EFFECT OF COARSE AGGREGATE SOURCES ON THE COMPRESSIVE STRENGTH OF VARIOUS GRADE OF NOMINAL MIXED CONCRETE

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Abstract

Various grades of nominal mix concrete from low to medium strength are being used in building construction works in Kathmandu Valley. The aim of the study was to investigate the source effect of various types of coarse aggregates on the compressive strength of different grade of nominal mix concrete. Here, 5 different types of coarse aggregates sources were selected (A-Panauti, B-Melamchi, C-Chaukidada, D-Khopasi and E-Kaaldhunga) based on field enquiry and questionnaire survey with suppliers and contractors. Majority of coarse aggregates were angular in shape with a few sub angular and flaky types. From physical test result, most of the coarse aggregates were found to be graded type with partial deviation from the gradation limitation of IS383:1970. Based on specific gravity and dry-rodded bulk density, coarse aggregates can be classified as medium weight aggregates. Mechanical test of aggregate shows all the aggregates are of medium strength with variation in mechanical properties among them. The next stage of study is related to determination of compressive strength. Total 90 concrete cubes of size 15 cm were made of 3 different grades of nominal mix M1 (1:2:4), M2 (1:2:3) and M3 (1:1.5:3) by weight. Water/cement ratio, cement, sand, water were kept constant for each mix ratio while only coarse aggregate sources were chosen as variable. Due to change in aggregate type only, variation in 28 days target compressive strength is found up to 47%. Sample C, D and E showed relatively higher 28 days compressive strength compared to Sample A and B. The results indicate that the coarse aggregate source has significant variation in the compressive strength of various grade of nominal mix concrete. The variation in compressive strength is relatively significant for lean mix concrete (1:2:4 & 1:2:3) compared to rich mix concrete (1:1.5:3). In terms of concrete cube failure mechanism, the cubes made of sample A & B failed by coarse aggregate crushing while the major failure mechanism in sample C, D & E was initiated by bond failure.

Keywords: Coarse Aggregate, Concrete, Compressive Strength, Source, Effect.

1. Introduction

Modern concrete consists of aggregate (fine & coarse), cement, water, admixture and other additives. Several factors are known to influence the strength of concrete. They include their batch ratios, processes, aggregate texture and shape and nature of other constituent materials (Woode, Amoah, Aguba, & Ballow, 2015). Aggregates are mixtures of various sizes of stone or rock particles in contact with each other. They are typically combinations of gravel and crushed materials, such as limestone, basalt and granite, but may also include blast furnace slag, or recycled concrete fragments. Particles with a diameter greater than 4.75 mm are usually classified as coarse aggregate, while smaller particles are called fine aggregate (McNally, 1998). For a long time aggregate was considered to be an inert filler which is added to cement paste simply for economic reasons. The properties of the resulting concrete were thought to be nearly independent of the properties of the aggregate (Stensatter, 1963).

Since approximately three-quarters of the volume of concrete are occupied by aggregate, it is not surprising that its quality is of considerable importance. Not only may the aggregate limit the strength of concrete, but the aggregate properties

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greatly affect the durability and structural performance of concrete. Aggregate was originally viewed as inert, inexpensive material dispersed throughout the cement paste so as to produce a large volume of concrete. In fact, aggregate is not truly inert because its physical, thermal and sometimes, chemical properties influence the performance of concrete (Neville & Brooks, 2010). Many studies have been made to determine the effect of the physical and chemical properties of aggregate on the behavior of concrete. They include investigations into the effects of particle strength, surface texture, shape and alkali reactivity. Significant findings indicate that aggregate plays a more "active role" than was previously believed and a better understanding will result from further research (Stensatter, 1963).

The compressive strength of fresh and hardened concrete is greatly affected by the type of coarse aggregate being used in concrete mixing. Since coarse aggregate occupies major volume in concrete, the overall property of coarse aggregates affect the property of concrete produced with different nominal mix. The property of coarse aggregate is governed by their source, size, shape, unit weight, texture, etc. Coarse aggregate properties (geological, physical and mechanical) are greatly influenced by the source from which they have been recovered. The variation on the aggregate properties (either mechanical or physical) also affects the property of concrete strength, workability and durability.

Aggregate type by source has a significant correlation with the overall strength and performance of various nominal mix design concrete in both green stage and hardened stage (Hassan, 2011; Aginam, Chidolue, & Nwakire, 2013; Jimoh & Awe, 2007). There is significant influence of different aggregate types on concrete compressive strength, with stronger aggregate types increasing the overall strength of the concrete (Aitcin & Mehta, 1990; Zhou, Barr, & Lydon, 1995; Larrard & Belloc, 1997).

Aggregate characteristics like shape, texture, and grading influence workability, finishability, bleeding, pumpability, and segregation of fresh concrete and affect strength, stiffness, shrinkage, creep, density, permeability, and durability of hardened concrete (Lafrenz, 1997). As the aggregate properties depend on the properties of the parent rock (e.g., chemical and mineralogical composition, petrographic classification, specific gravity, hardness, strength, physical and chemical stability and pore structure). All these characteristics have an important influence on the properties of both fresh and hardened concrete (Neville & Brooks, 2010; Donza, Cabrera, & Irassar, 2002). The study on effect of content and particle size distribution of coarse aggregate on the compressive strength of concrete revealed that compressive strength is strongly linked to the coarse aggregate parameters (content, proportion of fine to coarse aggregate and grain size distribution) of concrete mixture (Mohammed, Salim, & Said, 2010).

In 2003, Sahin et al., also observed that the increase in strength for a given increase in cement content depends on the type of aggregate used and the cement content itself while Ozturan and Cecen (1997) have found that for the same properties of paste, different types of coarse aggregate with different shape, texture, mineralogy and strength may result in different concrete strengths. In research on the effects of aggregate content on the behavior of concrete, Ruiz (1966) found that the compressive strength of concrete increases along with an increase in coarse aggregate content, up to a critical volume of aggregate, and then decreases. The initial increase is due to a reduction in the volume of voids with the addition of aggregate. In 1947, Glanville et al., has expressed the opinion that the shape, texture and porosity of aggregate affect concrete workability. Kaplan (1959) studied the effects of the properties of 13 coarse aggregates on the flexural and compressive strength of high-strength and normal-strength concrete. At all ages, flexural strengths for basalt mixes were higher than limestone mixes with the same mix proportions. The compressive strength for basalt mixes was also higher than limestone mixes. Kaplan also observed, contrary to most results, that concrete with compressive strengths greater than 69 MPa (10,000psi) was generally greater than mortar of the same mix proportions, indicating that at very high strengths, the presence of coarse aggregate contributed to the ultimate compressive strength of concrete.

In the context of Nepal, concrete is being used as an extensive material of civil construction works of buildings, dams, bridges, highways, retaining walls, irrigation canals, etc. Currently, in the construction works of building in Kathmandu, nominal mix concrete of different grades are being produced consuming various types of coarse aggregates coming from respective different sources. As has been stated earlier, the properties (either physical or mechanical) have significance impact on the property of concrete and its performance both in fresh state and hardened state. The primary emphasis here is thus the evaluation and analysis of coarse aggregate sources on the compressive strength of the various nominal mix concrete.

3.0. Methodology

Kathmandu Valley has been chosen as study area.

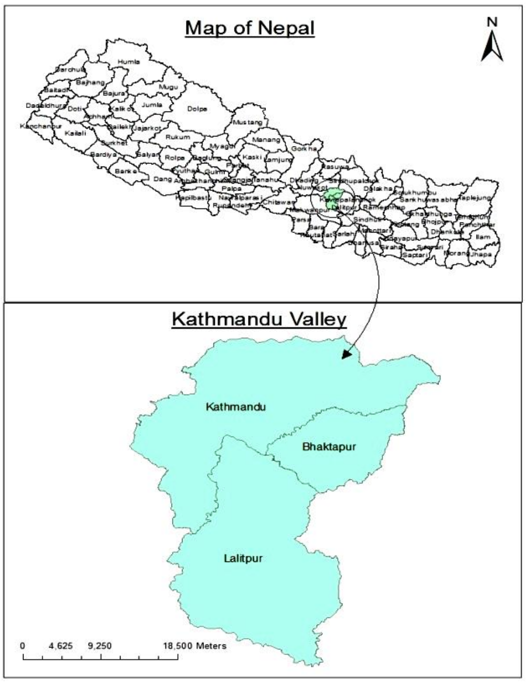

Fig. 1 Study area

In this research, both qualitative and quantitative research approaches were used.

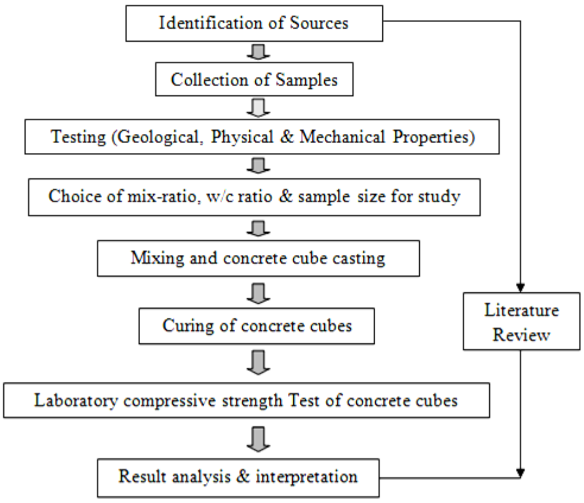

Fig. 2 Flow chart for conducting research

The source of coarse aggregate is chosen as an independent variable. As the study is aimed at assessing the coarse aggregate source effect on the compressive strength of various grade of nominal mixed concrete, the strength of concrete thus is a dependent variable. While nominal mix ratio, w/c ratio, cement, fine aggregate and water are the constant variable of the study.

3.1. Source Identification and Sample Collection

Qualitative approach was done by field enquiry and questionnaire survey with construction material suppliers and local contractors was carried out to have general overview of the major sources of coarse aggregate being used in building construction projects in Kathmandu valley.

Upon enquiry, the major sources of coarse aggregate being used in Kathmandu Valley were found to be extracted from quarry and river bed sources of Panauti, Nepalthok, Melamchi, Lele, Dhading, Kaal Dhunga, Khopasi, Chapagaon & Dolalghat (the areas lying in periphery of Kathmandu Valley). Among these sources of coarse aggregates, following five sources (Panauti-A, Melamchi-B, ChaukiDada-C, Khopasi-D & Kaal Dhunga-E) of coarse aggregates were selected for the research work.

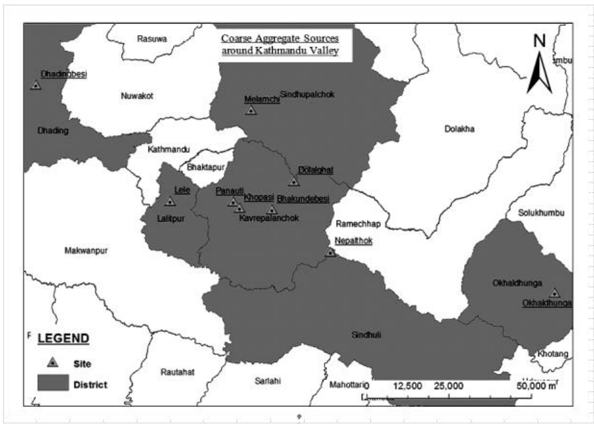

Fig. 3 Coarse aggregate source location

Samplings of the coarse aggregates were done by direct visit of the aggregate stockyard and sample collection from the coarse aggregate stockpile.

3.2. Geological, Physical and Mechanical Properties

Quantitative approach was used in laboratory tests carried to assess and analyze the geological, physical and mechanical properties of coarse aggregate samples as per IS: 383-1970 Specification for Coarse and Fine Aggregates from Natural Sources for Concrete; IS: 2386 (Part I) – 1963 Methods of Test for Aggregates for Concrete Part I Particle Size and Shape; IS: 2386 (Part III) – 1963 Methods of Test for Aggregates for Concrete Part III Specific Gravity, Density, Voids, Absorption and Bulking & IS: 2386 (Part IV) – 1963 Methods of Test for Aggregates for Concrete Part IV Mechanical Properties.

Geological properties of the coarse aggregate include identification of rock type, mineral composition, texture, color and shape. Physical properties of coarse aggregate were evaluated by sieve analysis, specific gravity, void ratio and bulk density. Mechanical properties of coarse aggregate were ascertained by Aggregate Impact Value test (AIV), Aggregate Crushing Value test (ACV) and Los Angeles Abrasion Value test (LAAV) and compared to requirements of IS383:1970.

Sieve analysis of coarse aggregate has been carried as per IS383:1970 to determine nominal maximum size of coarse aggregate. These gradation curves of the samples were then compared with the upper and lower limit of the IS383:1970. Nominal maximum size of the coarse aggregate was also determined.

Picnometer test was used to determine the specific gravity of the coarse aggregate as per IS: 2386 (Part III) – 1963.Similarly, Dry rodded bulk density, void ratio and Porosity of coarse aggregate samples were determined. For ascertaining mechanical properties as per IS383:1970; the Aggregate Crushing Value (ACV), Aggregate Impact Value (AIV) and Los Angeles Abrasion Value (LAAV) were determined in accordance with method specified as per IS: 2386 (Part IV)-1963.

3.3. Materials, Mixing, Casting, Curing and Compression Test

Quantitative approach was also applied to assess and analyze the compressive strength test data of concrete cubes. Concrete cubes were being casted. The materials of concrete were coarse aggregate, cement, sand and water. The variable of the mix ratio was coarse aggregate while other constituents water, cement, sand and water/cement ratio were kept constant. The cement being used was 43 Grade Ordinary Portland Cement manufactured by Hetauda Cement Factory. The sand was general type of washed river sand. Water being used for mixing was ordinary tap water. Water /cement ratio being maintained was 0.5. The quantity of constituents of concrete were calculated for three different nominal mix ratios 1:2:4, 1:2:3 and 1:1.5:3 by weight representing general practice in construction work in Kathmandu Valley.

Manual mixing by shovel was done to ensure consistent mixing followed by pouring the green concrete into 18 numbers of moulds of size 15cmx15cmx15cm made of plywood formwork. The green concrete was placed into the mould in 3 layers by tamping with a tamping rod. To ensure proper mixing of concrete, nozzle vibrator was used. After vibration, the surfaces of the moulds were trimmed with trowel to ensure smooth surface. Afterwards, the cubes were set for concrete setting. After 24 hours of concrete cube casting, the moulds were dismantled.

Table 1: Geological properties (shapes, color, rock type, mineral content)

Sample Type	Source	Rock Name	Rock Type	Shape	Color	Minerals
A	Panauti	Limestone Marble	Sedimentary Metamorphic	Angular	White/ Yellow	Calcite
B	Melamchi	Gneiss	Metamorphic	Angular	Dark	Biotite, Muscovite, Plagioclase, Quartz
C	Chauki Dada	Schist	Metamorphic	Angular with few Flaky	Dark	Biotite, Muscovite, Plagioclase, Quartz
D	Khopasi	Limestone	Sedimentary	Angular	Yellow	Calcite
E	Kaal Dhunga	Schist Quartzite	Metamorphic	Angular	Black, White	Biotite, Muscovite, Plagioclase, Quartz

The cubes were then placed in concrete curing tank and left for water curing for 7 days and 28 days. Concrete cube curing has been carried out in ambient temperature ranging from 10.8°C to 28.5°C. A total of 90 cubes (18 cubes for 5 coarse aggregate sample type) were casted. 28 days concrete bulk density of each cube was determined by weighing in digital balance. Compressive Strength of 7 and 28 days concrete cubes were determined by placing them in wet stage in Universal Testing Machine (UTM) and applying slow and continuous load until failure. The breaking load and ultimate load values were noted. The ratio of the ultimate load at failure (KN) and surface area of concrete cube (mm^2) gives the compressive strength (N/mm^2).

4.0. Results and Discussion

Following major sources of coarse aggregates were listed as per field enquiry and questionnaire survey with the suppliers of coarse aggregate and local contractors.

4.1. Physical Properties of Coarse Aggregate

The physical properties of the coarse aggregate were studied based on sieve analysis, specific gravity test, bulk density, void ratio, porosity, etc. The results obtained are summarized below;

Table 2: Physical properties of coarse aggregate

Source	Sp. Gravity	Dry-rodded Bulk Density (gm/cc)	Void Ratio (e)	Porosity (η)
A (Panauti)	2.45	1.5	0.63	0.39
B (Melamchi)	2.59	1.68	0.54	0.35
C (ChaukiDada)	2.64	1.592	0.66	0.40
D (Khopasi)	2.73	1.675	0.63	0.39
E (KaalDhunga)	2.70	1.519	0.78	0.44

4.2. Sieve Analysis and Gradation Curve

The sieve analysis of the coarse aggregate has been carried as per IS383:1970 using standard IS sieve. Majority of coarse aggregate were found to be graded type with partial deviation from the gradation limit given by IS383:1970. Nominal maximum size of all the samples is found to be 40mm as shown in Fig. 4.

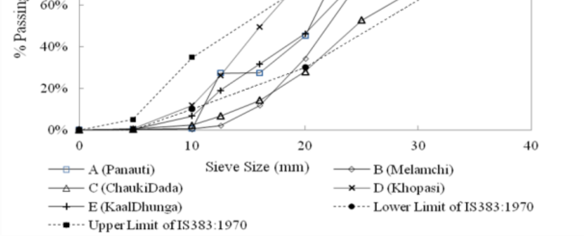

Fig. 4 Aggregate gradation showing upper and lower limits of IS383:1970

4.3. Mechanical Properties of Coarse Aggregate

Mechanical properties of coarse aggregate samples were determined as per IS2386 (Part IV):1963 carrying basically three types of tests: Los Angeles Abrasion Value (LAAV), Aggregate Impact Value (AIV) and Aggregate Crushing Value (ACV). The results of the mechanical properties of coarse aggregate are summarized in Fig. 5 below.

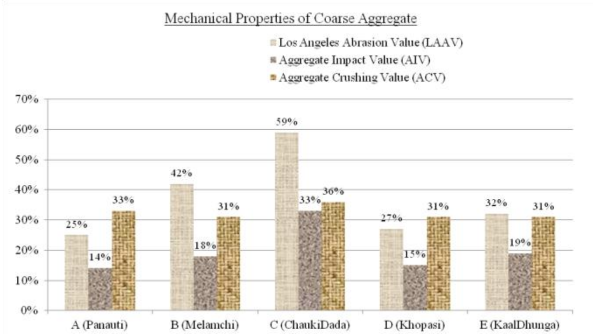

Fig. 5 Mechanical properties of coarse aggregates

4.4. Result of Compressive Strength Test

Three different nominal mixes 1:2:4, 1:2:3 and 1:1.5:3 were prepared for each type of coarse aggregate sample. IS: 516-1959 was referred to cast, cure and test the concrete cubes in the laboratory. 7 days and 28 days compression tests of the cubes were carried in the laboratory. The effect of aggregate source on the 7 and 28 days compressive strength of concrete was evaluated by testing concrete specimens prepared with A (Panauti), B (Melamchi), C (ChaukiDada), D (Khopasi) and E (KaalDhunga).

IS: 516-1959 was referred in order to test and determine the compressive strength of the concrete cubes. 7 days and 28 days compression test were carried by placing the cubes in UTM (Universal Testing Machine) and gradually applying the compressive load until failure. The result of the compressive strength for each type of nominal mix is shown in Fig. 6 and Fig. 7.

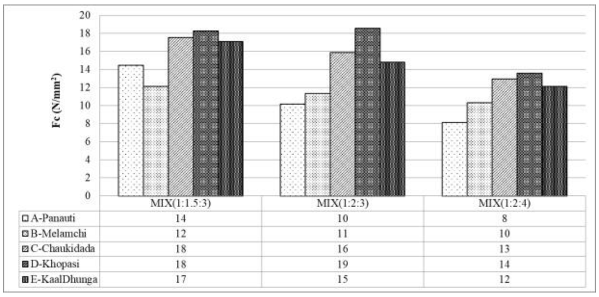

Fig. 6 Cube compressive strength (7 days) with various mix ratio and aggregate type

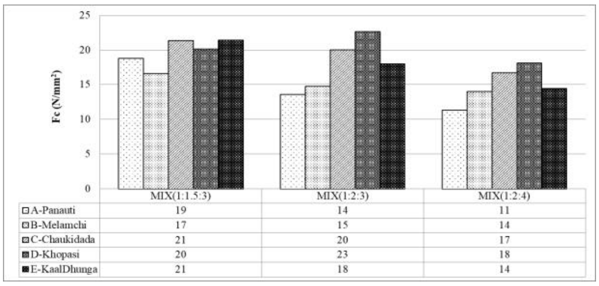

Fig. 7 Cube compressive strength (28 days) with various mix ratio and aggregate type

For nominal mix 1:2:4; the sample - D (Khopasi) shows highest value of 7 days and 28 days compressive strength with limestone (sedimentary rock) strength 14N/mm^2 and 18N/mm^2 respectively. Sample - A (Panauti) with limestone and marble (sedimentary and metamorphic origin) gave the lowest values of 7 days and 28 days compressive strength 8N/mm^2 and 11N/mm^2 respectively.

For nominal mix 1:2:3; the sample - D (Khopasi) with limestone (sedimentary rock) shows highest value of 7 days and 28 days compressive strength 19N/mm^2 and 23N/mm^2 respectively. Sample - A (Panauti) with limestone and marble (sedimentary and metamorphic) gave the lowest values of 7 days and 28 days compressive strength 10N/mm^2 and 14N/mm^2 respectively.

For nominal mix 1:1.5:3; the Sample - C(ChaukiDada) with Schist (metamorphic) rock shows highest value of 7 days and 28 days compressive strength as 18N/mm^2 and 21N/mm^2 respectively. Sample - B (Melamchi) with Gneiss (metamorphic) rock gave the lowest values of 7 days and 28 days compressive strength as 12 N/mm^2 and 17N/mm^2 respectively.

4.5. Comparison of Source Effect on Compressive Strength of Various Nominal Mix Ratios

The results from the compressive strength tests show that the change in source has a significant effect on the 7 days and 28 days compressive strength of concrete mix. The variation in compressive strength of concrete mix due to change in source is significant for lean mix concrete (1:2:4 & 1:2:3) while there is less significant variation in case of rich mix concrete (1:1.5:3). The test result shows that the compressive strength of limestone based coarse aggregate is found to be maximum while that of mixed type coarse aggregate (marble & limestone) is found to be minimum.

4.6.1 Source Effect on 7 Days Compressive Strength

The variation in 7 days compressive strength of concrete mix due to change in source is significant for lean mix concrete (1:2:4 & 1:2:3) while there is less significant variation in case of rich mix concrete (1:1.5:3).

4.6.2 Source Effect on 28 days Compressive Strength

The variation in 28 days compressive strength of concrete mix due to change in source is significant for lean mix concrete (1:2:4 & 1:2:3) while there is less significant variation in case of rich mix concrete (1:1.5:3).

Table 3: Variation of compressive strength for different mix ratios.

Nominal Mix Ratio	Target Mean Strength (N/mm2)	Minimum value below target (N/mm2)	Maximum value above target (N/mm2)	Variation (%)
1:2:4	15	-27 %	+20 %	47 %
1:2:3	20	-30%	+15%	45%
1:1.5:3	20	-15%	+5%	20%

Ozturan & Cecen (1997) found that 10-20% higher compressive strength are obtained with basalt and limestone coarse aggregates compared to gravel aggregate in high strength concretes. On the other hand, Loannides & Mills (2006) found that natural aggregate (basaltic) has relatively higher 28-day compressive strength as compared to the crushed coarse aggregates (limestone), the difference was significant ranging between 16% to 34%.

4.6.3 Concrete Cubes Failure Mechanism

The failure mode initiated in cubes made of sample A & B coarse aggregates is by aggregate failure. However, in concrete cubes made of Sample C, D & E; they failed mostly by bond failure.

In 2003, Beshr et al., found that when concrete is subjected to compressive loads, failure takes place at one or more of the following locations: (i) within the paste matrix; (ii) at the paste–aggregate interface; or (iii) within the aggregate. In a rich concrete mix, the possibility of failure within the paste matrix, alone, is very rare, since this phase is very strong. Therefore, the failure plain has to pass through the paste–aggregate interface or through the aggregate. In both modes of failure, the quality of aggregate significantly influences the mode of failure of concrete under compression.

It can be concluded from the results of failure mechanism, coarse aggregates samples A & B is weak relative to sample C, D & E. As the failure initiated in cubes made of sample C, D & E is due to bond failure, the reason may be due to low/medium mix strength mortar (low cement content).

4.6.4 Statistical Analysis for Source and 7 Days Compressive Strength

ANOVA tool has been used to test the correlation between the coarse aggregate source effect on the 7 days compressive strength of various nominal mix ratios 1:2:4, 1:2:3 & 1:1.5:3 respectively. ANOVA: Single factor analysis conducted to check the relationship between coarse aggregate source effect and 7 days compressive strength for Mix 1:2:4 and 1:2:3 resulted lesser Fcrit values than F values (i.e Fcrit < F). Hence, it can be stated that coarse aggregate source effect causes significant variation in 7 days compressive strength for Mix 1:2:4 and 1:2:3. However, for Mix 1:1.5:3, Fcrit value was found to be greater than F value (i.e Fcrit > F) concluding that coarse aggregate source effect causes insignificant variation in 7 days compressive strength for Mix 1:1.5:3.

4.6.5. Statistical Analysis for Source and 28 Days Compressive Strength

ANOVA tool has been used to test the correlation between the coarse aggregate source effect on the 28 days compressive strength of various nominal mix ratios 1:2:4, 1:2:3 & 1:1.5:3 respectively.

ANOVA: Single factor analysis conducted to check the relationship between coarse aggregate source effect and 28 days compressive strength for both Mix 1:2:4 and 1:2:3 resulted Fcrit less than F (i.e Fcrit < F). And hence, it can be stated that coarse aggregate source effect causes significant variation in 28 days compressive strength for Mix 1:2:4 and 1:2:3. However, for Mix 1:1.5:3, Fcrit value is found greater than F value (i.e Fcrit > F) concluding coarse aggregate source effect causes insignificant variation in 28 days compressive strength for Mix 1:1.5:3.

4.7. Comparison of Individual Physical and Mechanical Properties of Coarse Aggregate and Compressive Strength

Statistical tool has been used to analyze the correlation between physical and mechanical properties of coarse aggregate with the compressive strength of concrete. It has been found that specific gravity has a significant correlation with 28 days compressive strength. For lean mix concrete (1:2:4 & 1:2:3); the Pearson's Correlation Coefficient is 0.85 (> 0.5) which indicates that sp. gravity of coarse aggregate has a direct correlation with compressive strength of lean mix concrete. However, for rich mix concrete (1:1.5:3); the Pearson's Correlation Coefficient is 0.52 which indicates that the sp. gravity of coarse aggregate has less significant correlation with compressive strength of rich mix concrete.

5. Conclusion

The major coarse aggregates being used in the Kathmandu valley were found to be of sedimentary and metamorphic rocks with chief constituent of calcite, quartz, biotite, muscovite, plagioclase as minerals. The aggregate were observed to be crushed, angular and sub-angular shape. From the study of gradation, it can be concluded that the most of the aggregate available are of nominal maximum size 40mm with partially out of gradation limit given by IS383-1970. From mechanical test of aggregate, most of the aggregate samples can be concluded as medium strength aggregate although there is some variation in mechanical strength.

The effect of the coarse aggregate source on compressive strength of various nominal mix concrete can be concluded based on the 7 days and 28 days compressive strength test results. The results of 7 and 28 days compressive strength test showed there is significant effect of coarse aggregate sources on the compressive strength of various nominal mix design concrete. As per the research result, keeping other parameters same, variation in coarse aggregate source only can cause up to 47% variation in the 28 days compressive strength of nominal mix concrete. Test results show that the coarse aggregate source causes significant variation on the 28 days compressive strength of lean mix concrete (i.e. mix 1:2:4 and 1:2:3) however, for rich mix concrete (i.e. mix 1:1.5:3), the variation is relatively lesser. The fact is also supported by statistical test result. In terms of failure mechanism, the failure mode initiated in cubes made of sample A & B coarse aggregates is by aggregate failure rather than bond failure. However, in concrete cubes made of Sample C, D & E; the failure mode initiated is mostly by bond failure. Thus it can be concluded that coarse aggregates samples A & B is weak relative to sample C, D & E. This research also shades light on the fact that black color coarse aggregate are not the one always having higher strength as Sample D (Khopasi - Limestone based sedimentary rock) with yellow color aggregates shows higher strength compared to black color coarse aggregate. It can also be concluded that the correlation of compressive strength of concrete with mechanical properties (ACV, LAAV, and AIV) of aggregate is very less significant. Also, the physical properties, like void ratio and aggregate gradation, have very less correlation with compressive strength of concrete of selected mix. In contrary, the specific gravity of aggregate shows better correlation with compressive strength of concrete.

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