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Design and Performance of Sustainable concrete

M. Sneha [a,*], RM. Senthamarai [b]

[a] *Research Scholar, Structural Engineering Department, Annamalai University, Annamalainagar 608002, India.*

[b] *Professor of Structural Engineering Department, Annamalai University, Annamalainagar 608002, India.*

Abstract

Concrete is the most used construction material in the world. The production of cement consumes large amount of natural resources and energy and also releases approximately 5% of global carbon dioxide emissions to the atmosphere. As a remedy to this issue, a portion of cement can be substituted by supplementary cementing materials the possibilities of making sustainable concrete from locally available industrial and agro materials were investigated. Supplementary cementitious material bagasse ash and granite fines as filler were used in order to reduce the cement content and to improve the size distribution and the grading of the particles. The use of such ash in concrete by partial replacement of cement, not only reduces the cost of making concrete, but also improves the properties of concrete and reduces environmental pollution. Their quantities were determined based on a new mix modelling software called EMMA program. EMMA program modelling has been useful to improve particles packing in the concrete. The aim of this paper is to highlight the behaviour of concrete in fresh and hardened state which was modelled and analyzed using EMMA software with certain assumptions.

Keywords*:* *Sustainable concrete, Supplementary cementitious materials, EMMA modelling program, strength test.*

INTRODUCTION

A sustainable and eco-friendly green approach is essential for the construction industry, as it is one of the major units responsible for the depletion of the natural resources and the generation of greenhouse gases. Today supplementary cementitious materials (SCMs) are widely used in concrete either in blended cements or added separately in the concrete mixer. Typical examples are fly ash, slag, silica fume, rice husk ash etc, enable the concrete industry to use hundreds of millions of tons of by-product materials otherwise that would be land filled as waste. Furthermore, their use reduces the utilisation of Portland cement per unit volume of concrete. The idea of partially replacing OPC by other materials can be supported by the fact that there is an enormous amount of waste, produced by various industries, with suitable properties for usage in concrete. These waste materials usually need lots of effort and energy for disposal purposes.

In the present study sugar cane bagasse ash is used. (SCBA) is an agro-waste produced in sugar manufacturing plants after extraction of juice from sugar cane. Sugar cane is cultivated in about 74 countries, and its production rate is increasing, particularly in developing countries [8]. Sugarcane production in India is over 300 million tonnes per year. The processing of it in sugar-mill generates about 10 million tonnes of SCBA as a waste material. One tonne of sugarcane can generate approximate 26% of bagasse and 0.62% of residual. Ganesan et al. [9] evaluated the suitability of SCBA as a partial replacement for cement in concrete and indicated that BA is an effective mineral admixture, with 20% as optimal replacement ratio of cement. The authors concluded that this reduction was probably due to some factors like mode of mixing, specially hand mixing, compaction and the reactivity of the SCBA. Pozzolanic properties of SCBA have convinced the researchers around the world to investigate the feasibility of SCBA incorporation in concrete. The residue from the combustion, Bagasse ash (BA), contains high levels of silica and is found to be pozzolanic (de Soares et al., 2016), hence has been actively studied as a supplementary cementitious material for construction (Kazmi et al., 2016; Moretti et al., 2016; Noor ul et al., 120 2016).

Although SCBA utilization in concrete is proved to be an efficient approach for disposal of waste, there are limited investigations studying the influence of SCBA on flexural behaviour of concrete. Reduction in strength of concrete is faced with the increase in replacement percentage of SCBA. Several attempts have been made to overcome the negativity with the binary and ternary blended cements.

The global consumption of natural river sand is very high due to the extensive use of concrete particularly in developed countries. Among the 32 states in India, Tamilnadu state has the 45% of total granite reserve. During the industrial process, the fine granite particle and the water mixed together and become a granite colloidal waste. When the stone slurry is disposed in landfills, waste becomes a dry mud consisting of very fine powder that can be easily inhaled by human being and animals. Hebhoub et al. [10] demonstrated that the waste marble and granite powder can be potentially used as a substitution for fine aggregates in concrete production and the mechanical properties of concrete were found to be conforming to the concrete production standards. The granite dust exhibits appearance and particle size distribution nearly similar to that of natural fine aggregate i.e. river sand. Such properties make it a viable product as fine aggregate in concrete [11]. Many studies have ensured that the concrete made with granite fines is reliable in aggressive environment.

Here the cement content is replaced with sugarcane bagasse ash and fine aggregate with the granite fines/residue. Concrete mix design is the process of ascertaining the appropriate quantities of the ingredients of concrete required for a specified grade of concrete. Instead of using conventional method of mix design the particle packing concept is executed. It consists of selection of appropriate sizes and proportions of particulate materials in order to obtain a compact mixture. Aggregates and fillers occupy as high as 70 to 85% of the concrete volume. Hence, controlling the granular mixture proportion will help in minimizing the volume of void space and thereby ensuring higher strength and better workability due to improved macro-mechanical properties. Again when the granular mixture proportion is densely packed, smaller amount of water and lesser cement paste is adequate. Different authors have studied various techniques and methods in the material processing stage, mix design stage, mixing stage and even in curing stage to improve the performance of concrete. However, in the knowledge of the authors the Particle Packing Method (PPM) has not been applied to the mix design. The simplicity and effectiveness of PPM is the motivation to implement the same in this work to produce durable concrete.

PARTICLE PACKING

Producing concrete of a desired proportion using the available resources is still a trial and error process. The commonly practiced conventional concrete mix proportioning methods have certain flaws rendering them inefficient in case of mix designing of special concretes such as HPC, RMC, etc. Commonly used mix design methods make use of some empirical relations and ideal grading curve in deciding the relative proportion of the ingredients in the mix. Software Based on Particle Packing Theory are EMMA, MixSim, COMPASS

PARTICLE PACKING using EMMA

Based on the Andreassen equation, particles modelling software called EMMA (Elkem Materials Mix Analyzer) was developed. Elkem team has done studies on the packing of the particles of materials to enhance its performance by making the most possible compacted and air-free mixes. Nowadays investigations were carried on varying the particle size distributions in different building products, ceramics, concrete, etc.

EMMA MODELLING

The particle size distribution (PSD) of each material of the mix arrived from the sieve analysis test were created/entered as a customized library for different materials , and then EMMA will calculate the particle size distribution of the mix and compare it to Andreassen model. The materials quantities were changed in loop until best match between recipe model and Andreassen model was obtained. After the quantity of the individual materials has been entered, the distribution is given in numbers as well as presented in a graphical format.

MATERIALS

Various materials used for the present experimental work are as below.

Binding Materials

• Cement

A 53 Grade Ordinary Portland Cement, manufactured by Zuari Cement was used. During experimental work the cement was stored in a suitably compartment so as to protect it from dampness and warehouse deterioration. The cement procured was tested for physical requirements in accordance with IS: 12269-1987.

• Bagasse Ash in Portland cement Concrete

The ash collected was sieved through BS standard sieve size 75μm and its colour was black. It was then measured by volume to replace the cement. Bagasse ash is taken from the nearing sugar mill factory. Specific gravity of the ash is about 2.20. Sugarcane Bagasse Ash was collected during the cleaning operation of a boiler operating in the Madras Sugar Mills, located in the city of Tirukoilur, Tamilnadu.

Materials	**Specific gravity**	**Fineness %**	**28 days compressive strength MPa**
Cement	3.14	5	54.62
SCBA	2.20	1.2	-

Filler Materials

- **Aggregate**

Aggregates of size 20mm and 10mm were used as coarse aggregates. The quality of aggregates used was checked against the specifications given in the IS 383-1970. Sieve analysis of the aggregates were carried out as per the specifications given in IS 2386 (Part-I)-1963. The air-dry sample was weighed and sieved successively on the appropriate sieves starting with the largest. On completion of sieving, the material retained on each sieve, together with material cleaned from the mesh, was weighed.

Material		**Specific gravity**	**Bulk density (kg/m³)**	**Absorption (%)**
Coarse Aggregate	**10mm**	2.7	1645.30	1.56
	20mm	2.7	1620.52	1.80
Fine Aggregate		2.6	1860.72	1.1
Granite fines/residues		2.59	1900	2.20

The tests for determination of specific gravity, absorption /moisture content and bulk density of the aggregates was carried out as per the specifications given in the IS 2386 (Part-III)-1963. The saturated surface dry aggregates were used for tests. These properties of aggregates are necessary to decide proportions of the concrete mix.

Admixture

Super-plasticiser (CONPLAST 430) was used during investigation to improve the workability of concrete. As per Indian Standards, the dosage of superplasticiser should not exceed 2% by weight of cement. After trails, the optimal dosage of superplasticiser was found to be 1.2% to produce slump of 50-100 mm is used in this study.

MIX PROPORTIONING

In the preliminary trials it was observed that the minimum operating water required was 192 litres per cubic meter of concrete for 20 mm maximum size of aggregate. Therefore, the water content and the maximum size of coarse aggregate used were kept constant for both replaced concrete and the conventional concrete. Six mixes were designed by the volumetric method with different water–cement ratios. Similarly, six more conventional concrete mixes were designed. The replacement percentage of cement with bagasse ash is taken as 27.5% and granite fines with natural river sand is 12% is kept constant for all the six mixes. This percentage level found by EMMA software. The mix proportions are presented in Table 3.

Mix	w/c by weight	Cement kg/cu.m	Proportions (by volume) C:FA:CA
1	0.36	535	1:1.43:2.29
2	0.39	485	1:1.69:2.53
3	0.44	435	1:1.99:2.81
4	0.47	407	1:2.18:3.00
5	0.52	371	1:2.50:3.31
6	0.56	340	1:2.85:3.62

Test details

The nature of concrete mixes in the fresh state i.e. whether the mix is cohesive or non-cohesive and whether there was any segregation or bleeding, etc. was observed visually. To study the behaviour of the freshly mixed concrete, the workability of concrete was measured by the slump test was conducted as per IS 7320-1974

The hardened properties of the replaced concrete and conventional concrete, were determined as per IS 2386 (Part I–VIII)-1963

For each mix, nine cubes of size 100 mm were cast to determine compressive strength at 7,28,56 days The specimens were demoulded 24 h after casting and were cured under water at 27° ± 2 °C until the test age. The tests were conducted as per IS 516-1959

DISCUSSION

Workability

A high quality concrete is one which has acceptable workability (around 6.5 cm slump height) in the fresh condition and develops sufficient strength. The conventional concrete is made with constant amount of coarse aggregate and water for all the six mixes. The workability of the conventional concrete is 100mm therefore the requirement of water reducing admixture is negligible. But the effect of SCBA on the workability of the fresh paste decreases with increase in percentage of SCBA. This shows that SCBA absorbed more water than cement and makes the concrete mix denser therefore requires water reducer in 0.8 – 1.2% of water to achieve 50-100mm slump.

Compressive strength

Compressive strengths of bagasse ash blended concrete were greater compared to control concrete. On the whole, the compressive strength results indicate that the same grade of concrete as with OPC can be produced with SCBA replacement. The specimen is loaded onto the compressive test machine. The machine is switched on and a hydraulic jack starts to compress the concrete specimen until it reaches failure. At the failure, the value from the gauge is recorded and this value is used to calculate the compressive strength. The compressive strength of concrete can be calculated using the following formula:

$$f_c = \frac{P \times 1000}{A}$$

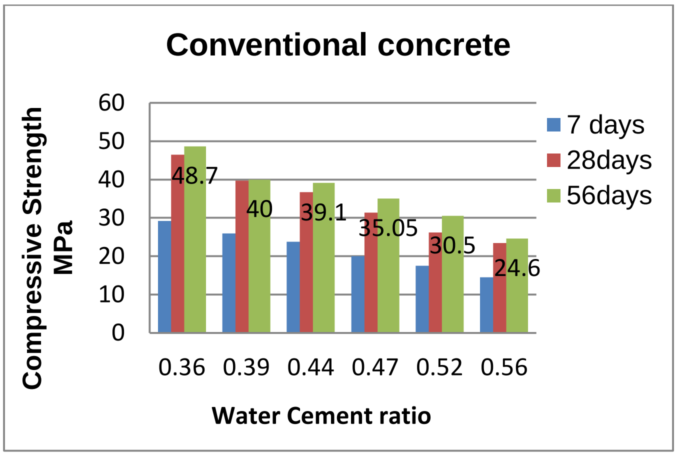
Where,

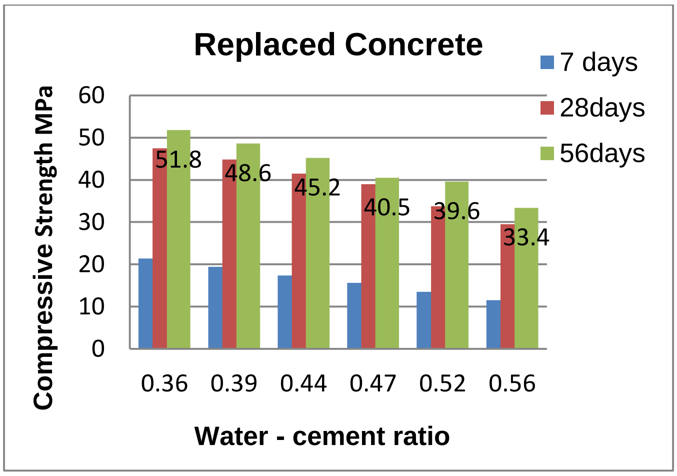
f_c= Compressive strength of concrete (MPa).

P= Maximum load applied to the specimen in KN.

A = Cross sectional area of the specimen (mm²)

From several research studies have proved that use of bagasse ash in concrete as a replacement material for cement is only upto 0-20%. But here the packing fractions are considered and SCBA 27.5% the volume of cement is used. The compressive strength varied from 51- 33MPa. As far as strengths are concerned, the basic trend in the behaviour of bagasse ash concrete is not significantly different from that of the conventional concrete. Increase in strength of the specimen observed with time – it is generally attributed to pozzolanic activity of material





CONCLUSION

The following conclusions are drawn from the study on SCBA concrete and they are applicable for the range of parameters and materials used in this study.

- For the same w/c without bagasse ash the 28 day compressive strength gradually reduces as no particle packing of aggregate is achieved.
- In the EMMA mix due to the proper particle packing considerable increase in compressive strength is attained.
- The selection of the maximum size of coarse aggregates and the gradation control of aggregates are the important factors in influencing the quality and the properties of concrete.
- Use of the particle packing approach for mix proportioning resulted in improved behavior of concrete in the fresh state. The workability of the concrete was improved and segregation was eliminated.
- The properties of SCBA concrete are not significantly different from those of conventional concrete. This research work is the basis for further experiments on reinforced concrete members with the use of SCBA concrete.

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