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Assessment of Target Mean Compressive Strength of Concrete Using Seti River Aggregates in Pokhara, Nepal

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Abstract

The sound properties of the coarse and fine aggregate play vital roles in achieving the strength and durability of the concrete. The physical and mechanical properties of aggregate were tested as per the Indian Standard (IS) and the Standard Specification for Road and Bridge Works (SSRBW). The test results reveal that all three sources in the Seti River from where aggregates were extracted satisfy the IS code provisions for standard concrete mix design. The standard concrete of M35 and M45 grade with the mix design was carried out, but the source of sample C does not meet the target mean compressive strength of M45 grade concrete as per Indian Standard. According to the Department of Roads Specification, only source A meets the target mean compressive strength, whereas sources from B and C do not meet the target mean compressive strength for M45 grade concrete. The geological origin of aggregate & mixture proportioning adjustment should be carried out to improve target mean compressive strength for M45 grade concrete of sample source C.

Keywords: *Aggregates, Grade Designation, Mix-design, Ordinary Portland Cement, Sustainable Concrete*

1. Introduction

Concrete is used worldwide for multidisciplinary, multifaceted infrastructure development. Concrete is a popular construction material because it can be moulded into any desired shape, possesses adequate strength and plasticity for mechanical working, and its strength and other properties can be easily varied by varying its proportion of the ingredients. The ingredients are cement, coarse aggregate, fine aggregate, and water. Next to cement, water is the most essential ingredient in concrete production, governing and enhancing concrete's properties, such as strength, durability, and water tightness. The fresh concrete should be easy to mix, transport, place, compact and finish the exposed surface, with a desirable shape that is free from segregation during these operations (Ratner, 1999).

The compressive strength is a fundamental property of concrete. As per IS 456:2000 code of practice; concrete having grade designation as M10, M15, M20 are ordinary concrete; M25, M30, M35, M40, M45, M50, M55 are standard concrete and M60, M65, M70, M75, M80 are high strength concrete. In the designation of concrete mix, M denotes the mix, and the number specifies the specified compressive strength of a 150 mm size cube at 28 days, expressed in N/mm2. The compressive strength of concrete depends on various factors such as the water-to-cement ratio, the bond between mortar and aggregate, the ratio of cement to aggregate, and gradation, shape, strength and size of aggregates used in concrete preparation. Therefore, the strength of concrete in the interfacial zone depends on the integrity of the cement paste and the nature of the coarse aggregate (M. Abdullahi, 2012). For a given water-cement ratio, concrete's strength, stiffness, and fracture depend on the type of aggregate. But at a lower water-to-cement ratio, a binary granular system produced the highest compressive strength. The compressive strength of concrete increases with the age of curing. At the same curing age, the highest compressive strength was obtained with crushed quartzite aggregate, followed by river gravel, and the lowest strength was obtained with crushed granite aggregate in concrete. Due to more voids within each coarse aggregate during concrete preparation, the voids to be occupied by mortar paste affect the concrete's workability, and adjustments in mixture proportions are made to improve the concrete's rheology (M. Abdullahi, 2012).

The compressive strength of cement mortar with 50% replacement of natural sand with manufactured sand is higher strength than that of the reference mix (Narayana and Manjunatha, 2016). The quality of aggregate determines the performance of concrete. Variation in aggregate properties (mechanical and physical) also influences concrete strength, workability, and durability (Prajapati and Karanjit, 2019). The coarse aggregate sources affect the strength of concrete made from them; i.e., the compressive strength of concrete varies with coarse aggregate source (Khadka, et al., 2021).

The aggregate material becomes more suitable in its hardness, toughness, and strength on moving from upstream towards downstream along the Birring River. The lower part of the stream was assessed to have somewhat better quality (Adhikari et al., 2022). The production and supplying of quality construction material and their commitment to quality are of prime concern in the construction industry. Today's quality is not quality for tomorrow; therefore, continual improvement is needed to achieve customer and societal satisfaction (Banstola and GC, 2023). Quality is free from faults and defects and in conformance with the contract documents or as per specification. Guessing on quality will only get you trouble in operations. It is desirable to know the general nature of concrete ingredients and their properties, such as soundness, cleanliness, proper gradation, and the requirement to determine specific gravity, moisture content, particle shape, and surface texture (Andres and Smith, 2001).

Concrete is also one of the most challenging materials to maintain its quality, design, and construction, with different types of concrete for different structural performance. In high-strength concrete, plasticizer, fly ash and micro silica are used in addition to the concrete ingredients to achieve the targeted compressive strength. The self-compacting concrete was used in Japan due to durability problems in heavily and complex reinforced structure, where a shortage of skilled worker and poor communication between designers and construction engineers are common. The failures in ordinary concrete or mortar are initiated in the transition zone, where the brittle materials between the matrix phases are present. In modern construction industries, ductile structural elements are needed to withstand high compressive, tensile, and flexural stresses. The higher compressive strength and greater toughness of cement-based composites with the presence of strong coarse aggregate and fibres contribute to improved impact resistance (Gyawali, 2019).

The quality of fresh and hardened concrete depends on the properties of aggregate used. The aggregate properties also depend on the properties of the parent rock, such as types, specific gravity, hardness, strength, pore structure, colour, chemical, and mineralogical composition, and physical and chemical stability. The cement paste volume depends on shape, texture, gradation, and degree of fineness of the sand to achieve adequate concrete workability. The water-cement ratio governs the mechanical properties of concrete at a given degree of hydration (Gambhir, 2006). The inclusion of super plasticizer as an admixture allows for reducing water demand to achieve a high slump value. But a higher dosage of superplasticizer was needed in concrete if the sand is of finer material to minimize the adverse effect of fine materials. High strength concrete mix with fine sand shows better compressive strength than a concrete mix with natural sand. The shape and texture of crushed sand particles have a good effect on the interlocking of paste and aggregates particles, which finally improved the strength of concrete (Al. Ameeri and Al. Baghdahi, 2012).

The primary source of compressive strength in concrete is the hydration reaction of cementitious materials, which produces C-S-H gels and a dense matrix. The compressive strength of sustainable concrete is influenced by eight significant factors: cement quality, blast furnace slag, fly ash, water, super plasticizer, coarse aggregates, fine aggregates, and testing age. An increase in cement has a beneficial effect on the compressive strength because more cementing particles are activated in the hydration reaction, forming CSH gels that enhance compressive strength. Increasing water to 140 Kg/m^3 improves the compressive strength; but it decreases above this threshold. If the water content increases further, more voids form with in the concrete, reducing its compressive strength. The compressive strength of concrete depends on the type and size of coarse aggregate. Increasing the coarse aggregate content reduces concrete strength. The coarse aggregate creates a weak interfacial transition zone in concrete, showing a detrimental impact on compressive strength. The quantity of the fine aggregate at 600 - 650 Kg/m^3 shows a positive effect on the compressive strength; however, further increases did not affect the compressive strength (LI et al., 2023).

The properties of concrete can be adjusted by adjusting and improving the mix ratio. The coarse aggregate is the strongest and stable inert materials of concrete. When the volume fraction is between 40% and 80%, the fundamental strength and the elastic modulus of concrete will increase as the volume fraction of coarse aggregate increases. Due to the high strength and strong crack resistance of coarse aggregate, it gradually improves the shrinkage deformation, elastic modulus, strength and durability of concrete. Replacing cement with coarse aggregate can address problems of aggregate suspension and excessive slurry in high performance concrete (Jia et al., 2024).

The quality of aggregate plays a significant role in improving concrete strength. It also affects the durability, structural performance and serviceability of the concrete. The physical, thermal and chemical properties of the inert filler material in concrete also affect concrete performance (Neville & Brooks 1987). The uncrushed aggregate i.e. gravel with gradation, was suitable for medium-grade concrete with respect to workability, strength and economy. Uncrushed aggregates are cheaper than crushed aggregates in construction industries that do not require quarrying, blasting, and production activities. The round aggregate provides 26%, 46% and 38% increases in concrete compressive, flexural tensile, and splitting tensile strength in 28 days, respectively. Rounded aggregate performs better than crushed aggregate in term of workability and reducing the need of mixing water in concrete production. Contractors selected the source of coarse aggregate based on factors such as lower price, ease of deliver, transportation route, good texture and appearance, market preference, and no stock issues. Among these factors, the unit rate per cubic meter of coarse aggregate is found to play a central role in the selection & giving preference to the source (Bhatta & Shrestha, 2023).

In Nepal, urban centers i.e. municipalities where services, business and trades activities take place, continue to expand in population and infrastructure. At present, nearly 66% of Nepal's population lives in urban centers such as Kathmandu, Lalitpur, Pokhara, Birgaunj and Biratnagar (CSO, 2021). The use of concrete as a construction material is increasing in significant infrastructure projects in urban centers due to its affordability and adaptability. Pokhara metropolitan city is one of the urban centers of Nepal, with a population of 5,13,504; households of 1,40,459, and covers a total area of 464. 24 Square Kilometer, which makes it the largest metropolitan city in Nepal by total land area. Pokhara metropolitan city has a population growth rate of 3 to 3.5 per cent per year. It is estimated that house construction in the Pokhara Metropolitan City has been growing at an average of 4-5% annually over the past 5 years (CSO, 2021). Pokhara is facing the pressure from rapid urban growth driven by pull factors and push factors from rural areas following the declaration of the capital city of Gandaki Province, as well as from unplanned urbanization, which is turning it into a concrete jungle. Infrastructure development projects such as rural and urban road networks, bridges, hydropower development, irrigation systems, landslides controls, buildings, sanitation, hygiene and disaster management are needed to accommodate the growing urban population of Pokhara Metropolitan City.

During the construction of infrastructure in Pokhara, confusion and conflicts arise when selecting the required quality of material extracted from Seti River across different crusher plants. People and institutions involved in infrastructure construction are using these construction materials to produce standard concrete of M35 and M45 to determine whether the required compressive strength is meet? and to define the standards for inert materials to promote quality construction in the future. The basic questions regarding standard concrete preparation of M35 and M45 are: does it meet the compressive strength? Does the crusher plants industry produce ingredient materials of the required specification of not? Therefore, quality is not to protect claims and disputes, but to ensure it works as per specification for each stakeholders & construction team. Finally, it is the time to act now by sharing knowledges & information about quality so that construction can be resilient, safe and support the livelihoods of people living in this area for sustainable future. In this research, standard concrete grades M35 and M45 were prepared using only crusher plant produced materials from the Seti River. Based on their properties, the compressive strength of the mixed design varies with cement, coarse and fine aggregate, plasticizer and silica.

Thus, aggregate for concrete must conform to or meet specific standards for optimal engineering use; they must be clean, hard, strong, durable, free from absorbed chemical coatings of clay, and free from foreign fine materials in amounts that may affect hydration and bond of the cement paste. The identification fraction of an aggregate's constituents cannot serve as a basis for predicting the aggregate's characteristics in operations. Visual inspection alone is not sufficient; it may disclose weakness in aggregates. Therefore, the aggregates should be tested before use in concrete production to evaluate their suitability (Kosmatka et al., 2002).

2. Material and Methodology

Methodology refers to the systematic and theoretical analysis of the methods employed in the study. The research design involved analysing and comparing experimental test results with the standards value as per the IS codal provisions. The primary data on cement and aggregate were collected through observation and laboratory testing. Secondary data were collected from guideline and standards, including the Indian Standard (IS), the Department of Urban Development and Building Construction (DUDBC), the Nepal National Building Code (NNBC), and the Standard Specification for Road and Bridge Works (SSRBW). Test results were analyzed and interpreted using descriptive methods to determine whether observed values met the standards. The validity and reliability of information were assessed by comparing with NS or IS standards.

All the ingredients used in making concrete were tested as per the procedures laid down in the IS code, and the test data were used to calculate the mix design as per IS: 10262-82 and SP: 23-1982. The physical properties and specifications of Ordinary Portland Cement (Shivam OPC 53 grade) conform to the respective IS code IS:12269-1987, laid down by the Bureau of Indian Standards. The physical properties of the sample such as sieve analysis of fine and coarse aggregate, particles finer than 75 microns of coarse and fine aggregates, specific gravity and water absorption of coarse and fine aggregate, and flakiness index of coarse aggregate, and the mechanical properties Aggregate Impact Value and Los Angle Abrasion Value was carried out as per procedure specified in the IS code 383:2016. In Sieve analysis, the cumulative percentage passing through each specified sieve was calculated and compared with the limits specified for aggregate mentioned in IS:383-2016. The water used for the preparation & curing of concrete was assumed to be fresh, potable, and of appropriate quality as per IS provision. For M35 & M45 grades, three sets of concrete mix were prepared, and mixing was done thoroughly to ensure a homogenous mix blend. The slump of the concrete measures in accordance with IS code 456:2000. From each type of source of aggregate, a total 6 number of cubes of size 150 mm x 150 mm x 150 mm were cast for M35 and for M45 grade of concrete as per the procedure defined in IS code 456:2000 for time crushing at 7 days and 28 days. After 24 hours of casting, the concrete cubes were removed from the mould and placed in a water tank for curing until the compression test.

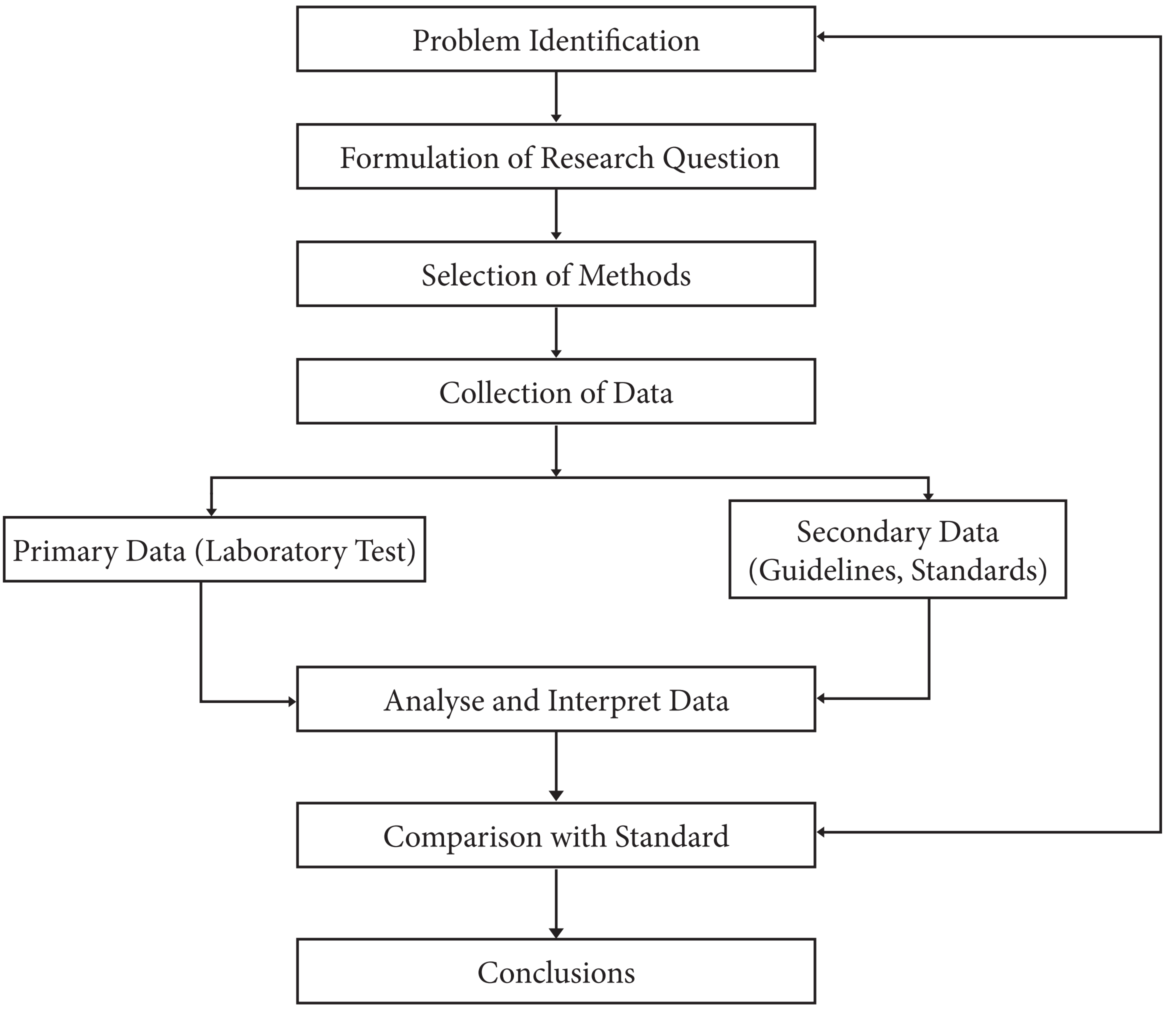

Fig. 1: Research Design Frameworks

The study area comprises of crusher plants which was installed along Seti River in Pokhara Metropolitan City. These crusher plants quarry, extract, & produce fine & coarse aggregates sourced from the Seti River, which are used as construction materials in Pokhara Metropolitan City. Field observations, and key informant interviews with construction entrepreneurs working in Pokhara, the Technical Head of the Pokhara Metropolitan Office, and material suppliers were conducted to determine the number of crusher plants, their names and production capacities within Pokhara Metropolitan City. Three major crusher plants within Pokhara Metropolitan City extract coarse & fine aggregates from Seti River. Three samples were collected from each crusher plant by quartering, then screened to test the physical and mechanical properties of the aggregates. The samples from each crusher plant were indicated randomly as source- A, source- B and source- C for confidentiality of the test results. The source- A indicates J.K Crusher Plant, Hemaja, PMC-25, Source- B indicates Feusharaka Baraha Crusher Udhyog Pvt. Ltd., Parunchaur, PMC-19 and Source- C indicates Shiva Shakti Crusher Plants, Dobilla, PMC-17. The average value obtained from the three samples was calculated & compared with the standard value specified in code IS: 383:2016.

Research was based on IS code provisions of standard concrete grades M35 and M45, using Nepal Standard OPC 53 grade cement, which was commercially available. The curing of each cube was done in accordance with the IS standard as specified in IS:456-2000. The concrete cube of M35 & M45 were tested using the compressive testing machine. The breaking load was recorded, then compressive strength was calculated as per IS:516-1959. The average compressive strength of concrete from each source and grade (M35 and M45) was used. The acceptance criteria for concrete, as indicated in IS:456-200, were used; the target mean compressive strength was calculated using the formula and relationships specified in IS:456-2000. The concrete was workable for both M35 and M45 grade concrete. All the laboratory test results were based on the laboratory's normal temperature and pressure as it is conditions. The influence of geological origin, and mineralogical source on aggregates was not taken into consideration.

3. Results and Discussions

3.1. Physical Properties of Coarse and Fine Aggregate:

Compressive strength increases with decreasing aggregate size, which provides a larger surface area for binding and consumes more cement in high-strength concrete. The maximum nominal size is limited to 10mm or 20mm only. The shape of the aggregate, such as thin, flat, elongated, or flakey aggregates, is highly unsuitable, resulting in decreased workability and strength.

Table 1: Physical Properties of Coarse and Fine Aggregate

Description	Source- A	Source- B	Source- C	Required Specification
I. Fine Aggregate				
Gradation	Zone II	Zone II	Zone II	IS 383: 2016
Sp. Gravity	2.75	2.601	2.64	2.5-3
Water Absorption (%)	0.83		1.01	1.523 Max
Particles finer than 75 microns (%)	1.28	1.31	2.01	15 Max

Description	Source- A	Source- B	Source- C	Required Specification
II. Coarse Aggregate				
Gradation	20 mm Down Single size	20 mm Down Single size	20 mm Down Single size	IS 383:2016
Sp. Gravity	2.83	2.67	2.65	2.5-3
Water Absorption (%)	0.23	0.36	1.01	5
Particles finer than 75 microns (%)	0.6	0.8	1.0	3 Max
FI (%)	14	15	17	FI 25% Max.
EI (%)	10	12	13	Maximum additive value of FI & EI is 35%

Table 1: attributes that physical properties of the fine and coarse aggregates of each source satisfy the specification declared by the IS 383:2016 code provision. The grading curve for the aggregate falls within the zone- II, indicating that it is suitable for engineering construction works. The gradation of aggregate specifies the size of the material used for construction works. As per the IS 383:2016, particles finer than 4.75 mm aggregate are classified as fine aggregate (Sand) and particles larger than 4.75 are classified as coarse aggregate. The specific gravity test helps determine the sample's density. Water indicates aggregate porosity. Aggregates with higher water absorption are more porous and are generally considered unsuitable unless they are found acceptable based on strength, impact, and hardness tests. Particles smaller than 75 microns IS sieve exhibit a slightly plastic or non-plastic behaviour regardless of moisture content, and which affects strength. The particle shape of aggregates is determined by the percentages of flaky and elongated particles contained in them. For the base course and construction of bituminous and cement concrete roads or pavements, the presence of flaky and elongated particles is considered undesirable, as they can cause inherent weakness and the potential to break down under heavy loads. Thus, evaluating particle shape, particularly flakiness and elongation, is necessary.

3.2. Mechanical Properties of Coarse Aggregate

The quality and properties of concrete depend on the mechanical properties of coarse aggregate. The strength and resistance to crushing, impact, and abrasion are to be determined to determine whether these coarse aggregates meet the standards for concrete mix design.

Table 2: Mechanical Properties of Coarse Aggregate

Description	Source- A	Source- B	Source- C	Specification
Los Angeles Abrasion Value	32	34	37	Less than 30% for standard and high-strength concrete and less than 50% for ordinary concrete.
Aggregate Impact Value	24	28	30	Less than 30% for standard and high-strength concrete and less than 50% of ordinary concrete

Table 2: shows that the Los Angeles Abrasion Value of each source is outside the recommended range. But the Aggregate Impact Value of each source falls within the range in accordance with specification IS: 383-2016. The Aggregate Impact Value and Los Angeles Abrasion Value indicate the aggregate's strength and durability. These properties of aggregates help engineers and builders select the highest quality materials for concrete and other infrastructure projects.

3.3. Physical and Mechanical Properties of OPC 53 Grade Cement

The type of cement and its physical and mechanical properties must be checked to ensure compliance with the relevant code's requirements. The physical and mechanical properties of cement influence the rate of development of concrete's compressive strength and durability in aggressive environments, as required for performance during construction.

Table 3: Physical and Mechanical Properties of OPC 53 Grade Cement

Description	Observed Value	Specification as per NS 572-2076
Consistency (%)	28	Not more than 35%
Fineness (%)	3.1	Not more than 10%
Initial Setting (Minute)	81	Not less than 30 minutes
Final Setting (Minute)	291	Not more than 600 minutes
Le-chaliter (mm)	1	Not more than 10mm
Compressive strength (MPa) at 7 days	41.67	Not less than 37 MPa
Compressive strength (MPa) at 28 days	60.33	Not less than 53 MPa

Table 3: shows the physical and mechanical properties of OPC 53 grade cement; these values are within the range in accordance with NS 572-2076.

3.4. Composition of Ingredients Materials of Different Sources for M35 and M45 Grade Concrete per Cubic Meter

The mixed design was carried out for specific value of compressive strength with specified workability so that fresh concrete can be mixed, transported, placed, compacted, achieve desired strength and durability at the construction site. The design of concrete mix is the determination of the appropriate proportions of material such as cement, aggregate, water, and admixture (if any) with the maximum economy in concrete preparation. Based on properties of the coarse and fine aggregate, the composition of M35 and M45 grade concrete is listed in Table 4. The variation in the quantities of coarse and fine aggregate depends on their specific gravity and water absorption. During the mixed design of M35 and M45 grade concrete using an inert material from the sampled source, the quantities of micro silica, admixture, water, and cement were kept constant.

Table 4: Composition of Concrete Ingredients Materials of Different Sources for M35 and M45 Grade Concrete per Cubic Meter

Description	Sample- A	Sample- B	Sample- C
I. M35	**Target Compressive Strength 43.25 MPa**		
Cement (Kg)	400	400	400
Fine Aggregate (Kg)	679	602.8	733.2
Coarse Aggregate (Kg)	1305	1119.5	1109.7
Micro Silica (Kg)	-	-	-
Admixture (Kg)	3.2	3.2	3.2
Water (Kg)	162	162	162
II. M45	**Target Compressive Strength 53.25 MPa**		
Cement (Kg)	450	450	450
Fine Aggregate (Kg)	664.1	602.8	730.2
Coarse Aggregate (Kg)	1276.1	1157.8	1109.7
Micro Silica (Kg)	22.5	22.5	22.5
Admixture (Kg)	3.8	3.8	3.8
Water (Kg)	152	152	152

Based on crushing times at 7 days and 28 days, the characteristic compressive strength are shown in Table 4, along with the proportion of constituent materials for economy in construction. The water cement-ratio was found to be 0.40 for M35 and 0.33 for M45 grade of concrete.

3.5 Slump Value of M35 and M45 Standard Concrete

The slump value indicates whether the concrete has the flowability required for placement. It is also known as the workability of concrete for transporting, placing, and compacting.

Table 5: Slump Value of Concrete Grade M35 and M45

Description	Sample- A	Sample- B	Sample - C	Specification
Slump for M35 (mm)	110	115	110	Greater than 100 to 150 mm Highly Workability
Slump for M45 (mm)	75	80	90	Greater than 75-100 mm Medium Workability

Table 5: shows that the mix design concrete was workable for both M35 and M45 grade concrete as per the specification of IS:456-2000.

3.6 Target Compressive Strength of M35 and M45 Standard Concrete

The mix design is intended for higher strength, known as the target mean strength which depends on the concrete's characteristic compressive strength and the quality control to be provided at the construction site. The relationship between the target mean compressive strength and the characteristic compressive strength of concrete at 28 days is determined in accordance with IS:456-2000.

Table 6: Compressive Strength of M35 and M45 Grade Concrete at 7 Days and 28 Days

Description	Sample-A	Sample- B	Sample-C
I. M35			
7 Days	33.8	33	31.7
28 Days	45.8	44.1	43.7
II. M45			
7 Days	47.94	44.02	38.37
28 Days	58.15	54.21	51.25

From the table 6:, it was found that the concrete mixes from sources A and B meet the target strength as per IS code 456:2000. However, the concrete mix from source C does not meet the target strength for M45 grade concrete. It was observed that the compressive strength increases with age at curing. The highest compressive strength was obtained from concrete made with source A at 7 and 28 days for both M35 and M45 grade of concrete, and the lowest strength was obtained from source C at 7 and 28 days for both M35 and M45 grade concrete.

4. Conclusions

The mix design of M35 and M45 grade concrete; water, cement, micro silica and plasticizer were kept constant. Considering the specific gravity and water absorption of coarse and fine aggregates from different sampled sources, their quantities were varied for the mix design of M35 & M45 grade concrete. Slump value of both M35 & M45 grade concrete indicates workability for moderate concrete structure as per IS 456:2000. The test result at 7 days and 28 days reveals that the compressive strength of grades M35 concrete satisfies the target mean compressive strength but for M45 grade concrete, source C does not fulfil the target mean compressive strength. This result illustrates that the strength of aggregate, i.e., the mechanical properties of coarse aggregate of source C, has more losses during the mechanical behavior test, i.e., the abrasion value obtained was outside the recommended range. According to the Department of Roads (DoR) Specification, only source A meets target mean compressive strength, whereas sources B and C do not meet the target mean compressive strength for M45 grade concrete.

5. Recommendations

The findings show that the abrasion value of the sample from source C was not within the range specified in the specification of DoR and IS codes. For the preparation of M45 grade concrete using source from sample C, the abrasion value needs to be improved by understanding the aggregate's geological origin and adjusting the mixture proportions to improve the concrete's rheology.

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Conflict of Interest

The authors declare no conflict of interest in the work reflected in this paper.

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