



# Development of High-Grade Concrete Using Low-Quality Aggregates via Advanced Concrete Technology

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**Abstract :** The production of high-grade concrete using locally available low-quality aggregates remains a major challenge in regions where aggregate quality is inconsistent and access to premium aggregates is limited. This study investigates the feasibility of developing concrete of strength approaching M100 by optimizing mix design, rheology, and admixture technology despite the use of aggregates exhibiting unfavorable properties such as relatively high crushing value, low specific gravity, and elevated silt and clay content in crushed sand. A sequence of trial mixes was developed using self-compacting and high-flow concrete approaches with low water-to-cementitious ratios, supplementary cementitious materials, and advanced chemical admixtures. Initial trials using conventional mix strategies and 10 mm and 20 mm aggregate systems showed that although compressive strengths in the range of 68–96.8 MPa could be achieved at 28 days, strength development was constrained by weak aggregate–paste interaction, poor interfacial transition zone performance, and inadequate rheology retention. Root-cause analysis identified aggregate quality, fine contamination, and mineralogical irregularities in reddish aggregates as key factors responsible for suboptimal performance. To overcome these limitations, a modified superplasticizer technology based on small-molecule dispersion and redox-polymerized poly aryl ether chemistry was introduced, along with optimized binder composition and fiber incorporation. The improved system substantially enhanced workability retention, cohesiveness, and compressive strength, producing 7-day strengths up to 101.5 MPa and 28-day strengths up to 120 MPa. Comparative evaluation confirmed that the advanced admixture technology significantly improved both early-age and later-age strength relative to the original mixes. The study demonstrates that, although local low-quality aggregates impose severe constraints on ultra-high-strength concrete development, an integrated materials-engineering approach can still enable the successful production of high-grade concrete with robust fresh and hardened properties.

**IndexTerms - high-grade concrete, low-quality aggregates, self-compacting concrete, interfacial transition zone, admixture technology, compressive strength, workability retention.**

## I. INTRODUCTION

High-grade and high-performance concrete has become increasingly important in modern construction owing to its use in tall buildings, long-span structural members, heavily loaded foundations, and durability-critical infrastructure. Previous studies have shown that the performance of such concrete depends not only on the binder system and low water-to-binder ratio, but also strongly on aggregate type, aggregate shape, grading, and fines characteristics [1], [2]. In high-strength concrete, the importance of aggregate quality becomes even more pronounced because the failure mechanism gradually shifts from the cement paste to the aggregate and the interfacial regions, making aggregate selection a critical factor in achieving the target compressive strength [1].

Among the various microstructural features of concrete, the interfacial transition zone (ITZ) is widely recognized as one of the weakest regions. Classical studies described the ITZ as a relatively porous zone around aggregate particles that governs bond strength and often serves as the preferred path for crack initiation and propagation [3]. Later investigations further demonstrated that the microstructure of the ITZ has a direct effect on compressive strength and durability, particularly when inferior aggregates are used [4]. More recent review articles have reaffirmed that ITZ properties are influenced by aggregate roughness, water content, curing regime, and mineral additions, and that improvement of the ITZ is essential for obtaining reliable high-grade concrete performance [5].

The quality of fine aggregate also plays a decisive role in advanced concrete systems. Research on alternative fine aggregates and crushed sand has shown that excessive clay and deleterious fines increase water demand, disturb particle packing, and reduce the strength and durability of concrete [6]. Investigations on crushed sand have indicated that its use can be beneficial only when

grading and fines content are properly controlled; otherwise, fresh-state instability and reduced mechanical performance may occur [7]. Similar findings have also been reported for self-compacting concrete made with manufactured sand, where mix performance was highly sensitive to fine aggregate characteristics and powder balance [8].

To overcome these limitations, many researchers have explored the use of supplementary cementitious materials such as silica fume, GGBS, and ultrafine mineral admixtures in high-strength and self-compacting concrete. Published studies show that these materials improve particle packing, refine pore structure, and enhance mechanical and durability properties when used in optimized proportions [9], [10]. In particular, work on M60, M80, and M100 self-compacting concrete has shown that combinations of GGBS and alccofine can significantly improve fresh and hardened properties, highlighting their importance in the design of high-grade concrete [10]. Studies incorporating silica fume and other supplementary materials in SCC have likewise reported improvements in compressive strength, flowability, and durability-related properties [9].

Another major area of research concerns the use of polycarboxylate ether (PCE)-based superplasticizers. The literature shows that these admixtures are essential in low water-to-binder ratio concretes because they improve dispersion and reduce water demand; however, their performance depends strongly on molecular structure, compatibility with cement, and interaction with silica fume or other mineral additives [11], [12]. Reviews on PCE chemistry indicate that anchoring groups, backbone structure, and side chains strongly influence the workability retention and rheological behavior of cement-based materials [11]. Experimental investigations have also shown that polymer compatibility becomes especially important in high-performance concrete containing silica fume, where appropriate admixture selection directly affects fluidity, cohesion, and hardened strength [12].

Overall, the literature suggests that the successful production of high-grade concrete using low-quality or marginal aggregates requires an integrated approach involving aggregate quality control, minimization of harmful fines, refinement of the ITZ, optimization of binder composition, and appropriate admixture chemistry [1], [5], [6], [10], [11]. In many practical construction situations, however, the availability of premium aggregates is limited, forcing concrete producers to rely on locally sourced materials that may not satisfy the conventional requirements for high-strength concrete production. Such aggregates may exhibit high crushing value, low specific gravity, high water absorption, mineralogical contamination, and high silt or clay content in associated fine aggregates, all of which adversely affect the ITZ, bond quality, durability, shrinkage behavior, and the overall strength of hardened concrete.

Accordingly, the present study focuses on the development of high-grade concrete using such low-quality local aggregates through advanced concrete technology. The objective was to establish a concrete mix capable of achieving strength close to M100 while maintaining acceptable rheology, retention, and self-compacting or high-flow characteristics. The study further examined the extent to which poor-quality raw materials could be compensated through optimized binder composition, reduced water-to-cementitious ratio, advanced admixture chemistry, and appropriate aggregate grading. The investigation was carried out through a sequence of mix design trials, strength monitoring, and performance comparison before and after the introduction of an improved admixture technology, with the aim of identifying feasible mix proportions, diagnosing the causes of low strength, and determining whether technological intervention could sufficiently compensate for material deficiencies to achieve high-grade concrete.

The main objectives of the study are as follows: (1) To develop high-grade concrete using locally available low-quality aggregates; (2) To achieve compressive strength close to M100 through advanced concrete technology; (3) To evaluate the extent to which low-quality raw materials can be optimized through mix design; (4) To examine the relationship between aggregate quality, concrete rheology, and compressive strength development.; (5) To improve strength and workability retention through modified admixture technology.

## II. TECHNICAL REQUIREMENTS AND PERFORMANCE TARGETS

The target concrete system was designed as a self-compacting or high-flow concrete with stringent fresh-property and durability requirements. The principal technical requirements adopted in the study are: (1) Maximum concrete temperature at pouring point: 32°C; (2) Water temperature for design input: below 10°C; (3) Strength evaluation at 1, 2, 3, 7, 14, 28, and 56 days; (4) Maximum water-to-cementitious ratio: 0.19 in the initial design concept; (5) Coarse aggregate: 10 mm down in the first phase, later blended with 20 mm aggregate; (6) Fine aggregate: crushed sand (7) Binder blend: cement + GGBS + Alccofine/ultrafine materials, with further refinement in later trials

The fresh-property performance targets included: (1) Flow: 600 mm after 210 min; (2) V-funnel time: less than 24 s; (3) L-box ratio: 0.9 to 1.0; (4) J-ring: 0 to 10; (5) U-box: 0 to 30

The durability-related requirements included drying shrinkage, rapid chloride permeability, modulus of elasticity, water permeability, and RCMT compliance.

## III. MATERIALS AND EXPERIMENTAL PROGRAM

### 3.1 Binder System

The binder system in the initial trials comprised OPC, GGBS, and Alccofine, with total cementitious content generally in the range of 750–800 kg/m<sup>3</sup> for the principal mixes. In the later optimized mixes, cement, GGBS, microsilica, and additional fine constituents were used in higher-performance combinations. The final optimized mixes also incorporated fibers to improve homogeneity and overall strength development.

### 3.2 Aggregates

The study used locally sourced coarse and fine aggregates that were recognized as low in quality relative to the demands of M100 concrete. The observed issues included:

- Coarse aggregates with crushing values around 21–23%
- Specific gravity values around 2.73–2.75 for coarse aggregates and 2.63 for crushed sand
- Crushed sand with water absorption of 4.82%

- Methylene blue test around 5% for crushed sand
- Silt content around 16.50% in crushed sand

These properties indicated a high probability of weak aggregate particles, elevated fines contamination, high water demand, and poor aggregate–paste interaction.

### 3.3 Admixture Technology

A major phase of the study involved the introduction of a new admixture technology based on poly aryl ether developed through redox polymerization. Unlike conventional polycarboxylate ether systems with a polymer backbone and side-chain architecture, the proposed system was based on small-molecule dispersion, with functionalized negatively charged groups acting as anchoring sites. This mechanism was intended to improve particle dispersion, concrete rheology, and workability retention under high-powder conditions.

### 3.4 Experimental Strategy

The experimental program may be broadly divided into three phases:

1. Initial self-compacting concrete trials using 10 mm down aggregate
2. Subsequent high-flow concrete trials using 20 mm aggregate or aggregate blending
3. Optimized trials using new admixture technology and fiber incorporation

Compressive strength was measured at early and standard ages. The influence of aggregate system, w/c ratio, admixture dosage, and binder composition was assessed through comparative analysis.

## IV. RESULTS OF INITIAL TRIALS

### 4.1 Trials with 10 mm Down Aggregate for Self-Compacting Concrete

The first set of trials used 10 mm down coarse aggregate with cement = 500 kg/m<sup>3</sup>, GGBS = 180 kg/m<sup>3</sup>, Alccofine = 70 kg/m<sup>3</sup>, crushed sand around 648–684 kg/m<sup>3</sup>, water in the range of 143–153 kg/m<sup>3</sup>, and admixture dosage ranging from 7.875 to 14.625 kg/m<sup>3</sup>. The water-to-cementitious ratio ranged from 0.19 to 0.205.

The compressive strength values showed mixed performance. The best-performing mix in this stage achieved approximately 51.1 MPa at 3 days, 69.4 MPa at 7 days, 83.0 MPa at 14 days, and 96.8 MPa at 28 days. Other mixes produced 28-day strengths in the range of about 76.85–87.1 MPa. These results indicated that near-M100 strength was approached in isolated cases, but the performance lacked consistency and robustness.

### 4.2 Trials with 20 mm Down Aggregate Blend for High-Flow Concrete

To improve the aggregate skeleton and reduce the limitations imposed by the 10 mm-only system, subsequent trials incorporated 20 mm aggregate. In these mixes, cement content was typically 540 kg/m<sup>3</sup>, GGBS 180 kg/m<sup>3</sup>, Alccofine 80 kg/m<sup>3</sup>, and total cementitious content 800 kg/m<sup>3</sup>, with w/c ratios of 0.17–0.18. One mix with 520 kg/m<sup>3</sup> cement and 360 kg/m<sup>3</sup> GGBS (total 880 kg/m<sup>3</sup> cementitious content) was also tested.

Although these modifications improved flow retention and early strength, the 28-day strengths remained in the range of 68–76 MPa for most of these trials. The gain in workability did not translate into the required level of compressive strength. This outcome indicated that the strength limitation was not caused solely by grading or maximum aggregate size, but was more fundamentally linked to aggregate quality and matrix–aggregate interaction.

## V. ROOT-CAUSE ANALYSIS OF LOW STRENGTH

The low strength achieved in the early trial phases was attributed to several material-related and microstructural factors.

### 5.1 Weak Interfacial Transition Zone

The interfacial transition zone is the weakest region in ordinary concrete and becomes especially critical in high-grade systems. Aggregates with high crushing value tend to possess fractured surfaces, weak internal structure, and poor load-bearing capacity. Under compressive loading, such particles may initiate micro cracking, weakening stress transfer from paste to aggregate and reducing the effective strength of concrete.

### 5.2 Effect of Low Specific Gravity and Porosity

Aggregates with lower specific gravity are commonly associated with higher porosity and water absorption. Such aggregates reduce mechanical interlocking and may allow a more porous ITZ to form. In high-grade concrete, where the matrix is otherwise dense, these localized weak zones significantly limit the attainable compressive strength and durability.

### 5.3 Excessive Silt and Clay in Crushed Sand

The crushed sand used in the investigation contained high silt and clay content, which increased water demand, interfered with bonding between paste and aggregate, and contributed to shrinkage. These fine contaminants do not contribute to strength and instead act as weak inclusions in the matrix. As a result, they impair both fresh and hardened performance.

### 5.4 Mineralogical Concerns in Reddish Aggregates

The study further noted the presence of reddish aggregates, which were suspected to contain iron oxides or related minerals. These particles may influence concrete negatively through weaker paste bonding, higher permeability, and long-term durability issues. Their possible role in internal micro cracking and reduced bond strength was identified as an additional reason for the low compressive strength obtained in the early mixes.

### 5.5 Aggregate Quality Threshold

A key inference from the investigation was that M100-grade concrete requires substantially better aggregate quality than was available in the initial source. The study indicated that, to reliably establish M100, an aggregate crushing value around 11 and specific gravity of at least 2.8 would be preferable. This conclusion implies that mix optimization alone cannot always fully compensate for inferior aggregate properties.

## VI. INTRODUCTION OF ADVANCED ADMIXTURE TECHNOLOGY

Recognizing that conventional mix optimization was insufficient, the study adopted an alternative superplasticizer technology based on small-molecule dispersion through redox-polymerized poly aryl ether chemistry. This approach was intended to address the rheology and retention problems associated with high powder content and low-quality fines.

The new admixture system improved dispersion of fine particles and produced a more cohesive, soft, and stable matrix. Fiber incorporation was also introduced to improve homogeneity and support more uniform strength development. The optimized mix series contained cement in the range of 550–700 kg/m<sup>3</sup>, GGBS between 230 and 300 kg/m<sup>3</sup>, micro silica of 90–100 kg/m<sup>3</sup>, coarse/fine solid constituents, water of 136–154 kg/m<sup>3</sup>, and admixture dosage around 15.40–17.60 kg/m<sup>3</sup>.

## VII. PERFORMANCE OF OPTIMIZED MIXES

The optimized mixes exhibited a substantial improvement in both early-age and 28-day strength. The 3-day compressive strength increased to 79.74–95.9 MPa for the 550 kg/m<sup>3</sup> cement series and to 87.25–88.1 MPa for the 700 kg/m<sup>3</sup> cement series. At 7 days, strengths ranged from 87.23 to 101.5 MPa in the 550 kg/m<sup>3</sup> series and from 93.1 to 94.8 MPa in the 700 kg/m<sup>3</sup> series. The 28-day strengths ranged from 105 to 111 MPa in the 550 kg/m<sup>3</sup> series, while the richer binder series achieved 115 and 120 MPa.

These results demonstrate that the admixture technology significantly enhanced both workability control and strength development. The best recorded mix attained 120 MPa at 28 days, exceeding the original M100 target.

## VIII. COMPARATIVE ANALYSIS

A direct comparison between mixes without technology and mixes with the new technology highlights the scale of improvement.

For 7-day strength, the conventional mixes produced values of 67, 70, 70, 68, 68, 61, and 60 MPa, whereas the improved mixes achieved 87.23, 91.3, 97.65, 101.5, 94.53, 93.1, and 94.8 MPa. The gain ranged from approximately 17 MPa to over 33 MPa.

For 28-day strength, the conventional mixes showed values of 70, 75, 74, 76, 72, 68, and 69 MPa, while the improved mixes reached 105, 106, 110, 108, 111, 120, and 115 MPa. The increase in 28-day strength ranged from about 30 MPa to 52 MPa.

This comparison confirms that the technological intervention transformed the system from a marginally performing high-powder concrete into a genuinely high-grade concrete capable of surpassing M100 strength.

## IX. DISCUSSION

The study illustrates an important principle in advanced concrete technology: high-strength concrete performance is governed not merely by cementitious content, but by the combined compatibility of aggregate quality, fines quality, particle packing, admixture chemistry, and rheological control. In the present case, increasing binder content alone was insufficient because the local aggregates imposed a cap on achievable strength through weak ITZ formation, fines contamination, and probable mineralogical instability.

The most significant contribution of the new admixture technology was its ability to maintain dispersion and cohesiveness in a system containing large quantities of fine particles and problematic local aggregates. The improved rheology likely reduced localized defects, improved particle packing, and enabled better hydration efficiency. In combination with fiber reinforcement and an optimized binder blend, this produced a denser and more homogeneous composite.

However, the results also indicate that there remains a material quality threshold below which optimization becomes inefficient or uneconomical. The study itself suggests that a better aggregate source could potentially permit a reduction in cementitious content while still achieving M100. Therefore, although the technological intervention was successful, the long-term strategy for economical high-grade concrete should include source-level improvement in aggregate quality.

## X. CONCLUSIONS

Based on the trial results and comparative evaluation, the following conclusions are drawn:

1. High-grade concrete close to or above M100 can be produced even with low-quality local aggregates when advanced concrete technology is employed.
2. Initial trials using conventional self-compacting and high-flow concrete approaches produced inconsistent results, with 28-day compressive strength generally ranging from about 68 to 96.8 MPa.
3. The main causes of low strength were weak aggregate quality, low specific gravity, high crushing value, excessive silt and clay in crushed sand, and possible mineralogical defects in reddish aggregates.

4. These factors weakened the interfacial transition zone, increased water demand, reduced bond quality, and limited the effectiveness of high cementitious-content mixes.
5. The introduction of a modified admixture technology based on redox-polymerized poly aryl ether and small-molecule dispersion substantially improved rheology, retention, cohesiveness, and strength development.
6. The optimized mixes achieved 7-day compressive strength above 100 MPa and 28-day strength up to 120 MPa.
7. The advanced technology therefore proved effective in overcoming several performance gaps associated with low-quality raw materials.
8. Despite this success, the study indicates that better aggregate quality remains essential for a more economical and reliable route to M100 concrete.

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