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To Study High-Strength Concrete in MMRDA Region: A Case Study of Mumbai Metro Line-5 (Thane-Bhiwandi Alignment)

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Abstract - The long-term serviceability of elevated metro guideways heavily relies on the resistance of structural materials to aggressive environmental factors and cyclic dynamic loading. This research focuses on the microstructural characteristics and durability performance of high-strength concrete grades M40 and M60. The study examines varying dosages of GGBS (Ground Granulated Blast Furnace Slag) (20% - 50%) as a supplementary cementitious material to densify the transition zone and reduce micro-cracking. Experimental tests were conducted to evaluate water absorption, rapid chloride penetration (RCPT), and sulphate resistance. Findings demonstrate that the optimized M60 concrete grade exhibits significantly lower permeability and superior resistance to chemical attacks compared to conventional grades. This paper provides actionable mix proportioning guidelines that engineers can directly implement to enhance the lifespan and safety of critical metro rail substructures. The salient features describing the properties of fresh and hardened concrete as well as the precautions taken during the production, transportation, placement and curing of high strength concrete (HSC) are presented. The mixing time for HPC has been kept at 90 to 120 seconds, ensuring good dispersion of cementitious material within the concrete. The low value of standard deviation for HPC of 2.1 MPa indicates good quality of the concrete.

INTRODUCTION

General

For metro rail projects, M60 is the ideal High-Strength Concrete (HSC) grade. It is widely used for heavy-duty structural elements like pre-stressed pier caps, girders, and track slabs. Its high compressive strength 60MPa minimizes structural thickness, maximizes durability against dynamic loads, and reduces long-term maintenance costs. Rapid urbanization has spurred a massive surge in modern mass rapid transit systems (MRTS), commonly known as metro rail networks, across densely populated metropolitan areas. To accommodate the severe dynamic and cyclic loadings induced by high-speed transit operations, infrastructure components—such as pre-tensioned U-girders, elevated piers, and track slabs—require superior mechanical properties and long-term durability. Consequently, High-Strength Concrete (HSC) has become a vital material in modern railway engineering, enabling the construction of lighter, slender, and more resilient structures.

As per global standards (e.g., Indian Standard (IS) 456), concrete with a characteristic compressive strength exceeding 50MPa to 60MPa is classified within the high-strength and high-performance territory. For heavy infrastructure like metro viaducts, M60 grade concrete is frequently designated. The successful deployment of M60 concrete hinges on a well-optimized mix design utilizing a low water-to-cementitious materials ratio w/c, premium crushed aggregates, and High-Range Water-Reducing (HRWR) admixtures.

Furthermore, the introduction of supplementary cementitious materials (SCMs)—such as silica fume, fly ash, and ground granulated blast-furnace slag (GGBS) has greatly enhanced the rheology and microstructural density of M60 concrete. These additions not only yield the target compressive and flexural strengths but also significantly decrease permeability, guarding against aggressive environmental elements like chlorides and sulphates.

LITERATURE REVIEW

1. PREDICTION OF COMPRESSIVE STRENGTH OF SILICA FUME BLENDED HIGH STRENGTH CONCRETE USING RESPONSE SURFACE METHODOLOGY APPROACH (D NIROSHA, C SASHIDHA, K NARASIMHULU)

In this study, a model was developed to predict the compressive strength of High Strength Concrete (HSC) mixed with silica fume using Response Surface Methodology (RSM). This study investigated the effects of cement, water, Silica Fume (SF), Coarse

Aggregate (CA), and silica fume-cement ratio (SF/C) on the 28-day compressive strength of HSC. Silica fume is added with varying amounts of SF (5% to 25%) to cement content. **Methods:** Response surface methodology (RSM) was performed to investigate the influence of independent variables on the compressive strength of HSC. **Findings:** Analysis of the response surface plot reveals a remarkably low error percentage of less than 5%. This reveals a high degree of confidence (95%) in the model's accuracy. This study yielded a coefficient of determination (R2) of 0. 9968. It is observed negligible deviation between predicted and actual 28-day compressive strength values, indicating high model accuracy. **Novelty:** The predicted equation is reasonably predicting the compressive strength of high strength concrete.

Keywords: High strength concrete, Response surface methodology, Silica fume, Compressive strength, Prediction model

2. HIGH STRENGTH CONCRETE USING GROUND GRANULATED BLAST FURNACE SLAG (GGBS) - THAVASUMONY D, THANAPPAN SUBASH, SHEEBA D.

Concrete is a brittle material when it undergoes heavy loads, cracks will form and to reduce this and improve high strength in concrete certain admixtures are used. To produce high strength, concrete these Ground Granulated Blast Furnace Slag is used. It is obtained by quenching molten iron Slag (a by-product of iron and steel making) from blast Furnace in water or steam. GGBS is used to make durable concrete structure in combination with ordinary Portland cement and (or) other pozzolana materials. Concrete containing GGBS cement has a higher ultimate strength than concrete made with Portland cement. It has a higher portion of the strength enhancing calcium silicate hydrates (CSH) than concrete made with Portland cement only and a reduce content of free lime which does not contribute to concrete strength, concrete made with GGBFS continues to gain strength overtime, and has been shown to double its 28-day-strength over periods of 10 to 12 years. Our project is a testing project compared with the compressive strength of PCC and GGBFS, using concrete. Here the amount of cement is reduced and that amount is replaced with GGBS

3. STRENGTH DEVELOPMENT CHARACTERISTICS OF CONCRETE PRODUCED WITH BLENDED CEMENT USING GROUND GRANULATED BLAST FURNACE SLAG (GGBS) UNDER VARIOUS CURING CONDITIONS-SHAHAB SAMAD, ATTAULLAH SHAH AND MUKESH C LIMBACHIYA.

To reduce the embodied carbon dioxide of structural concrete, Portland cement (PC) in concrete can be partially replaced with ground granulated blast furnace slag (GGBS). In this research effect of partial replacement of cement with GGBS on strength development of concrete and cured under summer and winter curing environments is established. Three levels of cement substitution i.e., 30%, 40% and 50% have been selected. Early-age strength of GGBS concrete is lower than the normal PC concrete which limits its use in the fast-track construction and post-tensioned beams which are subjected to high early loads. The strength gain under winter curing condition was observed as slower. By keeping the water cement ratio low as 0.32, concrete containing GGBS up to 50% can achieve high early-age strength. GGBS concrete gains more strength than the PC concrete after the age of 28 day till 56 day. The mechanical properties of blended concrete for various levels of cement replacement have been observed as higher than control concrete mix having no GGBS.

Keywords- Embodied; slag; partial replacement; compressive strength; curing; modulus of elasticity; flexural strength.

4. PROJECT AND QA/QC FRAMEWORK

Mumbai Metro Line-5 connects Thane, Bhiwandi and Kalyan (MMRDA; General Consultant Systra-CEG-SMCIPL). The study uses records from the elevated viaduct (Afcons, Ch. 12000-24700 m) and the Kasheli car depot (Rithwik). The Quality Management Plan (QP-1999-QC-01) defines the quality system; the Inspection Test Plan (Rev-4) specifies, for each material, the tests, the laboratory (in-house or third-party NABL), the IS reference and the frequency; and the Request-for-Inspection workflow provides closed-loop control through QC/Safety/Survey sign-off, consultant approval, and non-conformance management (Fig. 1).

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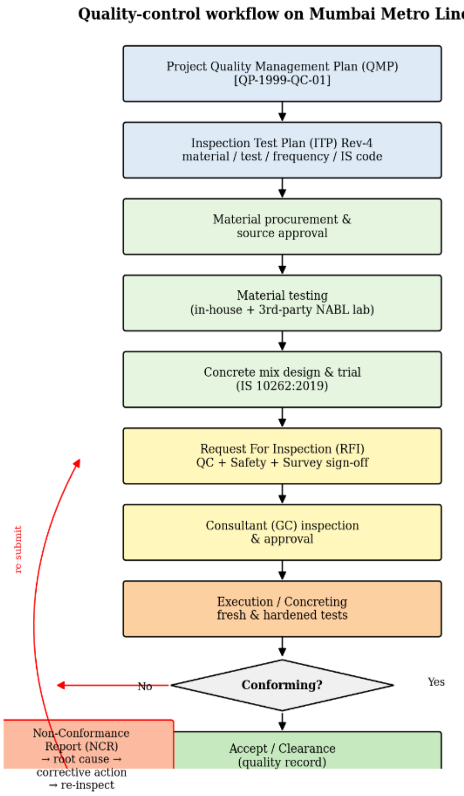

Fig. 1: Quality-control workflow on Mumbai Metro Line-5

5. MATERIALS AND METHODOLOGY

Constituent materials were tested in the site laboratory and by NABL-accredited laboratories. Concrete was proportioned per IS 10262:2019 for severe exposure and verified by 150 mm trial cubes at 7 and 28 days per IS 516, assessed against IS 456:2000. Materials and their reference standards: OPC-53 (Ambuja, Ultratech; IS 269:2015), PSC (JSW; IS 455:2015), 10/20 mm coarse aggregate and crushed sand (IS 383:2016), micro-silica (Elkem 920D; IS 15388:2003), admixture (CAC Hyper fluid R250; IS 9103:1999), construction water (IS 456:2000) and HT strand (Tata 1860-P 15.2 mm LRPC; IS 14268:2022).

6. RESULTS AND DISCUSSION

All tested materials conformed to their IS specifications. Representative aggregate results: 20 mm crushing value 13.89%, impact 9.67%, flakiness 9.5%, water absorption 2.09% (all within IS 383); micro-silica SiO_2 89.77% (>= 85%); HT strand UTS 1927.8 MPa and breaking load 269.8 kN (>= 259). The four mix designs and their verification are summarized in Tables I and II.

Table I: Concrete mix proportions (kg/m3, SSD)

Constituent	M40	M50	M55	M60
Cement (OPC)	330	350	365	372
PSC	-	-	-	-
GGBS	150	160	162	168
Micro-silica	16	18	20	25
20 mm	561	566	568	602
10 mm	444	465	471	411
Crushed sand	882	879	812	826
Water	158	168	164	158
Admixture	4.32	4.75	4.92	5.09
w/cm	0.32	0.33	0.30	0.28

Table II: Achieved strength versus target mean (N/mm2)

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Grade	fck	Target mean	7-day avg	28-day avg	Remark
M40	40	53.25	26.32	55.21	Pass
M50	50	63.25	35.15	66.85	Pass
M55	55	68.25	41.25	71.1	Pass
M60	60	73.25	45.22	77.85	Pass

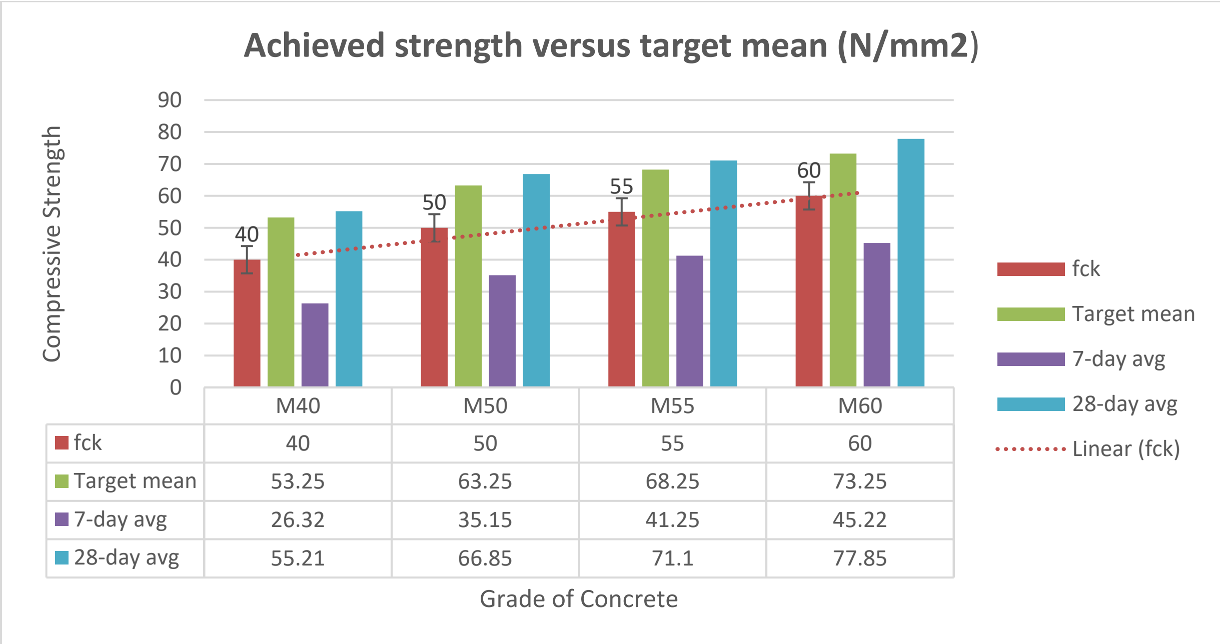

Fig. 2: Trial-cube strength versus target mean strength

Every grade exceeded its target mean strength with a comfortable margin, and 7-day strengths were 60-70% of 28-day values, consistent with normal strength development; all results satisfy IS 456:2000. The blended mixes achieved their strengths at low w/cm (0.33 for M40 with 45% GGBS; 0.28 for M60 with micro-silica and GGBS), confirming SCM effectiveness under disciplined QC. The non-conformance SCGC/L5/NCR/QA/0043 - During Site inspection, seepage and cracks observed on precast elements of concrete level wing slab segments.

1. W6-SP18-SP19-RHS (SP 18side), RFI No. 22760
2. W2-CSP50-SP1-LHS(SP1 side), RFI no. 22427.

7. CONCLUSIONS

The project operates a structured, document-driven quality system linking material approval, testing, mix design, inspection and non-conformance control. All constituent materials and all four mix designs conformed to the relevant Indian Standards, and the trial strengths exceeded their targets. A documented, IS-code-referenced QC chain is therefore the principal driver of consistent concrete quality in Mumbai Metro Line 5 construction. Recording production-cube data for statistical process control and adding durability testing are recommended to further strengthen field QC.

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