

Effect of Plasticizer on Workability and Compressive Strength of Recycled Coarse Aggregate Concrete

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ABSTRACT

The construction industry faces critical challenges concerning the depletion of natural aggregate resources and the escalating volume of construction and demolition waste. This research investigates the effect of Sikament 512 PKM plasticizer dosage on the compressive strength and workability of recycled coarse aggregate concrete. Four concrete mixtures were prepared with plasticizer dosages of 0%, 1%, 3%, and 5% by weight of water, with a constant mix proportion of 1:1.5:3. Workability was evaluated using slump tests, and compressive strength was determined at 7, 14, and 28 days. The results demonstrated that 1% plasticizer dosage provided optimal performance, achieving a slump of 74 mm and a 28-day compressive strength of 30.70 MPa, representing an 11.1% improvement over the conventional concrete. Higher dosages of 3% and 5% caused segregation and bleeding, with slump values reaching 120 mm and 175 mm, respectively, and compressive strengths decreased by 1.2% and 18.9%, respectively. The enhanced performance at 1% dosage is attributed to effective dispersion of cement particles and a 10% reduction in water, which lowered the effective water-to-cement ratio from 0.59 to 0.53. This study establishes that an optimized plasticizer dosage is essential for achieving adequate workability and superior compressive strength in recycled aggregate concrete, thereby supporting sustainable construction practices by effectively utilizing demolished concrete waste.

Keywords: Recycled coarse aggregate, Sikament 512 PKM plasticizer, Workability, Compressive strength, Sustainable concrete, Construction waste management

1. INTRODUCTION

Concrete is one of the most widely used construction materials because of its versatility, durability, availability, and cost-effectiveness [1, 2]. Its extensive applications in buildings, transportation infrastructure, and other civil engineering projects have supported development [3]. However, the enormous demand for concrete has also raised environmental concerns, particularly due to the intensive extraction of natural aggregates and the growing generation of construction and demolition waste [4, 5]. Continuous extraction of natural coarse aggregates contributes to resource depletion, landscape degradation, habitat disturbance, and emissions from quarrying and transportation [6]. Meanwhile, demolished concrete occupies valuable landfill space and represents a loss of potentially useful resources [7]. These challenges have increased the need for sustainable approaches that reduce virgin material consumption while effectively utilizing construction waste [8].

Recycled coarse aggregates obtained from demolished concrete provide a promising approach to these challenges [9]. Recycled aggregate concrete (RAC) can reduce dependence on natural aggregates, divert concrete waste from landfills, and promote resource recovery within construction [10]. This approach supports a circular economy by converting waste concrete into useful construction material. Recycling can also conserve natural resources and potentially reduce transportation and environmental impacts associated with aggregate production and waste disposal. Therefore, incorporating recycled aggregates can improve the sustainability of concrete [11, 12].

Despite these advantages, recycled aggregates have characteristics that distinguish them from natural aggregates and influence concrete performance [13]. They commonly contain adhered old mortar, resulting in a porous, irregular particle structure [14]. Consequently, recycled aggregates generally exhibit higher water absorption, lower density, and greater surface area than natural aggregates. Their properties are also affected by the quality

of the original concrete and processing. Higher absorption can increase water demand, while rough surfaces can increase interparticle friction [13]. These characteristics may reduce workability and influence strength development when the mixture is not appropriately designed.

Workability is particularly important for RAC because insufficient workability can make mixing, placement, and compaction difficult. Poor compaction may increase internal voids and adversely affect mechanical performance [15]. Increasing mixing water can compensate for reduced workability but may increase the effective water-to-cement ratio and reduce strength. Therefore, improving workability without unnecessarily increasing water content is essential [16]. Chemical admixtures, particularly plasticizers or water-reducing agents, provide an effective solution [17].

Plasticizers improve concrete workability at a given water content or permit water reduction while maintaining consistency. Their effectiveness is associated with the dispersion of cement particles, which reduces interparticle attraction and friction. Improved dispersion enhances flow and facilitates placement and compaction [18]. Water reduction can also contribute to higher strength by maintaining a lower water-to-cement ratio. Thus, plasticizers may be useful in RAC, where the higher absorption and rough texture of recycled aggregates can adversely affect fresh concrete behavior [19]. However, plasticizer performance depends strongly on dosage. An insufficient dosage may provide little improvement, whereas excessive dosage can cause segregation, bleeding, delayed setting, or unfavorable strength development. The optimum dosage is influenced by cement characteristics, aggregate properties, water-to-cement ratio, mixture proportions, and admixture compatibility [20]. Different dosage ranges reported in previous studies demonstrate that plasticizer performance cannot be generalized across all mixtures [21]. This issue is particularly important for RAC because the porous and variable nature of recycled aggregates may modify interactions between the admixture, cement paste, and aggregate system [22].

Previous RAC investigations have reported inconsistent mechanical properties. Some studies have observed reductions in compressive, tensile, and flexural strength with increasing recycled aggregate content, whereas others have reported comparable or improved strength under specific conditions [13, 23-25]. These differences are associated with recycled aggregate quality, replacement level, source concrete, processing techniques, and mixture design. Although adhered mortar and increased porosity can weaken recycled aggregates, their rough surfaces may also improve mechanical interlocking with cement paste. Therefore, RAC performance depends not only on recycled aggregate content but also on appropriate mixture proportioning and material optimization [26]. Although considerable research has investigated recycled aggregates and plasticizers separately, limited attention has been paid to determining the optimum plasticizer dosage for recycled coarse aggregate concrete, considering both fresh and hardened properties [21, 27]. The interaction between recycled aggregate absorption and plasticizer dosage requires systematic evaluation. Establishing an appropriate dosage is important because maximizing workability alone may lead to undesirable effects, while focusing solely on compressive strength may overlook practical placement requirements [28]. This research gap highlights the need for experimental evaluation of both workability and strength at different curing ages.

Accordingly, this study investigates the influence of Sikament 512 PKM plasticizer on recycled coarse aggregate concrete using dosages of 0%, 1%, 3%, and 5%. Workability is evaluated through slump testing, while compressive strength is determined at 7, 14, and 28 days. The aim is to identify a dosage providing adequate workability and compressive strength without segregation. By establishing relationships among plasticizer dosage, fresh concrete behavior, and strength development, the study seeks to provide practical guidance on the effective use of recycled coarse aggregates in sustainable construction applications for future infrastructure development. The findings are expected to support sustainable concrete production by promoting effective recycling of demolished concrete while maintaining satisfactory engineering performance.

2. METHODOLOGY

2.1 Materials Characterization

Ordinary Portland Cement manufactured by DG Cement was used throughout this research. The cement conformed to ASTM C-150 specifications for Type I Portland cement [29]. The physical properties were determined in accordance with applicable ASTM standards and are presented in Table 1 [30]. Chenab sand was used as the fine aggregate component. The sand was obtained from the Chenab River region and processed to ensure it passed through a 4.75 mm sieve. The physical properties of sand, determined in accordance with ASTM C136 and C128 standards, are presented in Table 2, and its gradation is shown in Figure 1 [31]. Recycled coarse aggregates were obtained from demolished concrete waste collected from construction sites in Multan,

Pakistan. The concrete debris was processed using a laboratory jaw crusher to produce aggregates ranging from 4.75 mm to 12.5 mm [32, 33]. The physical properties of recycled coarse aggregates, determined in accordance with ASTM C127 and C29 standards [34-36], are presented in Table 2, and their sieve analysis is shown in Figure 2. Potable tap water from the municipal supply was used for both mixing and curing purposes. The water was free from organic matter, suspended solids, and excessive concentrations of harmful chemicals that could adversely affect cement hydration or concrete properties. Sikament 512 PKM, manufactured by Sika Pakistan, was used as the plasticizer. The plasticizer provides a high degree of compaction and greater durability while improving surface finish. The physical and chemical properties of the plasticizer are summarized in Table 3.

Table 1. Physical properties of cement

Property	Value	ASTM C-150 requirement
Specific Gravity	3.15	—
Initial Setting Time	47 min	≥ 45 min
Final Setting Time	350 min	≤ 375 min

Table 2. Physical properties of fine and recycled coarse aggregates

Property	FA value	RCA value
Water Absorption	0.74%	5.51%
Moisture Content	0.21%	0.72%
Bulk Density (Loose)	5.31 kg/m ³	5.23 kg/m ³
Bulk Density (Roded)	10.05 kg/m ³	9.92 kg/m ³
Fineness Modulus	1.43	3.79
Specific Gravity	2.54	2.82

Table 3. Properties of Sikament 512 PKM plasticizer

Property	Specification
Type	Water-reducing admixture
Appearance	Brown liquid
Specific Gravity	1.20 ± 0.02 at 25°C
pH Value	6.0 - 8.0
Chloride Content	< 0.1%

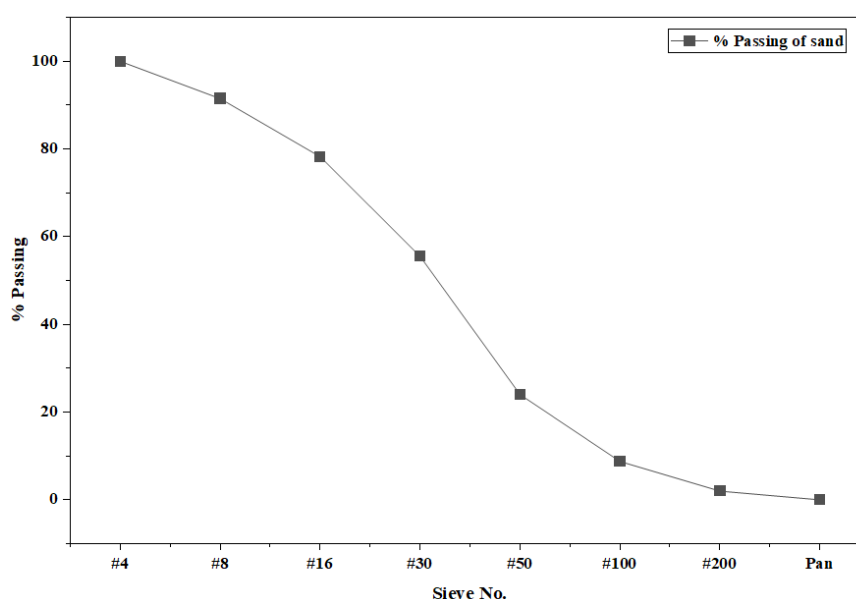


Figure 1. Gradation of fine aggregates (sand).

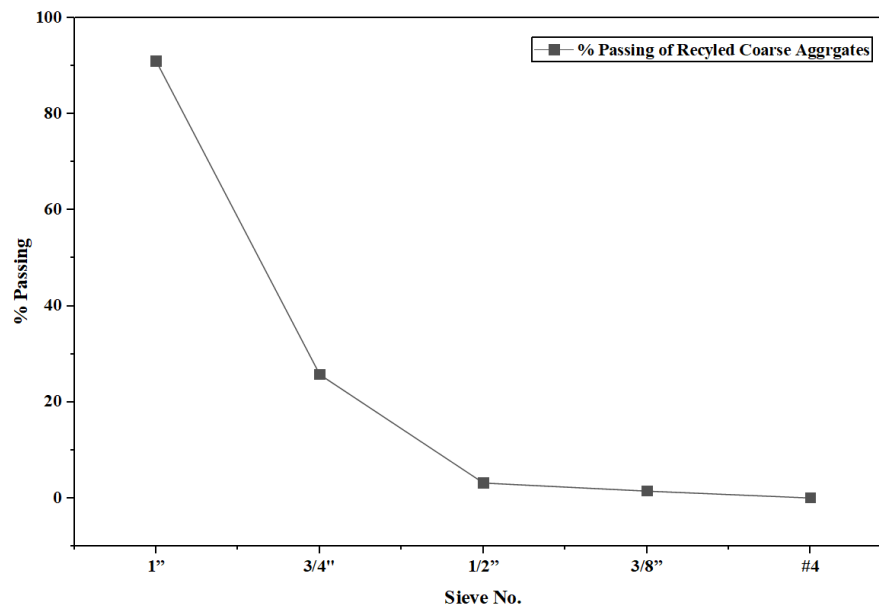


Figure 2. Gradation of recycled coarse aggregates.

2.2 Mix Design and Batch Composition

The mix design was performed according to ACI guidelines for a specified strength of 20 MPa, a required slump of 70-100 mm, and a maximum aggregate size of 12.5 mm [37]. The target strength was calculated to be 27 MPa due to insufficient statistical data. The water-to-cement ratio was determined as 0.59, and the mix proportion was established as 1:1.5:3.

Four batches were prepared with plasticizer dosages of 0%, 1%, 3%, and 5% by weight of water. The water content was adjusted for each batch to account for the plasticizer's water-reducing effect. The complete batch compositions are presented in Table 4.

Table 4. Batch composition for concrete mixes

Component	0% Plasticizer	1% Plasticizer	3% Plasticizer	5% Plasticizer
Cement (kg)	14.40	14.40	14.40	14.40
Fine Agg. (kg)	23.70	23.70	23.70	23.70
Coarse Agg. (kg)	46.95	46.95	46.95	46.95
Water (kg)	10.90	9.71	10.04	10.36
Water Reduction	—	10%	5%	0%
Plasticizer (g)	0	109	327	545

2.3 Workability Evaluation

Workability was evaluated using the slump test in accordance with ASTM C143 [38] as shown in Figure 3. The procedure involved cleaning the slump cone, placing it on a smooth base plate, filling it with concrete in three layers with each layer rodded 25 times, leveling the top surface, slowly removing the cone, and measuring the slump as the difference between the cone height and the height of the concrete after subsidence. The slump values were recorded for all four mixes to assess the effect of plasticizer dosage on workability.

2.4. Specimen Preparation and Curing

A total of 36 cube specimens of 150 mm × 150 mm × 150 mm were prepared, with three specimens for each combination of plasticizer dosage and curing age. The preparation procedure included:

1. Cleaning and oiling of steel molds
2. Filling concrete in three layers with 35 strokes of compaction per layer
3. Striking off the top surface with a trowel
4. Curing in a shed covered with wet gunny sacks for 24 hours
5. Demolding and immersion in a water tank at 24-30°C
6. Testing at 7, 14, and 28 days



Figure 3. Workability of fresh concrete setup.

2.5. Compressive Strength Testing

Compressive strength tests were conducted using a compression testing machine in accordance with ASTM C109 [39] as shown in Figure 4. The specimens were removed from the curing tank, wiped with a towel, and tested in saturated-surface-dry condition. The load was applied continuously without shock until specimen failure, and the maximum load was recorded. The compressive strength was calculated by dividing the maximum load by the specimen's cross-sectional area.



Figure 4. Testing of cubes under universal testing machine.

3. RESULTS AND DISCUSSION

3.1 Workability Results

The slump test was performed on all four concrete mixtures to evaluate the effect of plasticizer dosage on workability. The results are presented in Table 5 and illustrated graphically in Figures 5 and 6.

The control mix without any plasticizer gave a slump of 69 mm. This value falls slightly below the target slump range of 70-100 mm that was set during mix design. The main reason for this reduction appears to be the high water absorption capacity of recycled coarse aggregates. As shown in Table 2, these aggregates have a water

absorption of 5.51%, which is considerably higher than natural aggregates. This means a portion of the mixing water is absorbed by the aggregates, leaving less free water available to lubricate the mixture and provide workability.

Table 5. Slump values for different plasticizer dosages

Plasticizer Dosage	Slump (mm)	Observation
0%	69	Adequate workability
1%	74	Improved workability
3%	120	Moderate segregation observed
5%	175	Excessive segregation observed

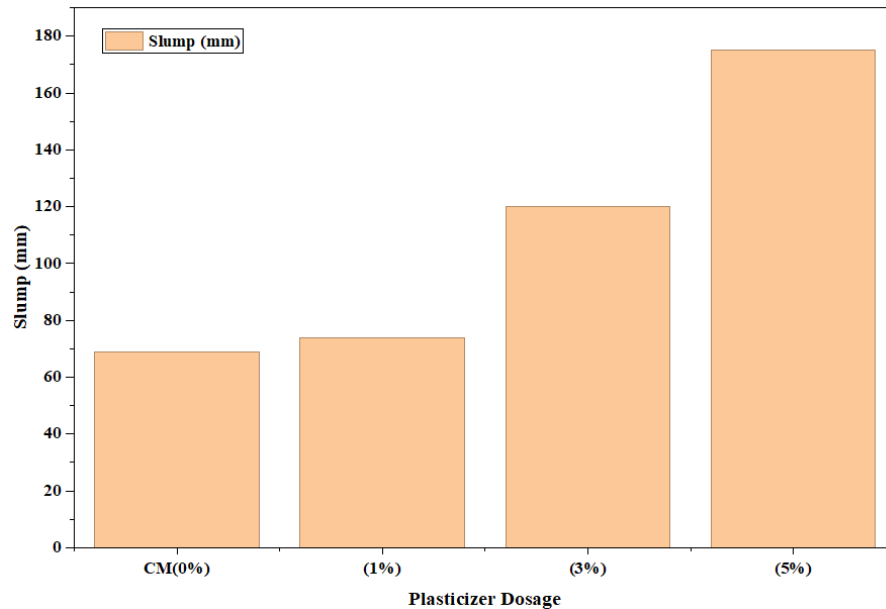


Figure 5. Slump of fresh concrete.

When 1% plasticizer was added, the slump increased to 74 mm. This 7% improvement was enough to bring the slump to the desired range. More importantly, the concrete remained cohesive and showed no signs of segregation or bleeding. The plasticizer works by dispersing cement particles that tend to form clumps when mixed with water. Once these particles are separated, the water trapped between them becomes available to improve flow. The mix at this dosage is handled well during placement and compaction.

At 3% plasticizer content, the slump jumped to 120 mm. While this represents a significant gain in workability, the mixture began to show signs of trouble. Moderate segregation was observed, indicating that the heavier coarse aggregates were beginning to settle while the lighter cement paste rose to the surface. The paste had become too thin to properly suspend the aggregates. This indicates that the plasticizer dosage had exceeded the point where it could be effectively utilized by the mixture.

The worst performance was observed at the 5% dosage, which produced a slump of 175 mm. This mixture was visibly unstable, with coarse aggregates settling at the bottom of the slump cone and water bleeding out from the top. Such excessive fluidity makes the concrete unsuitable for structural applications because the segregation leads to non-uniform properties throughout the member. The mixture had essentially lost its internal structure and could not maintain homogeneity.

Based on the results, Sikament 512 PKM improves workability only to a certain limit. Recycled aggregates are more porous and have rougher surfaces than natural aggregates, which increases particle friction and raises the water requirement. The plasticizer addresses these issues by enhancing particle dispersion. Nevertheless, when the dosage exceeds what the mix can tolerate, the positive effects diminish, and the concrete loses stability. A 1% dosage offers the optimal balance, delivering sufficient workability for effective placement while maintaining stability.

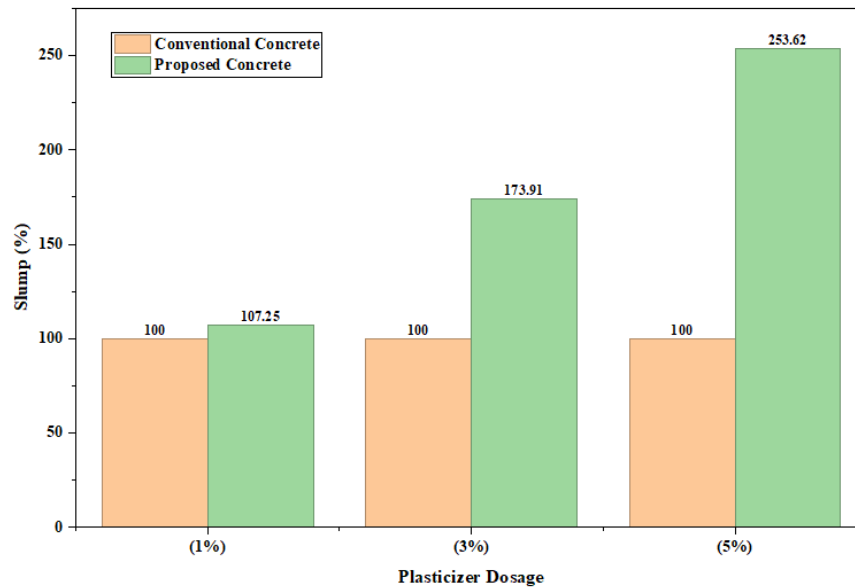


Figure 6. Residual slump in proposed mixes.

3.2 Compressive Strength Results

Compressive strength testing was conducted at 7, 14, and 28 days to monitor strength development. The results are presented in Table 6 and illustrated graphically in Figures 7 and 8.

Table 6. Compressive strength of cubes

Plasticizer dosage	7-Day cube strength (MPa)	14-Day cube strength (MPa)	28-Day cube strength (MPa)	Change vs Control
0%	20.46	24.90	27.63	-
1%	25.00	29.00	30.70	+11.1%
3%	20.90	24.90	27.30	-1.2%
5%	17.91	21.60	22.40	-18.9%

The control mixture without plasticizer gave strength values of 20.46 MPa, 24.90 MPa, and 27.63 MPa at 7, 14, and 28 days, respectively. These numbers meet the 28-day design strength requirement of 20 MPa, confirming that recycled aggregate concrete can achieve acceptable structural performance even without chemical admixtures. The strength gain pattern follows what would be expected from normal cement hydration, with about three-quarters of the final strength developed within the first week and 90% reached by two weeks.

The mixture with 1% plasticizer outperformed all others at every age. The 7-day strength reached 25.00 MPa, the 14-day strength was 29.00 MPa, and the 28-day strength was 30.70 MPa. This represents an 11.1% improvement over the control at 28 days. The reason for this improvement is straightforward—the plasticizer allowed a 10% reduction in mixing water while still maintaining adequate workability. With less water in the mix, the water-to-cement ratio dropped from 0.59 to about 0.53. A lower water-to-cement ratio means less capillary porosity in the hardened paste, which directly translates to higher strength. The improved dispersion of cement particles also leads to more complete hydration, as more of the cement surface area is exposed to water.

The 3% plasticizer mixture gave strengths of 20.90 MPa, 24.90 MPa, and 27.30 MPa at the three ages. Compared to the control, this represents a slight drop of about 1.2% at 28 days. The interesting thing here is that, despite having much better workability than the control, the strength decreased slightly. This suggests that the segregation observed during slump testing had a real impact on the hardened concrete. When aggregates settle unevenly during placement, some regions end up with too many aggregates and too little paste, while others have the opposite problem. These non-uniform areas become weak points where cracks can easily form under load.

The 5% plasticizer mixture performed the worst, with strengths of only 17.91 MPa at 7 days, 21.60 MPa at 14 days, and 22.40 MPa at 28 days. The 28-day value is 18.9% below the control. This severe strength loss can be directly linked to the excessive segregation and bleeding observed during testing. When a mixture bleeds excessively, water rises to the surface, creating a weak, porous layer at the top. Meanwhile, the bottom of the member becomes overly dense with aggregates but lacks sufficient paste to bond them together. The interfacial

transition zone, the region between aggregates and paste, becomes particularly weak under these conditions, and this is where cracks typically initiate under compressive loading.

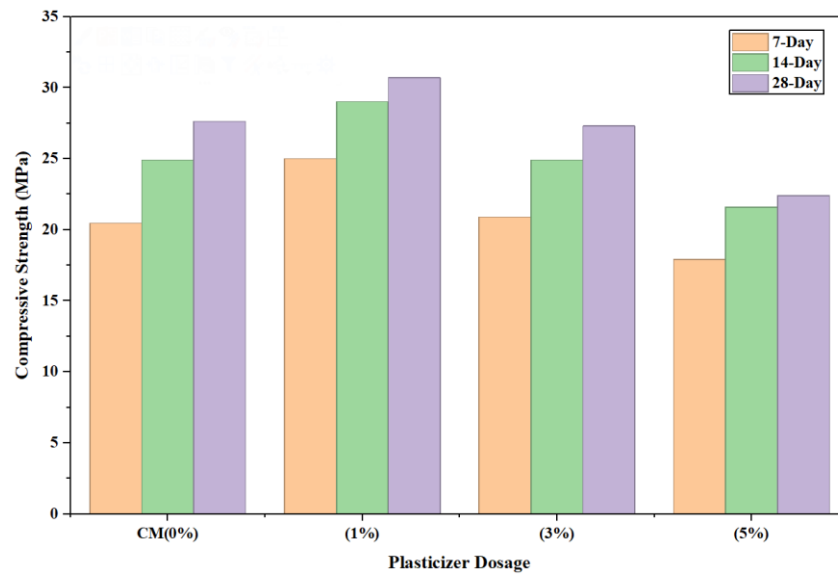


Figure 7. Compressive strength of concrete at 7, 14 and 28 days.

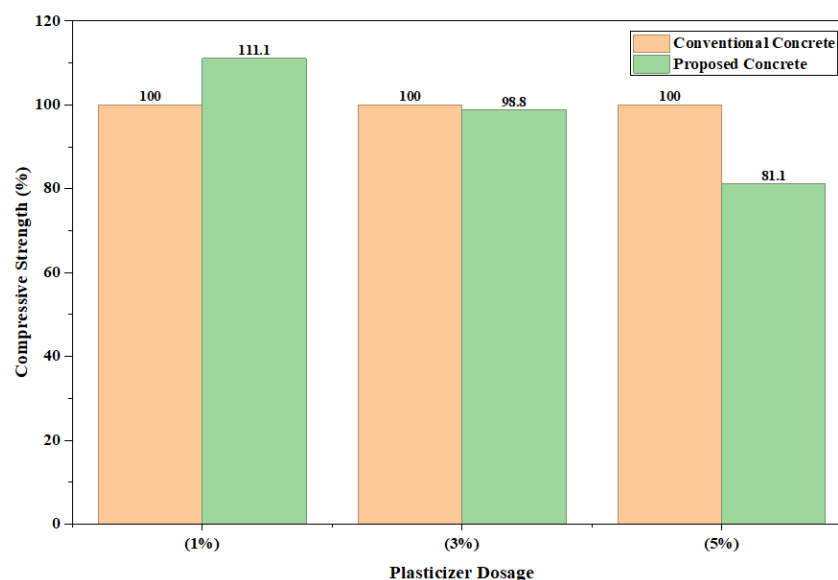


Figure 8. Residual compressive strength in proposed concrete at 28 days curing.

4. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusions

Based on the experimental investigation, the following conclusions are drawn:

1. The 1% plasticizer dosage provided the optimal balance between workability and compressive strength. The 28-day compressive strength reached 30.70 MPa, representing an 11.1% improvement over the control concrete (27.63 MPa).
2. Workability improved with increasing plasticizer dosage. Slump values increased from 69 mm (0%) to 74 mm (1%), 120 mm (3%), and 175 mm (5%). However, dosages above 1% caused segregation, with 3% showing moderate segregation and 5% showing excessive segregation.

3. Excessive plasticizer dosage (3% and 5%) resulted in significant strength reduction. At 28 days, the 3% dosage showed a 1.2% decrease, while the 5% dosage showed an 18.9% decrease compared to the control.
4. The 1% plasticizer dosage achieved the target slump range of 70-100 mm while maintaining mixture homogeneity without segregation or bleeding.
5. Recycled aggregate concrete with optimized plasticizer dosage (1%) can achieve superior compressive strength compared to conventional concrete, demonstrating that sustainable construction materials can meet or exceed performance requirements.
6. The high water absorption (5.51%) of recycled coarse aggregates reduces workability by absorbing mixing water. The plasticizer compensates for this effect by improving particle dispersion and reducing water demand.
7. The water reduction achieved at 1% dosage (10%) lowered the effective water-to-cement ratio from 0.59 to 0.53, contributing to improved strength development.
8. Segregation caused by excessive plasticizer dosage creates non-uniform microstructure and weak interfacial transition zones, resulting in strength loss.

4.2 Recommendations

1. Investigate long-term durability, shrinkage, and creep behavior of optimized recycled aggregate concrete with plasticizers through extended studies.
2. Validate laboratory findings through field-scale trials to confirm applicability under real construction conditions.
3. Characterize recycled aggregates thoroughly, particularly for water absorption, to properly adjust mix water and plasticizer dosage.
4. Promote recycled coarse aggregates with optimized plasticizer dosage in construction to reduce natural resource depletion and waste disposal.
5. Conduct economic analysis to evaluate the cost-effectiveness of using plasticizers in recycled aggregate concrete compared to conventional concrete.

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