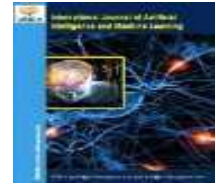




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Resistance of Modified M40 Concrete with GGBS and ALCCOFINE too Aggressive Chemical Environments

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Abstract

The rising need for materials that provide both sustainability and long-lasting performance has resulted in the use of unconventional materials as additives in traditional concrete to achieve better performance and decrease environmental damage. The research examines how M40 grade concrete performs in both mechanical strength and long-lasting properties when different amounts of G and A are used as partial substitutes for the control mix. The experimental program tested three types of materials which included cubes to measure their compressive strength and prisms for their flexural strength and cylinders to assess their split tensile strength during the 28-day and 56-day curing periods. The researchers tested durability through chemical exposure events which involved the use of acid and chloride and sulfate environments to measure how well materials maintained their strength. The results demonstrate that G and A substitution has a major effect on both M40 grade concrete strength development and its ability to withstand aging. All modified mixes met the required target strength standards while their performance showed improvement during the later curing periods. C(50)G(40)A(10) showed the best mechanical performance among the tested mixes because it achieved the material has a maximum 56-day compressive strength of 53.25 MPa, a flexural strength of 5.60 MPa, and a split tensile strength of 8.10 MPa. The improvements result from better particle arrangement and pore structure refinement and successful pozzolanic reactions which create extra calcium silicate hydrate to form a denser and more connected microstructure. The study showed that blended mixes with G and A had better protection against acid and sulfate attacks compared to the control mix but their strength decreased only slightly when exposed to chlorides. The study found C(50)G(40)A(10) to be the best mix because it provides equal strength and durability needed for building projects in harsh conditions.

Keywords: Partial replacement materials, Durability performance, Aggressive environmental exposure, Chemical resistance of concrete, Sustainable construction materials, High-strength concrete.

Introduction

The construction industry uses more natural resources than any other industry and it significantly damages the environment because it produces concrete through cement and natural aggregates. Ordinary Portland Cement production requires significant energy consumption which results in more than 90 percent of worldwide carbon dioxide emissions while natural aggregate extraction results in environmental damage through resource exhaustion and biodiversity decline and ecosystem disruption. Sustainable construction practices now serve as a mandatory solution to environmental challenges because they enable development of infrastructure which uses fewer resources and reduces environmental harm.

A key strategy for improving sustainability in concrete construction is the partial replacement of conventional materials with alternative or supplementary constituents. Use of industrial by-products and locally available materials contributes to waste utilisation, reduces dependence on virgin raw materials, and supports circular economy principles. Such practices not only minimise environmental impact but also offer potential technical benefits, including improved microstructural characteristics, enhanced long term strength, and better durability performance. Consequently, sustainable concrete design is increasingly focused on achieving an optimal balance between environmental efficiency and structural performance. High-strength concrete, such as M40 grade, is widely used in modern infrastructure due to its superior mechanical properties and enhanced endurance compared with normal-strength concrete. However, the production of high-strength concrete typically involves higher cement content, which further intensifies environmental concerns. Incorporating alternative materials in high-strength concrete therefore provides an effective approach to reduce cement consumption while maintaining or improving performance. Optimised replacement levels have been shown to improve particle packing density, refine pore structure, and promote secondary hydration reactions, leading to improved strength development and reduced permeability.

The longevity of concrete structures depends on their ability to withstand environmental damage so durability becomes essential for sustainable construction practices. Structures exposed to aggressive agents such as acids, chlorides, and sulphates are particularly vulnerable to chemical attack, which can result in strength loss, cracking, reinforcement corrosion, and premature failure. Enhancing the durability

of concrete in such environments reduces maintenance requirements, lowers life-cycle costs, and minimises the environmental footprint associated with repair and rehabilitation activities. Therefore, durability-based design is a fundamental component of sustainable infrastructure development.

In recent years, more focus has been given to creating mixed concrete systems that provide better protection against chemicals and help reduce harm to the environment. The incorporation of suitable replacement materials can reduce calcium hydroxide content, limit the formation of expansive reaction products, and produce a denser cementitious matrix, thereby enhancing chemical stability. These improvements directly contribute to the sustainability of concrete by extending service life and improving performance under aggressive exposure conditions.

This study looks at M40 grade concrete that uses different amounts of G and A, with an emphasis on using materials in a sustainable way, improving strength, and making the concrete more durable. The experimental program tests how strong the material is under compression, bending, and splitting, and also checks how well it resists damage from acids, chlorides, and sulphates. The goal is to find the best mix of materials that enhances the structure's performance and supports eco-friendly building methods that work well in tough conditions.

2. Methodology

The research implemented a systematic testing program to assess how M40 grade concrete performs in mechanical strength and durability tests when different amounts of G and A materials are used as partial replacements. The methodology comprised material selection, mix proportioning, specimen preparation, curing, mechanical testing, and durability assessment, as described below.

2.1 Materials

Ordinary Portland Cement that meets the appropriate Indian Standards was used as the main binding material. Fine aggregate consisted of clean, well-graded natural river sand, while coarse aggregate of nominal maximum size was used in accordance with standard specifications. The materials denoted as G and A were used as partial replacements in the concrete mix at predetermined proportions. Clean water that is safe to drink was used for mixing and curing the concrete samples.

2.2 Mix Proportioning

The control mix was designed for M40 grade concrete following standard mix design procedures. Based on the control mix, five different concrete compositions were prepared by varying the proportions of G and A while maintaining consistent water-to-binder ratio and total binder content across all mixes. The mix proportions investigated included C(100)G(0)A(0), C(70)G(20)A(10), C(60)G(30)A(10), C(50)G(40)A(10), and C(40)G(50)A(10). This approach enabled a direct comparison of the effect of replacement levels on mechanical and durability performance.

2.3 Specimen Preparation and Curing

The process of concrete mixing used a mechanical mixer to achieve consistent mixing results. The team created fresh concrete by pouring it into standard moulds which included cube and prism and cylinder moulds to assess compressive and flexural and split tensile strength testing. The team compacted the specimens until all air was removed from the specimens and proper densification was achieved. The team covered the specimens after casting and let them set for 24 hours before removing the moulds. The team cured all specimens in clean water at room temperature until they have reached their testing ages of 28 days and 56 days.

2.4 Mechanical Testing

Compressive strength tests were conducted on cube specimens at 28 and 56 days using a calibrated compression testing machine, in accordance with standard testing procedures. Flexural strength was determined on prism specimens using a standard loading arrangement, while split tensile strength tests were performed on cylindrical specimens. The average of three specimens was reported for each test to ensure reliability and reproducibility of results.

2.5 Durability Assessment

Durability performance was evaluated by subjecting 56-day cured cube specimens to aggressive chemical environments, including acid, chloride, and sulphate solutions. Prior to exposure, the compressive strength of the specimens was recorded. The specimens were then immersed in the respective solutions for a specified exposure period under controlled conditions. After exposure, the specimens were removed, surface dried, and tested again for compressive strength. The reduction in strength was used as an indicator of resistance to chemical attack.

2.6 Data Analysis

The experimental results were analysed by comparing strength development and durability performance of all mixes with the control concrete. Variations in mechanical properties and strength loss due to chemical exposure were evaluated to identify trends and determine the optimum mix proportion. The findings were interpreted in the context of sustainable concrete development and durability enhancement.

3. Literature review

New studies are taking place to look at supplementary cementitious materials like Ground Granulated Blast Furnace Slag and Alccofine because there is a growing demand in the market for eco-friendly building materials that also work very well. This research focuses on ways to make materials stronger and more long-lasting, while also helping the environment by using less Ordinary Portland Cement (OPC).

Initial studies on modified concrete systems established the effectiveness of mineral additives in improving fresh and hardened properties. Grdic et al. (2008) reported that self-compacting concrete containing mineral additives exhibits improved workability, homogeneity, and mechanical stability due to enhanced particle packing. Such findings laid the groundwork for incorporating ultra-fine SCMs, including Alccofine, in high-performance concrete formulations.

Extensive research has examined the individual role of GGBS as a cement replacement material. Strength and durability investigations consistently indicate that GGBS enhances later-age strength, reduces heat of hydration, and improves resistance to aggressive environments (SSRG International Journal, 2015; Revathy et al., 2019; SULTHANA, 2024). Ingale et al. (2023) further observed improved workability and refined pore structure in GGBS-based concrete, attributing these benefits to its latent hydraulic behaviour. Similar conclusions were drawn by Nayaz et al. (2017), who demonstrated that optimal GGBS replacement contributes significantly to the development of high-performance concrete.

The synergistic use of GGBS and Alccofine has been widely reported as an effective strategy to overcome the limitations of single SCM systems. Alccofine, owing to its ultra-fine particle size and high calcium oxide content, accelerates early hydration and enhances particle packing density. R and J (2019) observed notable improvements in durability characteristics, including resistance to chloride ingress and sulphate attack, when GGBS and Alccofine were used together. Experimental studies published in IRJIET (2024a, 2024b) further confirmed that blended mixes exhibit increased compressive strength, reduced permeability, and improved microstructural densification.

Review articles offer solid theoretical backing for these experimental results. Sagar and Sivakumar (2021) did a thorough review of how well Alccofine-1203 works mechanically and lasts over time, and they pointed out how it works well together with GGBS. Boobalan et al. (2021) emphasised that Alccofine-based high-performance concrete benefits from accelerated pozzolanic reactions and improved interfacial transition zone characteristics. Vallepup et al. (2025) summarised recent developments in GGBS–Alccofine blended systems and highlighted optimal replacement levels and sustainability benefits associated with reduced cement consumption.

Advanced applications of Alccofine and SCM-based concrete have also been explored. Gautham Kishore and Ramadoss (2020) demonstrated that ultra-high-performance concrete incorporating Alccofine achieves superior strength and durability due to significant microstructure refinement. Ahmad et al. (2022) linked the use of SCMs such as GGBS and Alccofine to sustainability objectives, reporting substantial reductions in carbon emissions and embodied energy.

Recent strength-based investigations by Kota Chandu Prakash et al. (2025) confirmed that GGBFS incorporation at controlled replacement levels enhances both early and later-age strength characteristics. Performance improvements in self-compacting concrete incorporating mineral admixtures were further validated by the ARPN Journal study (2025), which reported enhanced rheological properties and compressive strength.

Beyond cementitious systems, emerging research highlights the relevance of polymer and composite technologies in advancing construction materials. Nadigatla Naveen Kumar et al. (2024) reviewed recent advances in polymer processing, identifying improved material tailoring, enhanced durability, and multifunctional performance as key benefits. The study emphasised the growing convergence between polymer composites and cementitious materials, particularly in developing hybrid systems with superior mechanical and environmental performance. These insights are particularly relevant for future integration of polymer-modified concrete and fibre-reinforced systems.

Durability and environmental sustainability remain critical considerations. Nazarpour and Jamali (2020) demonstrated that alternative binder systems improve resistance to freeze–thaw cycles, while environmental risk assessment studies published in ARPN Journal of Engineering and Applied Sciences (2025a, 2025b) highlighted the importance of eco-friendly material substitutions in mitigating environmental hazards. Complementary studies involving carbon fibre reinforcement and waste-based materials further support sustainable material innovation (Prasad et al., 2025; ARPN, 2025).

The reviewed literature demonstrates that using GGBS together with Alccofine improves concrete mechanical properties and its ability to endure and its sustainable development. The research on polymer and composite materials enables new material development through expanding existing material development boundaries. The existing research requires systematic testing because different studies report various optimal replacement levels and curing conditions and long-term durability performance results for developing standard mix design protocols for structural applications.

4. Results and Discussion

4.1 Concrete Cubes Compressive Strength

The results for the compressive strength of M40 grade concrete cubes tested at 28 and 56 days are shown in Table 1 and also shown in Figure 1. The control mix with 100% cement, 0% gypsum, and 0% ash reached a compressive strength of 45.85 MPa after 28 days, and this strength slightly rose to 47.90 MPa after 56 days, showing it meets the M40 grade standards.

Mix ID	28 Days (MPa)	56 Days (MPa)
C(100)G(0)A(0)	45.85	47.90
C(70)G(20)A(10)	46.35	49.20
C(60)G(30)A(10)	47.90	51.75
C(50)G(40)A(10)	49.65	53.25
C(40)G(50)A(10)	44.30	49.15

Table 1: Compressive Strength of M40 Grade Concrete Cubes

Concrete that uses both G and A showed better strength over time. Among all the mixes, C(50)G(40)A(10) showed the highest compressive strength after 56 days, reaching 53.25 MPa. This is about 11% higher than the strength of the control mix. This improvement happened because the particles are packed more tightly, the pores are smaller and more uniform, and the material reacts better with water. These changes led to a stronger, more compact structure and better ability to handle stress.

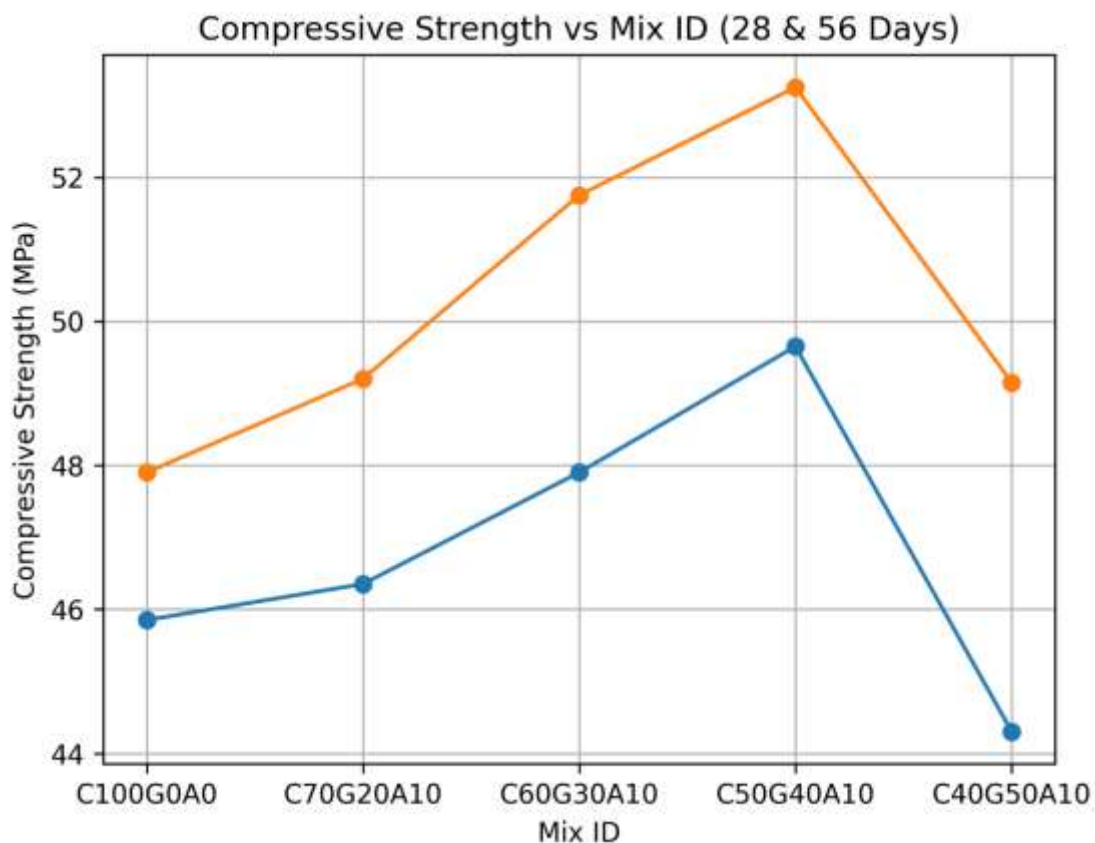


Figure 1 : Variation of compressive strength of M40 grade concrete cubes at 28 and 56 days.

4.2 Flexural Strength of Concrete Prisms

The results of flexural strength at 28 and 56 days are summarized in Table 2 and depicted in Figure 2. The flexural strength followed a trend similar to compressive strength, with notice able improvement at later ages.

Mix ID	28 Days (MPa)	56 Days (MPa)
C(100)G(0)A(0)	4.52	4.98

C(70)G(20)A(10)	4.79	5.15
C(60)G(30)A(10)	4.96	5.35
C(50)G(40)A(10)	5.15	5.60
C(40)G(50)A(10)	4.82	4.45

Table 2: Flexural Strength of M40 Grade Concrete Cubes

The mix C(50)G(40)A(10) achieved the maximum 56-day flexural strength of 5.60 MPa, indicating superior crack resistance and improved interfacial transition zone characteristics. The enhancement in flexural performance suggests improved bonding between aggregate and cementitious matrix, which is critical for structural applications subjected to bending stresses.

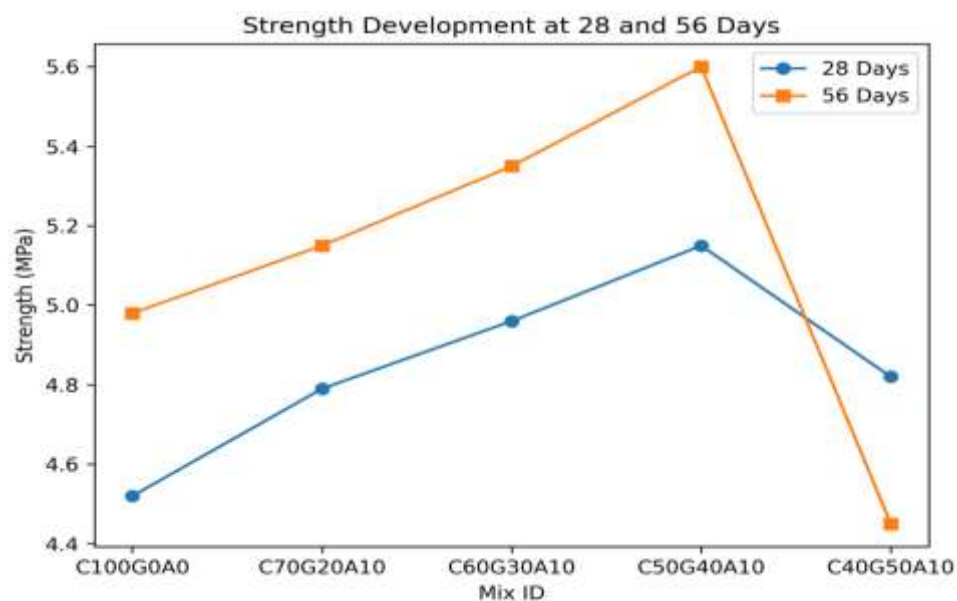


Figure 2 : Flexural strength development of concrete prisms at 28 and 56 days.

Lower flexural strength values were observed in mixes with higher G content beyond 50%, which may be associated with reduced paste quality and weaker bonding at the aggregate–paste interface.

4.3 Concrete Cylinders Split Tensile Strength

Strength results for Split tensile are provided in **Table 3** and shown in **Figure 3**. The tensile strength values increased consistently from 28 to 56 days for all mixes, reflecting continued hydration and microstructural refinement.

Mix ID	28 Days (MPa)	56 Days (MPa)
C(100)G(0)A(0)	5.20	5.42
C(70)G(20)A(10)	5.95	6.35
C(60)G(30)A(10)	7.05	7.25

C(50)G(40)A(10)	7.65	8.10
C(40)G(50)A(10)	6.95	6.40

Table 3 : Strength of Concrete Cylinders Split Tensile

The highest 56-day split tensile strength of 8.10 MPa was recorded for mix C(50)G(40)A(10), which is significantly higher than the control mix. This improvement highlights the effectiveness of optimized replacement levels in enhancing tensile resistance, which is crucial for controlling crack initiation and propagation.

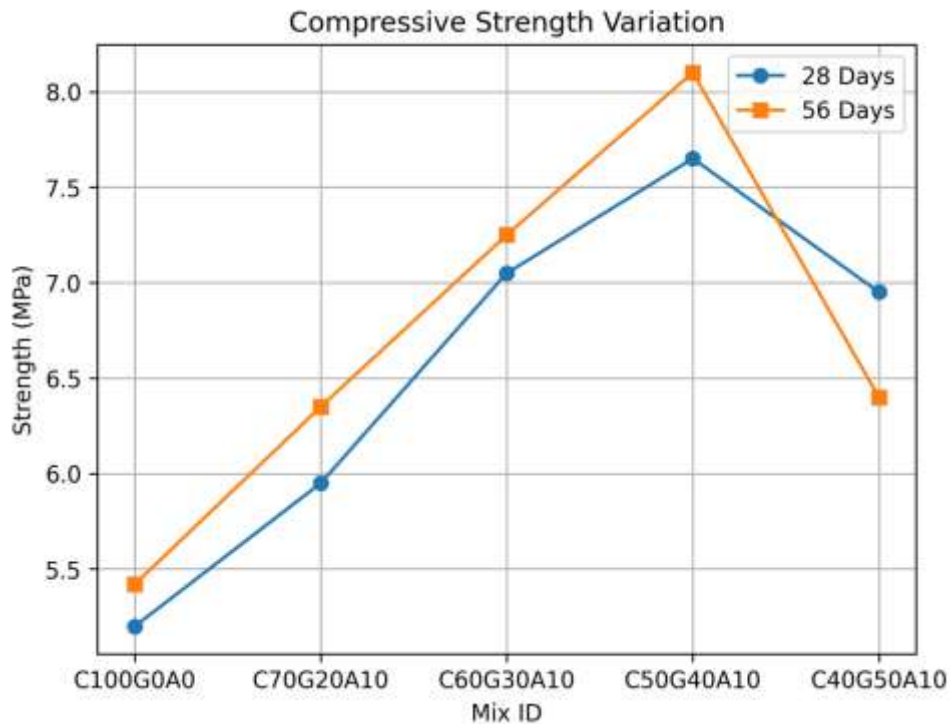


Figure 3: variation of concrete cylinders Split tensile strength at 28 and 56 day.

The results demonstrate a strong correlation between compressive and tensile strengths, indicating that the optimized mix proportion enhances overall mechanical performance.

4.4 Durability Performance under Acid Attack

The effect of acid exposure on compressive strength is presented in **Table 4** and **Figure 4**. All mixes experienced strength degradation after acid attack; however, the extent of deterioration varied with mix composition.

Mix ID	Before Exposure (MPa)	After Exposure (MPa)	Loss (MPa)
C(100)G(0)A(0)	47.90	32.9	15.81
C(70)G(20)A(10)	49.20	34.70	14.50
C(60)G(30)A(10)	51.75	39.60	12.15
C(50)G(40)A(10)	53.25	43.28	9.97
C(40)G(50)A(10)	49.15	38.69	10.46

Table 4: Compressive strength variation under acid attack.

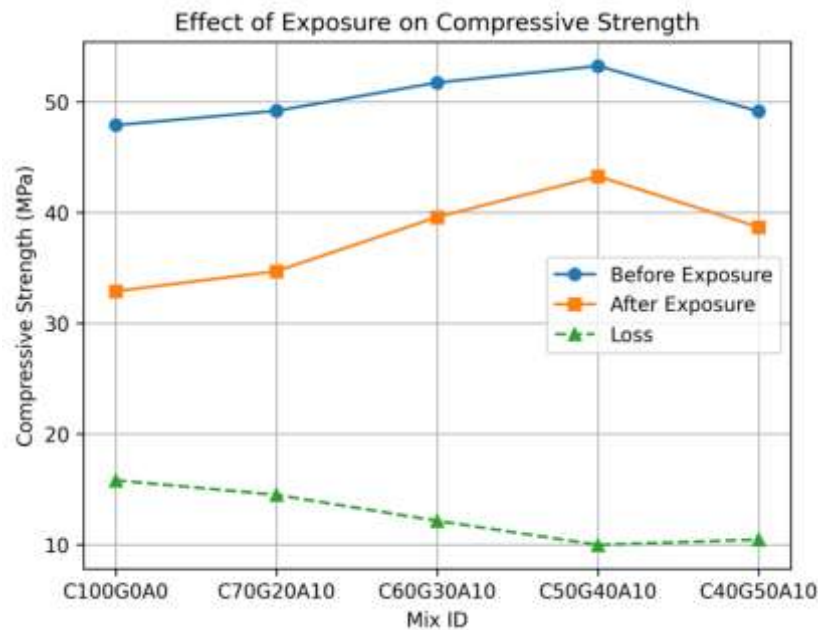


Figure 4: Effect of acid attack on compressive strength of concrete mixes.

The control mix displayed maximum strength reduction at 15.81 MPa whereas mix C(40)G(50)A(10) experienced the least strength reduction at 9.97 MPa. The blended mixes show better acid resistance because they contain less calcium hydroxide and produce secondary calcium silicate hydrate (C-S-H), which improves their chemical stability against harsh conditions.

4.5 Durability Performance under Chloride Attack

Chloride resistance results are presented in **Table 5** and **Figure 5**. Compared to acid and sulphate exposure, chloride attack resulted in minimal strength loss across all mixes, with reductions limited to approximately 1–1.25 MPa.

Mix ID	Before Exposure (MPa)	After Exposure (MPa)	Loss (MPa)
C(100)G(0)A(0)	47.90	46.65	1.25
C(70)G(20)A(10)	49.20	48.10	1.10
C(60)G(30)A(10)	51.75	50.55	1.20
C(50)G(40)A(10)	53.25	52.24	1.01
C(40)G(50)A(10)	49.15	47.96	1.19

Table 5. Compressive strength variation under chloride attack.

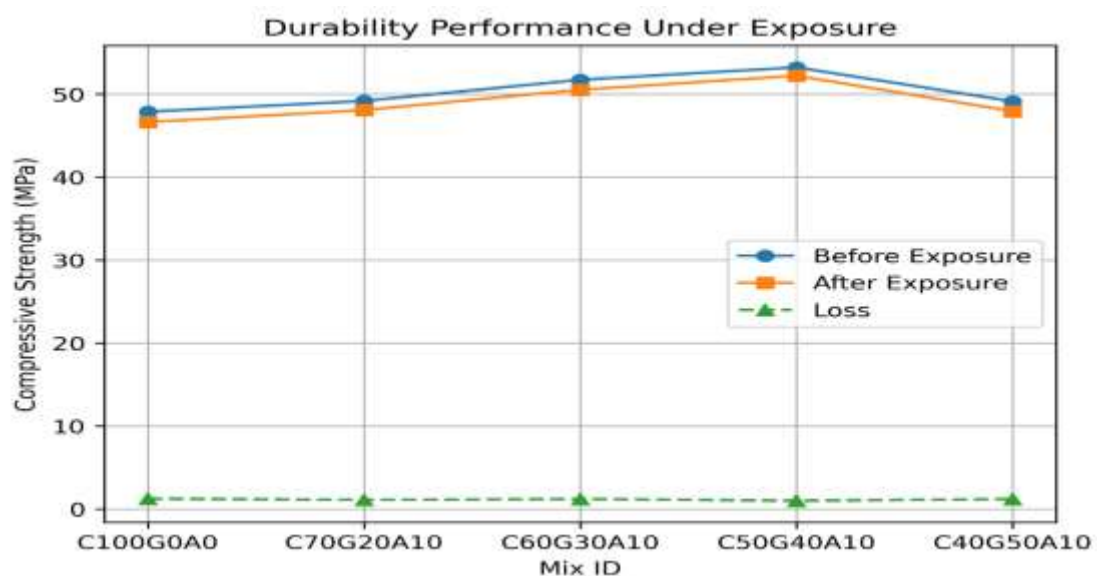


Figure 5: Effect of chloride attack of concrete mixes on compressive strength.

The minor strength reduction indicates that chloride ingress had a limited effect on the cementitious matrix within the exposure duration. Mix C(40)G(50)A(10) exhibited the least strength loss (1.01 MPa), highlighting its superior resistance to chloride-induced deterioration.

4.6 Durability Performance under Sulphate Attack

Sulphate attack results are summarized in **Table 6** and illustrated in **Figure 6**. Sulphate exposure caused significant strength reduction due to expansive reactions leading to microcracking and matrix degradation.

Mix ID	Before Exposure (MPa)	After Exposure (MPa)	Loss (MPa)
C(100)G(0)A(0)	46.70	31.0	16.91
C(70)G(20)A(10)	49.35	34.7	14.50
C(60)G(30)A(10)	51.85	39.16	12.59
C(50)G(40)A(10)	48.45	44.44	8.81
C(40)G(50)A(10)	47.25	40.16	8.99

Table 6: Compressive strength variation under sulphate attack.

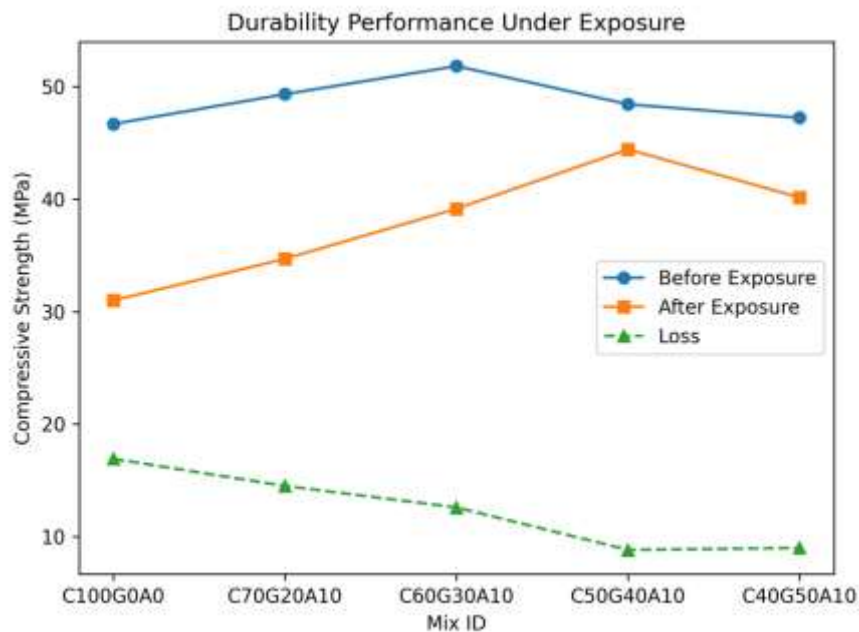


Figure 6: Effect of sulphate attack of concrete mixes on compressive strength.

The control mix experienced the highest strength loss of 16.91 MPa, whereas mixes with higher G and A content showed improved resistance. Mix C(40)G(50)A(10) demonstrated the lowest loss (8.81 MPa), confirming the beneficial role of blended materials in mitigating sulphate-induced damage.

4.7 Optimum Mix Identification

Based on how strong and long-lasting the mix is, C(50)G(40)A(10) is chosen as the best combination. It had better strength when pressed, bent, and split, and it also resisted acids, chlorides, and sulphates better. This balance between strength and durability makes the mix suitable for structural applications exposed to aggressive environments.

5. Conclusion

The current study looked at how well M40 grade concrete performs mechanically and lasts over time when different amounts of G and A are used to replace part of the regular concrete mix. The experiment involved testing the strength of cubes under compression, prisms under bending, cylinders under splitting tension, and checking how durable the material is when exposed to acid, chloride, and sulphate.

The results indicate that all modified mixes satisfied the strength requirements of M40 grade concrete, with notable improvement in strength development at 56 days. The inclusion of G and A enhanced long-term mechanical performance, particularly at moderate replacement levels. Among the tested mix designs, the one with 50% cement, 40% gravel, and 10% sand reached the highest strength after 56 days. It had a compressive strength of 53.25 MPa, a flexural strength of 5.60 MPa, and a split tensile strength of 8.10 MPa. This improvement happened because the particles were packed better, the pores became more organized, and the pozzolanic reactions worked well to create more calcium silicate hydrate (C-S-H), making the material structure tighter and stronger.

Durability studies demonstrated that blended concrete mixes exhibited improved resistance to aggressive chemical environments when compared with the control mix. Acid and sulphate exposure caused considerable strength deterioration in all mixes; however, the magnitude of strength loss was significantly lower in mixes containing G and A. The control mix had the biggest drop in strength, but the mixes with the best replacement levels were more resistant to chemicals because they had less calcium hydroxide and a tighter matrix structure. Being exposed to chloride caused only a small decrease in strength for all the

mixtures, showing that they resisted chloride entry well during the exposure time.

Based on the combined assessment of mechanical strength and durability performance, the mix C(50)G(40)A(10) is identified as the optimum composition. The findings confirm that the controlled incorporation of G and A in M40 grade concrete can produce a structurally efficient and durable material suitable for applications in aggressive environments. Future studies are recommended to focus on long-term durability behaviour, microstructural analysis, and large-scale field validation to further support the practical implementation of the proposed mix proportions.