

EXPERIMENTAL INVESTIGATION ON SELF-COMPACTING CONCRETE PREPARED USING BAILEY AGGREGATE GRADING TECHNIQUE

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Abstract:

The study presents the results of an experimental evaluation of M30, M40 and M50 grade Self Compacting Concrete (SCC) with three Nominal Maximum Aggregate Sizes (NMAS), namely 20mm, 16mm and 12.5mm, with Bailey Gradation (BG) in comparison with Indian Standard Gradation (ISG). Rheological and mechanical properties of SCC were evaluated in detail and according to the results, the concrete sample containing lower NMAS with BG demonstrated improvement in modulus of elasticity and compressive strength, while improving the rheological properties as well. Meanwhile, SCC demonstrated poor performance in split tensile and flexural strengths with lower NMAS gradations and a direct correlation was evident as the increase in NMAS caused an increase in the strength and vice-versa. Upon comparison of BG with ISG, it was revealed that BG mixes succeeded to demonstrate superior performance. From the material optimization, rheological and mechanical performance study, it is recommended that BG with NMAS 16mm can be utilized for conventional SCC. For further investigation only, M40 grade with BG is considered to analyse the performance of recycled aggregate importance in self-compacting concrete.

Further developing sustainable self-compacting concrete (SCC) through the optimization process by incorporating Reclaimed Asphalt Pavement (RAP) and Total Recycled Concrete Aggregate (TRCA) is carried out. Besides Cashew Nut-shell Ash (CNA) was utilized as a cementitious material. To achieve this optimization technique is implemented in four stages, which are the RAP and TRCA aggregate treatment process, gradation selection process, RAP and TRCA replacement percentage, and considering the CNA replacement percentage. RAP and TRCA have been treated by a novel freeze-thaw cyclic procedure followed by the abrasion treatment method. Bailey's Aggregate Grading Technique (BAGT) has been implemented to line up the aggregate packing gradation.

Keywords: SELF- COMPACTING POLYMERS, NMA.

I. INTRODUCTION

Concrete is a well-known construction material and it is a homogeneous mixture that consists of cement, sand and aggregates. Compaction is a specifically induced process, for the rearrangement of particles in all types of concrete mixtures to engage designed gradation. Aggregates are major particles in concrete mix and their existence varies from 75% to 90% of the total concrete mix. The voids created by these aggregate particles are further fulfilled by binders, which include the blends of cement, fly ash, lime powder, Ground Granulated Blast-furnace Slag (GGBS), metakaolin, silica fume, etc [1]– [6]. But conventional concrete needs vibration compaction for a better fit of aggregates in the same mix. In the era of 1980s, Japan developed a new technology that implements the self-reorientation of particles as an effect of its own weight, leading to a better interlocking of particles and resulting in improved

mechanical properties. In a later stage, concrete was named self-compacting concrete and abbreviated as SCC.

In 1988, a prototype of SCC is launched in the market, and it assured satisfactory performance concerning rheological and mechanical properties. Later it spread throughout the world as an advancement, which, at this stage, was represented by the new name, “Self- Compacting High-Performance Concrete”. High performance is a word that signifies the importance of the rheology properties of the SCC, in this way it has an advanced scope of interest, in other areas of material science. These influence the characteristics of SCC to showcase flow, passing and filling abilities. However, SCC has become the type of concrete to which the principles of concrete rheology can be applied. The recent development of research indicates rheological importance in SCC, and a practical understanding of its flow properties has advanced a practical user’s interest in concrete rheology and its application

Importance of bailey gradation

Robert Bailey is the founder who developed the packing concept of aggregates based on aggregate orientation factor, which results to achieve the required design density in a mixture regardless of binder importance. The motivation of this approach is to achieve the packing density by optimizing the interlocking of aggregates, which elaborate optimum performance in the designed mixture. Besides particle packing of aggregate based on particle orientation factor. Loose Unit Weight (LUW) and Rodded Unit Weight (RUW) are measurable parameters of the aggregate orientation factor. LUW is the extent of achievement of aggregate density in the absence of external effort or the rearrangement of aggregates achieved through self-orientation. RUW is the extent of achievement of density by compacted aggregate with an external effort or it is the density of three-layered compacted aggregate particles. Although RUW is representative of the maximum achievable density through aggregate particle orientations in a compacted state.

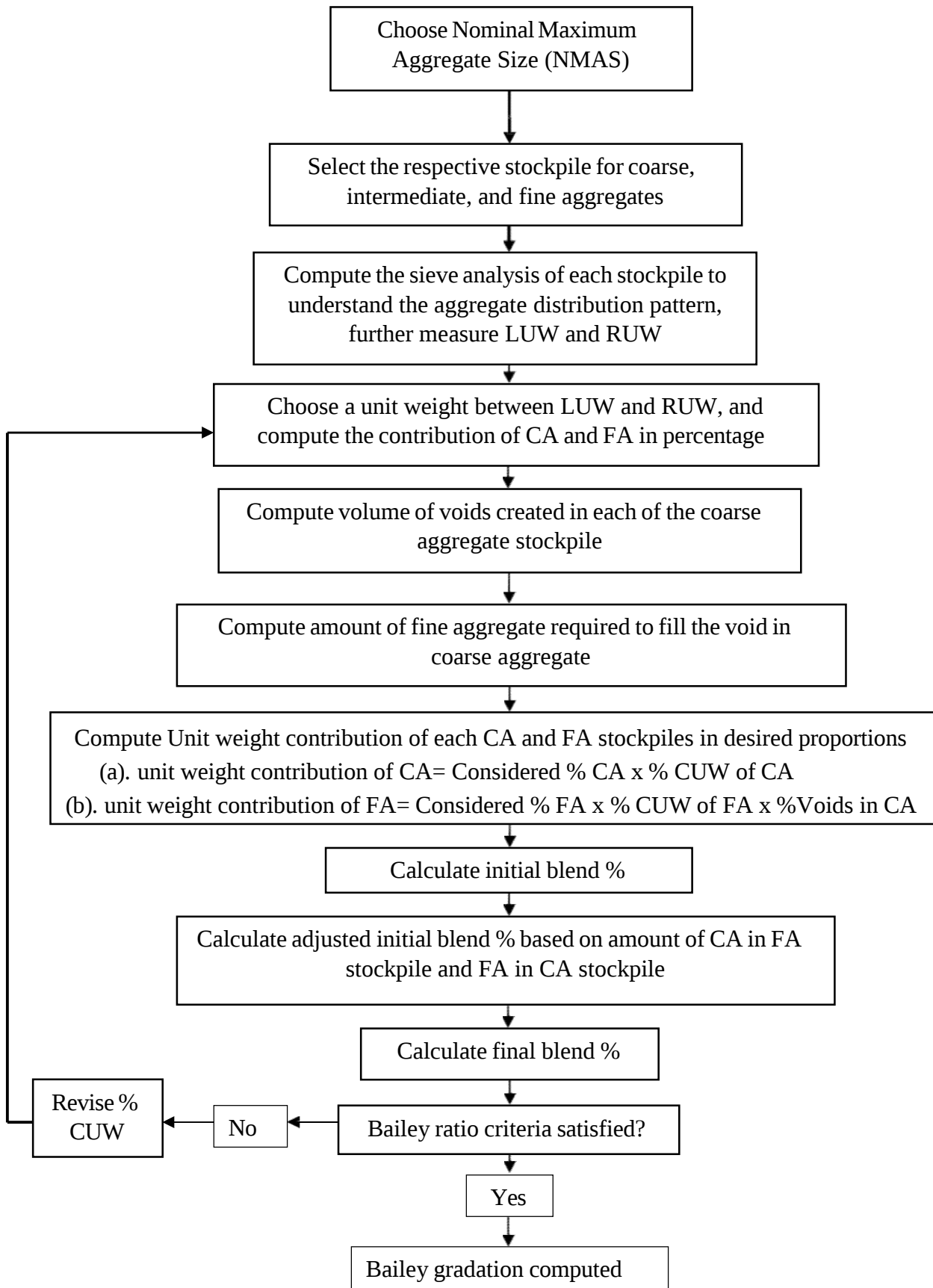


Fig. 1.1 Flow chart of bailey gradation

II. LITERATURE

Aggregates are the key elements of concrete, especially rheological properties of self-compacting concrete (SCC) is influenced by aggregate distribution patterns and aggregate orientation characteristics. Aggregate orientation characteristics influence the flowing ability, passing ability and filling ability, and poor aggregates orientation characteristics are the reason for the segregation of SCC. As per IS 383 (2016) [24], fine aggregates are classified into IV-Zones, and progressive finer fractions appear from Zone I to Zone IV. Along with this, the blend of coarse and finer aggregates should conform to either Zone I, Zone II or Zone III. Here, Zone, I represent coarse sand, Zone II represents normal sand, Zone III represents fine sand and Zone IV represents very fine sand, but Zone IV is not preferable for reinforced structures. Although these parameters result in satisfactory normal concrete mixes, the application of these in SCC is difficult, as it inhibits the rheological properties [1]. This has been influenced many researchers to develop dense-packed aggregate gradation with new mix design approaches, to promote the rheological and mechanical properties of SCC

Brouwers et al. 2005 [32], made a theoretical study on the comparison of Japanese and Chinese mix design method aspects of SCC. It was found that the Chinese method is purely based on the modified Andreasen and Andersen concept and it is possible to achieve SCC mix with lesser cement paste without compromising the workability and mechanical characteristics in comparison to the Japanese SCC mix design.

Liberato et al. 2006 [34], introduced a new mix design for fibre reinforced SCC mixes based on the modified Andreasen and Andersen concept. By adopting this approach, paste rheology properties were significantly enhanced. It was found that a satisfactory mix design is possible for fibre reinforced SCC with Andreasen and Andersen's concept.

Bakhtiyari et al. 2011 [38], undertook a study on the mix design of SCC with Fuller and Thomson's equations based on the particle size distribution of aggregates and experiments were conducted using two filler materials, limestone and quartz powder. There was no variation in the compressive strength with the incorporation of limestone and quartz powder. At the same time, the effect of Fuller and Thomson equations was observed through an increase in the compressive strength with minimum paste content in comparison with conventional concrete mixes.

Marllon et al. 2016 [42] carried out an experimental investigation on the influence of aggregate characteristics on the workability properties of concrete. In this study, aggregate blend performance was evaluated with different methods such as power curves, Toufar method, Individual percent retained chart, Coarseness factor chart, void content and specific surface area method. Limestone, river gravel, and natural sand are considered for performance evaluation of these methods. It was found that the coarseness factor chart, Void content and specific surface area and Toufar method are unfit to learn about workability properties. At the same time, it was recommended to use Power curves and Individual percent retained chart methods for the evaluation of the same

III. MATERIALS CHARACTERIZATION AND MIX PROPORTIONS

Materials of SCC

Materials characterized and utilized in the mix proportions are Ordinary Portland Cement, Class F Fly Ash (FFA), Cashew Nut-shell Ash (CNA), Natural Aggregates (NA), Reclaimed Asphalt Pavement (RAP) aggregates, Total Recycled Concrete Aggregates (TRCA), water and superplasticizer

Binders of SCC

Ordinary Portland Cement (OPC) (43 grade) conforming to ASTM Type-1 [112] cement was used as the primary binder, FFA (class F fly ash is procured from JSW plant Jaigad, Ratnagiri, Maharashtra) was used as a secondary binder with partial replacement to OPC by 25%, and CNA was also used as a tertiary binder with partial replacement to cement varying between 5% to 20%. The summation of SiO₂, Al₂O₃, and Fe₂O₃ was found to be more than 50% for both FFA and CNA which categorize these mineral admixtures as pozzolana materials as in Table 3.1. CaO composition was found to be more than 18% for CNA and it is conforming to cementitious properties as per ASTM C618-19 [113]. Table 3.1

represents the physical and chemical properties of all binders. Particle morphology is studied through Field Emission Scanning Electron Microscopy (FE-SEM) on Carl Zeiss, Oxford equipment.

Table 3.1 Chemical composition and physical properties of FFA, CNA, and OPC

physical properties of FFA, CNA, and OPC						
Properties	FFA	CNA	OPC			
Specific gravity	2.81	3.11	3.14			
Specific surface area (m ² /kg)	456	594	353			
Fineness (%)	4.52	1.96	3.57			
Chemical composition of FFA, CNA, and OPC						
ASTM C618-19			ASTM			
Oxide			Requirements [113]		C150/C150M	– 20
Composition	FFA	CNA	OPC		Requirements for	
Pozzolana+ cementitious (%)			Pozzolana		OPC [112]	
CaO	1.11	25.81	< 18 %	> 18%	63.12	61-69
SiO ₂	56.50	11.05			21.18	18-24
Al ₂ O ₃	30.26	12.38	SiO ₂ + Al ₂ O ₃ + Fe ₂ O ₃ =		6.18	2.6-8.0
Fe ₂ O ₃	3.71	26.93	50 to 70% min		4.75	1.5-7.0
MgO	0.36	0.13			1.51	0.5-4.0
K ₂ O	1.35	9.74			0.61	0.2-1.0
Na ₂ O	0.11	3.25			0.13	-
SO ₃	0.19	0.20	5% max		1.16	0.2-4.0
LOI	2.72	2.18	10% max		1.25	5.0 max

Fig. 3.1 FE-SEM images of binders

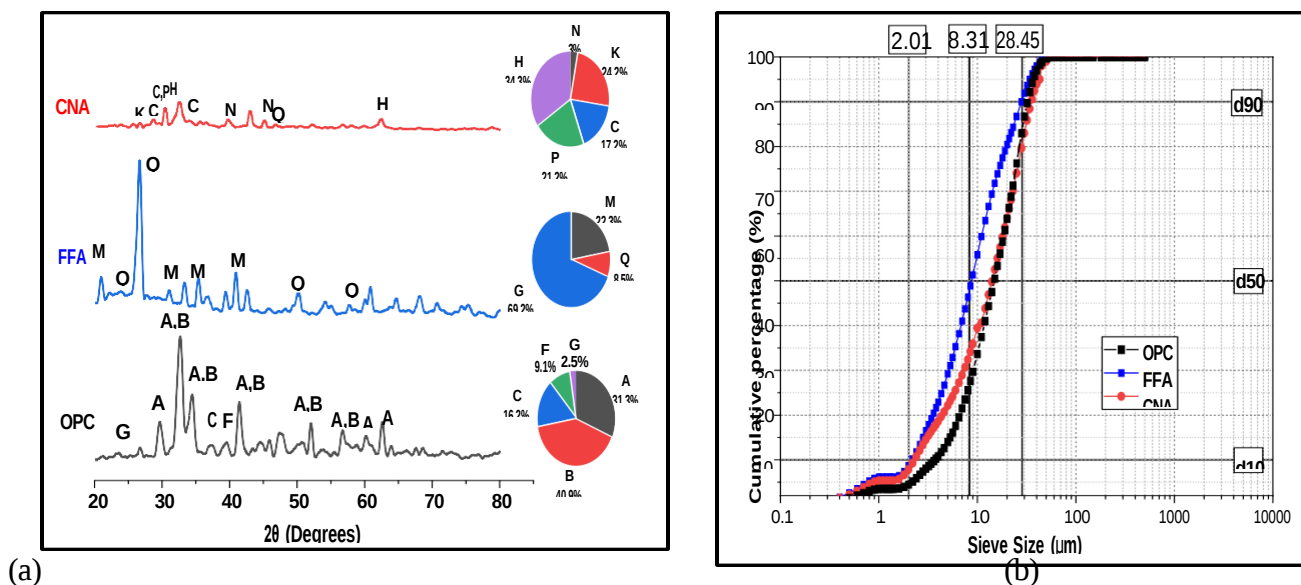


Fig 3.2 (a) XRD and (b) Particle size distribution of binder materials

Table 3.2 Identification of the compound name and chemical formula of binder materials

CNA

Identity	Ref. Code	Compound Name	Chemical Formula
N	96-412-4686	Sodium peroxide	Na ₂ O ₂
K	96-900-8656	Potassium oxide	K ₂ O
C	96-900-8230	Cristobalite	SiO ₂
P	96-900-9099	Portlandite	Ca(OH) ₂
H	96-900-0140	Hematite	Fe ₂ O ₃
FFA			
M	96-901-0160	Mullite	Al ₂ SiO ₅
Q	96-710-3015	Quartz	SiO ₂
G	96-101-1003	Gehlenite	Ca ₂ Al ₂ Si ₂ O ₁₀
OPC			
A	01-070-1846	Calcium silicate oxide	Ca ₃ (SiO ₄) ₂ O
B	00-029-0371	Calcium silicate	Ca ₂ SiO ₄
C	01-070-0134	Calcium aluminum oxide	CaAl ₂ O ₄
F	01-074-0803	Iron aluminum calcium oxide	Fe ₂ O ₃ Al ₂ O ₃ (CaO) ₄
G	01-072-0596	Calcium sulfate hydrate	Ca (SO ₄)(H ₂ O) ₂



Fig. 3.4 Bulk RAP distressing from the NH169

TRCA Aggregates

TRCA is extracted from concrete laboratory waste, Initially, bifurcation of these aggregate was carried through a drilling machine as in Fig. 3.5 (a). As in Fig. 3.5 (b) refining of distressed TRCA was carried through the aggregate grinding machine, further TRCA coarse aggregates ($\geq 4.75\text{mm}$) and TRCA fines ($\leq 4.75\text{mm}$) are collected and stored separately. But the further treatment of TRCA fractions was necessary to remove the adhering mortar because the previous investigation revealed that the presence of adhering mortar significantly reduces the concrete characteristics.



(a)



(b)

Fig. 3.5 (a) Bulk TRCA distressing from concrete waste (b) Refining the distressing material through an aggregate grinding machine

Chemical admixture

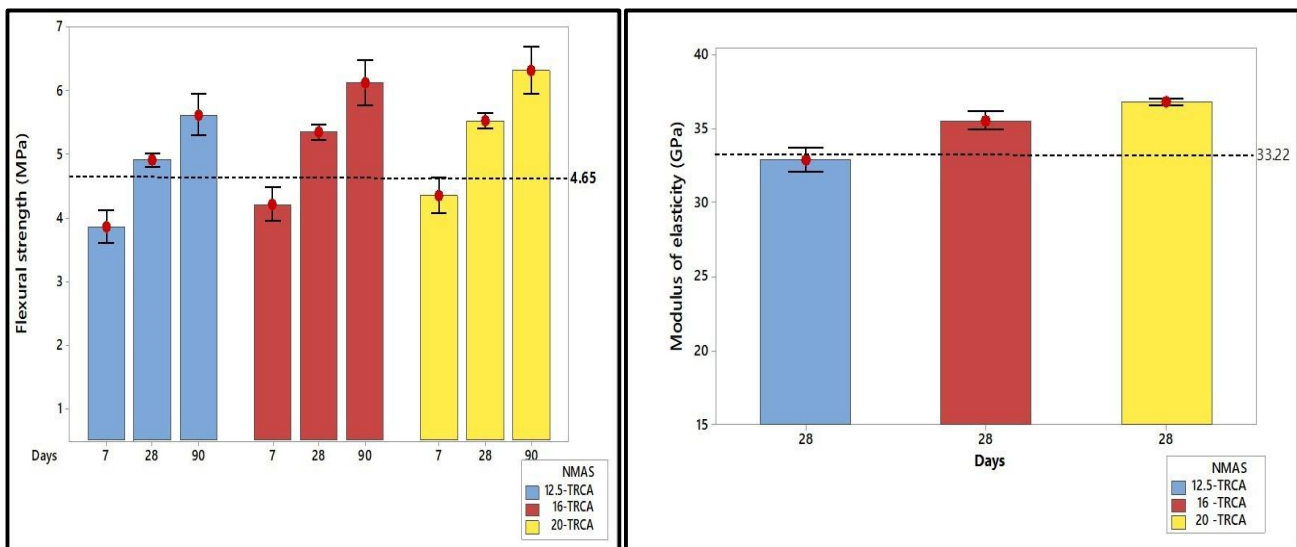
Superplasticizer (SP) based on modified polycarboxylic ether polymer having a specific weight of 1.085 kg/liter and 6 pH has been utilized for the promotion of rheological properties of a concrete mixture (Fig. 3.6). Recommended dosage range from the manufacturer was 0.5 to 3.0 liters/1000 kgs of cementitious materials.



Fig. 3.6 Superplasticizer-Aura Mix 300 plus

IV. ANALYTICAL ANALYSIS

Analyzing the NMAS impact on the optimized SCC-mix (TRCA-CA75-FA75-2- CNA15).



V.CONCLUSIONS

Performance of reclaimed asphalt pavement aggregate incorporated self- compacting concrete

- Restriction of RAP-FA size up to 1.18 mm or less by BAGT improves the rheological properties of SCC.
- Replacement of NA by 75% RAP-CA and 50% RAP-FA with BAGT succeeds to fulfil the minimum compliance requirement of SCC.
- Replacement of 15% CNA was found to increase the compressive strength by 16.28%, flexural strength by 10.52%, and modulus of elasticity by 4.12%.
- NMAS impact on mechanical properties of RAP based SCC revealed that with the decrease of NMAS, decrement in mechanical properties of concrete was found.

Evaluation of self-compacting concrete efficiency

- In terms of CNA, the maximum efficiency was achieved with TRCA-CA75- FA75-2-CNA20 and was around 23.011% and 26.98% compared to CM at 7 and 90 days of age.
- The lowest CO₂ emission rate of about 347.16 kg CO₂/m³ was found for RAP- CA75-FA50-3-CNA20 and the reduction was about 19.14% in comparison to CM.
- NMAS's impact on self-compacting concrete efficiency was found to be insignificant.

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