to fill the formwork has recently become a research focus [2–5]. Although fresh SCC is known for its high flowability and has been successfully used to fill formwork of different shapes and configurations, potential issues remain when it is used under certain circumstances, such as flow through dense reinforcements. In these cases, the coarse aggregates in SCC may form stable granular arches at restricted zones between obstacles which thereby resist the flow, as long as the size of the coarsest particles is not far from the characteristic size of obstacles [2]. This issue is of paramount importance to RFC because the properties of RFC highly depend on the filling process of SCC. Combining existing studies on granular blocking and their own experimental results, Roussel et al. [2] claimed that granular blocking is a matter of probability, and that this probability may be influenced by many factors such as the volume fraction of coarse particles, the grading and shape of aggregates in SCC, etc. Most of these factors are related to SCC, while ratio between the diameter of the coarse particles and the free spacing between obstacles is the only factor related to the obstacles. This ratio is very important to the study of casting process of RFC, in which whether SCC can effectively fill the voids between large rocks may be closely related to the physical properties of the rocks. Previous studies on granular flow through an outlet [6–9] show that there may be a critical value of the size ratio between outlets size and particle diameter (jamming threshold). If the value of the size ratio is above this threshold, flow will not be blocked. However, existing studies in passing and filling ability of SCC are insufficient for determining the best strategy for addressing SCC flow in rock skeleton. In RFC, the rock skeleton is a product of the random packing of particles with different sizes and shapes, which is more like a porous media (PM). The flow paths in rock skeleton consist of various void spaces between aggregates that are far more complex and heterogeneous than those in any regular reinforcements or filtration sheets. Pore-scale network is a PM model that represents the topological features of PM and can be used to study fluid with yield stress at microscopic scale [10–12]. In this model, void space is described as a network of pores connected by throats. The pores and throats are assigned an idealized geometry, and rules are developed to determine fluid configuration and transport in these elements [11]. However, the analytical expressions of throats are based on the concept of equivalent radius and are therefore not representative of reality because actual void space retains highly complex shape and connectivity [12]. Therefore, to investigate the casting process of RFC, in this study a laboratory experimental setup was designed and fabricated to simulate SCC flow in rock skeleton by using self-compacting mortar (SCM) and large aggregates. Several factors related to the properties of SCM and aggregates were selected as variables, and their effects were carefully investigated. In some previous researches, the interfacial transition zone (ITZ) has been regarded as a weak link in concrete that may significantly undermine the mechanical properties and permeability of concrete [13, 14]. As for conventional concrete, wall effect and micro bleeding around aggregate surfaces are believed to be possible causes of the ITZ formation [13, 15]. When it comes to RFC, properties of these large interfaces may highly depend on the filling capacity of SCC. Accordingly, in this study the microstructure of the interface in RFC-type concrete was also investigated by means of backscatter electron (BSE) image analysis. This paper aims to provide a preliminary understanding of the filling Capacity of SCC in rock skeleton, as well as the consequential properties of large interfaces between SCC and rocks with regard to the effects of Carefully selected parameters.

II. MATERIALS AND METHODS

Experimental program has been designed to provide sufficient information for ascertaining the quality of Rock filled based self-compacting concrete. To evaluate the behavior of Rock filled based self-compacting concrete, mechanical strength has been studied in this investigation

A. Cement

Ordinary Portland cement-53 grade have used in examination. The cement was tested according to IS 4031:1988. It confirmed to IS 12269:1987.

B. Fine Aggregate

Manufactured sand (M-Sand) is a substitute of river sand for concrete construction. Manufactured sand is produced from hard granite stone by crushing. The crushed sand is of cubical shape with grounded edges, washed and graded to as a construction material. The size of manufactured sand (M-Sand) is less than 4.75mm. Manufactured sand is an alternative for river sand. Due to fast growing construction industry, the demand for sand has increased tremendously, causing deficiency of suitable river sand in most part of the world. Due to the depletion of good quality river sand for the use of construction, the use of manufactured sand has been increased. Another reason for use of M-Sand is its availability and transportation cost.

C. Coarse Aggregate

In the case of SCC, rounded aggregates would provide a better flowability and less blocking potential for a given water-to-powder ratio, compared to angular and semi-rounded aggregates. Moreover, the presence of flaky and elongated particles may give rise to blocking problems in confined areas, and also increase the minimum yield stress. The maximum aggregate size varying from 10 to 20mm.Incorporation of aggregate shape in the mixture design would enable the selection of appropriate paste content required to overcome these difficulties. It is possible that the highly flowable nature of SCC could allow a higher proportion of flaky aggregates compared to normal concrete. However, this aspect needs to be checked.

D. Rock Gravel

Process of RFC involves two major steps:
Filling in-situ formwork with large-scale rocks (grain size >30 cm).
Pouring fresh SCC into pre-packed rock skeleton to fill the voids between rocks

E. Super Plasticizer

Super plasticizer, also known as high range water reducers, are chemical admixture used where well dispersed particle suspension is required. These polymers are used as dispersants to avoid particle segregation (gravel, coarse and fine sands) to improve the flow characteristics of suspension such as in concrete applications. Their addition to concrete or mortar allows the reduction of the water to cement ratio, not affecting the workability of the mixture, and enable the production of self-consolidating concrete and high performance concrete. Master Glenium sky ensure that rheoplastic concrete remains workable in excess of 45 minutes at +25˚C. Workability loss is dependent on temperature, and on the type of cement, the nature of aggregates, the method of transport and initial workability. Master Glenium sky is ready to use liquid which is dispensed into the concrete together mixing with the water. The plasticizing effect and water reduction are higher if the admixture is added to the damp concrete after 50 to 70% of the mixing water has been added. The additions of Master Glenium Sky to dry aggregate or cement is not recommended. Automatic dispensers are available.

F. Mineral Admixture

High flowablity requirements of SCC allows the use of mineral admixtures in its manufacturing, use of mineral admixtures results in the cost of concrete. The incorporation of one or more mineral admixtures and powder materials having different morphology and grain distribution can improve particle packing density and reduce inner particle friction and viscosity. Hence its improve deformability and stability of SCC.

III. Experimental Procedure

The cement, sand and coarse aggregates were weighted according to the mix proportion of 1:1.8:1.7. In order to study the effect on fresh concrete properties in SCC the rock gravel is added in concrete at bed level. To this dry mix the required quantity of water was added and thoroughly mixed. To this the super plasticizers was added at the rate of 1.5lit/m^3 of cementations material and mixed immediately. The entire mix was thoroughly mixed once again.

At this stage, almost the concrete was in a flowable state. Now, the flow characteristic experiments for self-compacting concrete like slump flow test, V-funnel test, L-box test, & U box test were conducted. In terms of slump flow, all SCC exhibited satisfactory slump flows in range of 550-800mm, which is an indication of a good deformability.

After conducting the flow characteristic experiments the concrete mix was poured in the moulds required for the strength assessment. After pouring the concrete in the moulds, no compaction was given either through vibrated or through hand compaction. Even the concrete did not require any finishing operation. After 24 hours of casting, the specimens were demoulded & were transferred to the curing tank. Wherein they were allowed to cure for 28 days.

For compressive assessment, cubes of size 150mm x 150mm x 150mm were prepared. For tensile strength assessment, cylinders of diameter 150mm & length 300mm were prepared. Indirect tension test was carried on these cylindrical specimens. After 28 days of curing the specimens were tested for their respectively strengths. The test results were studied and the optimum SCC were found.

Same procedure of mixing is repeated for the adding of rock gravel in bed level to optimum SCC mix. The 5cm rock gravel was settled down in moulds at bed level. The entire mix was thoroughly mixed & poured into the moulds without any compaction. After 28 days curing, the specimens were tested for their respectively strength and the optimum value of SCC has been found.

Self-compacting concrete is a high performance concrete that can be compacted into every corner of a formwork, purely by means of its own weight and without the need for vibrating compaction .This concrete is defined as follows at the three stages of concrete: Fresh: self-compactable; Early age: avoidance of initial defects; After hardening: protection against external factors.
The addition of super plasticizers in the truck during transit is a fairly new development within the industry. Admixtures added in transit through automated slump management systems, allows concrete producers to maintain slump until discharge without reducing concrete quality. I Summarized here that the addition of super plasticizers in SCC and improves the mechanical properties mainly the tensile and compressive strength of self-compacting concrete (SCC).

IV. FRESH PROPERTIES OF SCC

The main properties of SCC in plastic state are:

1. Filling ability (Slump-flow, V-funnel).
2. Passing ability (J-ring, L-box)
3. High resistance to segregation (V-funnel)

A. GENERAL PROPERTIES

One principal difficulty in devising such tests is that they have to assess three distinct, though related, properties of fresh SCC – its filling ability (flowability), its passing ability (free from blocking at reinforcement), and its resistance to segregation (stability). No single test so far devised can measure all three properties. There is no clear relation between test results and performance on site. There is little precise data, therefore no clear guidance on compliance limits. The test methods and values are stated for maximum aggregate size of up to 20 mm; different test values and/or different equipment dimensions may be appropriate for other aggregate sizes. Different test values may be appropriate for concrete being placed in vertical and horizontal elements. Similarly, different test values may be appropriate for different reinforcement densities.

B. Filling Ability of Self Compacting Concrete

It is the ability of SCC to flow into all spaces within the formwork under its own weight. Tests, such as slump flow, V-funnel etc, are used to determine the filling ability of fresh concrete.

C. Passing Ability of Self Compacting Concrete

It is the ability of SCC to flow through tight openings, such as spaces between steel reinforcing bars, under its own weight. Passing ability can be determined by using U-box, L-box, Fill-box, and J-ring test methods

D. Segregation Resistance

The self-compacting concrete must meet the filling ability and passing ability with uniform composition throughout the process of transport and placing.
It is important to appreciate that none of the test methods for SCC has yet been standardised, and the tests described are not yet perfected or definitive. The methods presented here are

descriptions rather than fully detailed procedures. They are mainly ad-hoc methods, which have been devised specifically for SCC. In considering these tests, there are a number of points which should be taken into account:

E. *FLOWABILITY TESTS:*

Slump flow test

Introduction

The slump flow is used to assess the horizontal free flow of SCC in the absence of obstructions. It was first developed in Japan for use in assessment of underwater concrete. The test method is based on the test method for determining the slump. The diameter of the concrete circle is a measure for the filling ability of the concrete.

Assessment of test

This is a simple, rapid test procedure, It can be used on site, though the size of the base plate is somewhat unwieldy and level ground is essential. It is the most commonly used test, and gives a good assessment of filling ability. It gives no indication of the ability of the concrete to pass between reinforcement without blocking, but may give some indication of resistance to segregation. It can be argued that the completely free flow, unrestrained by any boundaries, is not representative of what happens in practice in concrete construction, but the test can be profitably be used to assess the consistency of supply of ready-mixed concrete to a site from load to load.

J Ring test :

Introduction:

The principle of the J Ring test may be Japanese, but no references are known. The J Ring test itself has been developed at the University of Paisley. The test is used to determine the passing ability of the concrete. The equipment consists of a rectangular section (30mm x 25mm) open steel ring, drilled vertically with holes to accept threaded sections of reinforcement bar. These sections of bar can be of different diameters and spaced at different intervals: in accordance with normal reinforcement considerations, 3x the maximum aggregate size might be appropriate. The diameter of the ring of vertical bars is 300mm, and the height 100 mm.

The J Ring can be used in conjunction with the Slump flow, these combinations test the flowing ability and (the contribution of the J Ring) the passing ability of the concrete. The J Ring bars can principally be set at any spacing to impose a more or less severe test of the passing ability of the concrete. After the test, the difference in height between the concrete inside and that just outside the J Ring is measured. This is an indication of passing ability, or the degree to which the passage of concrete through the bars is restricted.

Assessment of test

These combinations of tests are considered to have great potential, though there is no general view on exactly how results should be interpreted. There are a number of options – for instance it may be instructive to compare the slump-flow/JRing spread with the unrestricted slump-flow.

V funnel test

Introduction

The described V-funnel test is used to determine the filling ability (flowability) of the concrete with a maximum aggregate size of 20mm. The funnel is filled with about 12 litre of concrete and the time taken for it to flow through the apparatus measured. After this the funnel can be refilled concrete and left for 5 minutes to settle. If the concrete shows segregation then the flow time will increase significantly

Assessment of test

Though the test is designed to measure flowability, the result is affected by concrete properties other than flow. The inverted cone shape will cause any liability of the concrete to block to be reflected in the result – if, for example there is too much coarse aggregate. High flow time can also be associated with low deformability due to a high paste viscosity, and with high inter-particle friction. While the apparatus is simple, the effect of the angle of the funnel and the wall effect on the flow of concrete is not clear.

V. MIX DESIGN

The very first step to assure the flow requirement of SCC is to determine the optimum dosage and super plasticizer. Various mixes were prepared and tested to satisfy the EFNARC guidelines. Finally a mix is chosen which gave fulfilling fresh properties. The addition of different percentage of admixtures would be done in this mix. The mix proportion was done based on the EFNARC guidelines. The mix design was carried out for M40 normal grade of self-compacting concrete

TABLE. 1. Mix Ratio

CEMENT	FINE AGGREGATE	COARSE AGGREGATE
1	1.8	1.7

TABLE. 2. Workability Test Results

S.NO	METHODS	RESULTS	PERMISSIBLE LIMITS	UNITS
1.	Slump flow	686	650-800	mm
2.	J ring apparatus	7.4	0-10	mm
3.	V funnel	7	6-12	Sec
4.	V funnel at T5min	3	2-5	Sec
5.	L box (h_2 / h_1)	0.93	0.8-1.0	mm

V. HARDENED CONCRETE TEST

A. COMPRESSIVE STRENGTH TEST RESULTS ON SCC:

Compressive strength test results are primarily used to determine that the concrete mixture as delivered meets the requirements of the specified strength, in the job specification. Strength test results from cast cylinders may be used for quality control, acceptance of concrete, or for estimating the concrete strength in a structure for the purpose of scheduling construction operations such as form removal or for evaluating the adequacy of curing and protection afforded to the structure. Cylinders tested for acceptance and quality control are made and cured in accordance with procedures described for standard-cured specimens in ASTM C 31 Standard Practice for Making and Curing Concrete Test Specimens in the Field. For estimating the in-place concrete strength, ASTM C 31 provides procedures for field-cured specimens. Cylindrical specimens are tested in accordance with ASTM C 39.

A test result is the average of at least two standard-cured strength specimens made from the same concrete sample and tested at the same age. In most cases strength requirements for concrete are at an age of 28 days. Design engineers us the specified strength to design structural elements. This specified strength is incorporated in the job contract documents. The concrete mixture is designed to produce an average strength, f'cr, higher than the specified strength.

TABLE. 3. Compressive strength of Rock filled self-compacting concrete.

Specimen	7 days (N/mm^2)	28 days (N/mm^2)
M40 mix Without rock filled	27.8	42
M40 mix With rock filled	29	43.5

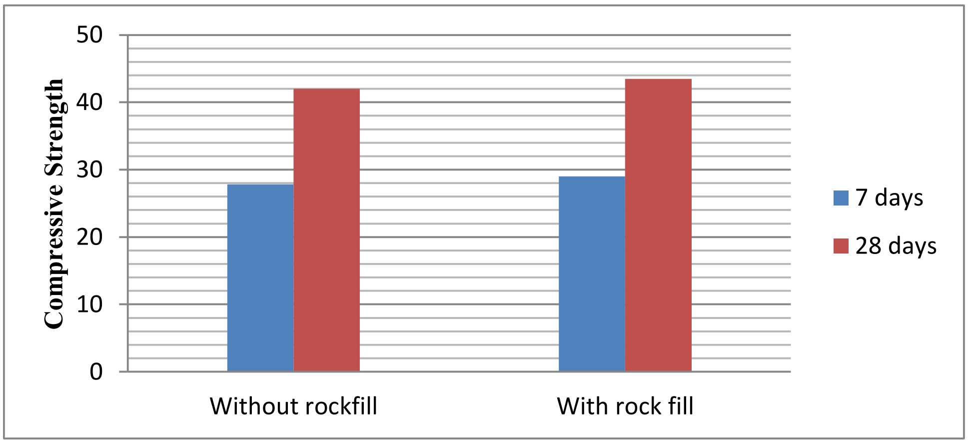

Fig.1. Compressive strength of concrete

B. *SPLIT TENSILE STRENGTH TEST RESULTS ON SCC:*

This test method is used for the determination of splitting tensile strength of cylindrical concrete specimen. Splitting tensile strength is helpful for the following purposes;

Splitting tensile strength is generally greater than the direct tensile strength and lower than the flexural strength (modulus of rupture).

Splitting tensile strength is used in the design of structural light weight concrete members to evaluate the shear resistance provided by concrete and to determine the development length of the reinforcement.

This test method consists of applying a diametrical force along the length of a cylindrical concrete at a rate that is within a prescribed range until failure. This loading induces tensile stresses on the plane containing the applied load and relatively high compressive stresses in the area immediately around the applied load. Although we are applying a compressive load but due to Poisson's effect, tension is produced and the specimen fails in tension. The maximum load sustained by the specimen is divided by appropriate geometrical factors to obtain the splitting tensile strength. Same procedure of mixing is repeated for the adding of rock gravel in bed level to optimum SCC mix. The 5cm rock gravel was settled down in moulds at bed level

TABLE. 4. Tensile strength of Rock filled self-compacting concrete

Specimen	28 days (N/mm^2)
M40 mix (Without Rock fill)	2.26
M40 mix (Rock filled concrete)	3.25

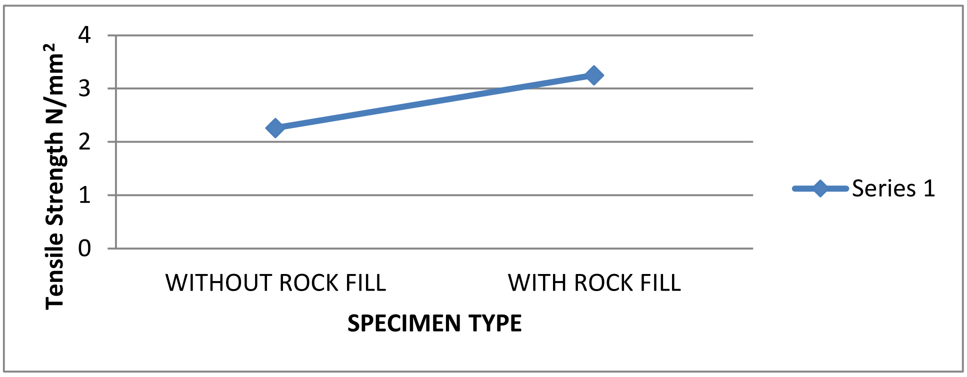

Fig.2. Tensile strength of concrete

VII. CONCLUSIONS

As a new kind of concrete, RFC performs satisfactorily in the early age and after hardening, which could satisfy the requirement of hydraulic engineering project, especially in the massive concrete construction because of its simple execution, low heat of hydration, low cost, and so on of RFC, such as drying and hardening shrinkage and freeze-thaw resistance. In addition, establish an efficient construction system of RFC.

1. It has been verified, by using the slump flow, L-box test and other tests on fresh SCC that self-compacting concrete (SCC) achieved consistency and self-compactability under its own weight, without any external vibration or compaction.
2. It can be concluded that method of curing has considerable effect on the mechanical properties including compressive, split tensile strength of Rock filled SCC. The strengths are found better for Rock filled self-compacting concrete.
3. Immersion curing seems to be best method for curing in Rock filled concrete as well.

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AUTHOR(S) BIOGRAPHY

L.Arun Raja is an Assistant Professor in Civil Engineering at P.S.R Engineering College, Sivakai, and Tamilnadu, India. He graduated in Civil Engineering from Anna University of Chennai, Tamilnadu, India. He received his M.E in Structural Engineering from Anna University of Chennai, Tamilnadu, India. His research interests include concrete technology, reinforced concrete, fibre reinforced concrete and self-compacting concrete. He is a member of The Institution of Engineers, India.

Dr. M. Shahul Hameed is a Dean (Research) &Professor in Civil Engineering at P.S.R Engineering College, Sivakai, and Tamilnadu, India. He graduated in Civil Engineering from Madurai Kamaraj University, Tamilnadu, India. He received his M.E in Structural Engineering from Madurai Kamaraj University, Tamilnadu, India and PhD in Structural Engineering from Anna University, Chennai Tamilnadu, India and also he received PhD in Management Studies from Madurai Kamaraj University, Tamilnadu, India. His research interests include concrete technology, reinforced concrete, fibre reinforced concrete, Ferro cement, light weight concrete, self-compacting concrete, rehabilitation of RCC structures. He is a member of American Concrete Institute and a Fellow of The Institution of Engineers, India.