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Evaluation of Compressive Strength of Concrete with Various Proportions of Stone Dust as Fine Aggregate

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Abstract

Concrete is the most dynamic engineering material in construction due to its durability and strength properties, which have been used in almost all types of physical infrastructure construction. Crushed stone dust is a supplementary material that can be utilized to produce sustainable concrete. The concept of replacing natural fine aggregate in concrete production with stone dust (SD) could enhance the consumption of stone dust produced during aggregate production as well as reduce the requirement for landfill area for stone dust management. The study aims to compare the compressive strength of nominal mixed M_{20} and M_{25}-grade concrete by replacing fine aggregates with stone dust. The results reveal that compressive strength increases with an increase in stone dust, but the rise in SD percentages beyond a certain level has a negative impact on the strength of concrete. However, fresh density has a similar trend of compressive strength, and the workability of concrete shows a declining trend with a rise in SD levels. From the results of the experimental investigations conducted, it is concluded that the SD can be used as a replacement for fine aggregate. It is found that 40% replacement of fine aggregate by SD gives a maximum compressive strength than normal M_{20} and M_{25} grade concrete, which starts decreasing beyond 40% replacement. The compressive strength of the concrete has been quantified by replacing sand with varying percentages of stone dust and found that it does not satisfy the specification except for 40% replacement for M_{20} grade concrete, though it can be used for low and medium strength concrete production. The cost savings for M_{20} and M_{25}-grade concrete at 40% sand replacement are 8.23% and 7.62%, respectively.

Keywords: Sand, Concrete, Stone dust, Physical properties, Compressive strength

1. INTRODUCTION

Concrete is a composite construction material composed primarily of cement, fine aggregate (sand), coarse aggregate, and water and may contain chemical admixture to improve strength and durability. The concrete may also contain some amount of entrapped air and purposively entrained air using admixture or air-entraining cement [1]. Due to the dynamic behavior of concrete, it has become the most popular construction material for industry. The Romans are being credited as the first concrete inventors. A form of concrete dating to 6500 B.C. has been discovered by archaeologists in Syria, but mass production has become successful after the invention of Portland Cement in 1824 [2]. The production and use of concrete has dramatically increased, consequently causing a depletion of the natural resources available on Earth

[3]. Sand and gravel are the most mined materials on Earth for the construction of physical infrastructures. Aggregates constitute the foundation for modern civilization and are essential for providing shelter, infrastructure, and communication but they are an increasingly scarce resource due to overexploitation of natural resources [4]. Every year, there is an increase in demand for sand in developing countries, including Nepal; therefore, sand is extracted between 32 and 50 billion tons globally, which has the negative impacts on society and the environment [5].

The detrimental effect of excessive dredging of sand from riverbeds on the environment and the unavailability of land for disposal of stone dust have forced the researchers to search for the impact of stone dust on concrete production as a feasible alternative [6]. Hence, various studies are focusing on the development of green concrete, which beneficially conserves natural resources and reduces carbon emissions as compared to conventional concrete. Researchers around the globe have been involved in evaluating the various properties of concrete by replacing aggregate with different materials. The use of concrete or brick debris is a sustainable alternative to producing concrete to make clean and smart cities in Nepal, which reveals that the use of recycled powder has a significant decrease in the compressive strength of the concrete [7]. 10.9% lighter concrete can be produced with 10% volume replacement of course aggregate with coconut shells and 3% volume replacement of cement with coconut fiber [8]. Manufactured sand is one of the alternate materials that replaces river sand for structural concrete production. The manufactured sand enhances the durability and strength of concrete through better bonding than the natural river sand [5]. There is a significant decrease in the compressive strength of concrete while increasing the content of stone dust in the partial replacement of sand, though the compressive strength requirement has been satisfied for target-grade concrete [9]. The use of alternate materials in concrete should be based on the strength requirements as well as a feasibility analysis to create trust with end users. The utilization of fly ash and quarry dust up to 30% each into high-strength concrete has proved feasible and beneficial in terms of mechanical performance, which has created trust for the construction [10]. The laboratory results of partial replacement of Crushed Stone Dust (CSD) as fine aggregate and Nylon Fiber (NF) as reinforcing material reveal that both compressive and splitting tensile strength increase with increased NF, but with the rise in CSD percentages beyond a certain level, the strength of concrete starts decreasing; however, fresh density and workability of the concrete show a declining trend with the rise in both CSD and NF levels [11]. The 90-day compressive strength of geopolymer concrete has been found to be decreased by the partial replacement of recycled coarse aggregate (RCA) with conventional coarse aggregate, and even at 40% RCA level, the compressive strength was found to be quite sufficient for most of the structural applications [12]. Up to 15% replacement of fine aggregates in concrete mixtures with marble powder had a positive effect ranging between 2% and 26% on the concrete compressive strength owing to the reduction in the micro voids in the concrete mixture, which promotes the sustainable use of materials using waste marble [13]. In general, the partial replacement of dust with fine aggregate has a significant decrease in workability and improves the mechanical strength of the concrete, but it is essential to develop the site-specific relationship between the properties of the concrete and the origin of the concrete materials.

Previous studies have suggested that the chemical properties of stone dust depend on its origin and concluded that the workability of concrete decreased with increasing stone dust content due to higher water absorption, while concrete mechanical properties had a decreasing trend with higher stone dust contents [14]. A detailed investigation of the properties of the material is essential to determining the targeted strength of the concrete. It is essential to establish the relationship between the mechanical properties and the origin of the materials. The present research work has been undertaken to gain a better insight into the strength evaluation of cement concrete with various proportions of fine aggregate (sand), and crushed stone dust which are collected from various sources in Pokhara, Nepal. Nepal is a developing country and is currently undertaking a major initiative to develop infrastructure such as highways, airports, hydropower, industries, and huge buildings to meet the requirements of globalization. River sand, which is used in the production of conventional concrete, has become expensive and scarce due to the depletion of the riverbed. The research based on the material origin has been conducted by replacing the alternate material for concrete production, which will help to utilize the stone dust produced during the aggregate crushing. Most of the construction materials mining industries are on a small scale, with less than 150 m^3 per day of stone production and 200 m^3 per day of sand production [15]. The production of stone dust has not been commercially well established, but the waste produced during aggregate processing can be used to replace sand in concrete production. This research will help to fill the research gap regarding the strength performance of concrete using different proportions of sand and stone dust, enabling the sustainable use of natural resources and environmental protection from the dumping of stone dust. Besides, the strength parameter evaluation will also help to motivate the industries for the commercial production of stone dust so that the loss of construction material can be utilized.

2. METHODOLOGY

2.2 Study Zone

Pokhara Metropolitan City is famous for its natural beauty and for contributing toward sustainable development goals through tourism and other economic means. Due to urbanization and infrastructure development, the environment has been deteriorating. The Seti-Gandaki River, which flows through Pokhara Valley, is the most important river in the valley in terms of construction material extraction. Because of the fast-growing urbanization and availability of public services, people used to migrate to Pokhara from other regions of the country. The growth in population demands infrastructure development, resulting in the construction of more than 100 kilometers of firm pavement each year, construction of a new international airport, and the construction of houses, necessitating the requirement for aggregates. If development increases in this trend, the shortage of natural aggregates may become critical. So, it is essential to justify the use of an alternate material (stone dust) for the replacement of fine aggregate (sand).

2.2 Data Collection

Primary Data: The coarse and fine aggregate processed from Hemja Crusher Plant and Kotre Crusher Plant were collected for the investigation. The following materials and sources were selected for material collection to conduct laboratory-based research analysis.

Secondary Data: The secondary data were obtained from the norms and specifications of the Department of Roads, Government of Nepal, published research articles, reports, and other design guidelines.

2.3 Material for concrete preparation

Aggregate (Coarse and Fine):

For the analysis of the concrete, the aggregate has been well graded to ensure a uniform concrete mix. The source and physical properties of the aggregate have been tested based on the following test method, which are presented in Table 1 , 2 and 3.

Table 1: Aggregate source

Material	Material Sources
Coarse aggregate	Hemja and Kotre Crusher Plant
Fine aggregate	Hemja and Kotre Crusher Plant
Stone dust	Hemja and Kotre Crusher Plant

Table 2: Test methods for physical properties of coarse and fine aggregate

Name of Test	Test Methods
Sieve analysis	IS:2386 Part IV
Water absorption	IS:2386 Part IV
Specific gravity	IS:2386 Part IV
Bulking of sand	IS:2386 Part I

Table 3: Test methods for mechanical properties of coarse aggregate

Name of Test	Test Methods
Los Angeles Abrasion Test (LAA)	IS:2386 Part IV
Aggregate Impact Test (AIV)	IS:2386 Part IV
Aggregate Crushing Value Test (ACV)	IS:2386 Part IV

Cement:

For the preparation of the mixture, 43-grade ordinary portland cement (OPC) was used. The cement has been tested and checked as per the Nepal Standard [16], and IS standard .The initial setting time, final setting time, and strength test were conducted according to IS, and the results are shown in Table 4.

Table 4 : Test method for cement

Name of Test	Test Methods
Initial setting time	IS: 4031 Part V
Final setting time	IS: 4031 Part V

2.1 Study design:

For each chosen sample, the appropriate numbers of samples were created to test the various strength characteristics of concrete. In the laboratory, a sieve was used to separate the stone dust from the other particles. Fine aggregates (sand) were largely replaced with stone dust in the construction of this structure. The nominal mix for nominal grade M_{20} (1:1.5:3) and M_{25} (1:1:2) concrete at a water-to-cement ratio of 0.5 was prepared in accordance with Indian standards (IS) for the nominal grades. The samples were made by replacing the fine aggregates with stone dust at various replacement ratios, including 0 percent, 20 percent, 40 percent, 50 percent, and 100 percent in both classes of concrete. Workability, unit weight, and compressive strength tests were performed on the sample after it had been produced.

A total of 72 samples were produced, three for the 7-day cube test and three for the 28-day cube test which is presented in Table 5. The M_{20} and M_{25}-grades of concrete were selected for study purposes, and a nominal mix was done for concrete production.

Table 5 : Sample preparation for the study

(%) replacement of sand	Number of cubes	
	M_{20}	M_{25}
0	6	6
20	6	6
40	6	6
50	6	6
80	6	6
100	6	6

3. RESULTS AND DISCUSSION

The samples of fine aggregate, stone dust, cement, and coarse aggregate were tested to find out their physical and mechanical properties. The properties have been accessed based on Indian standards and DoR guidelines [17-20]. The experimental results have been presented in the following sections:

3.1 Test result of aggregate:

Gradation analysis of coarse and fine aggregate:

The particle size distribution of fine aggregate (sand) and stone dust was performed as per IS 383–1970. The obtained results of the samples are presented in Table 6, Figure 1 (a and b), and Figure 2. The result and its comparison with the IS 383-1970 standards showed that the fine aggregate and stone dust fulfilled the criteria of Zone II/DoR norms. The coarse aggregate meets the complies grading limit as per IS 383-1970.

Table 6 : Gradation of sand and stone dust

Particle size (mm)	% passing	Specification Limit (Zone II)/DoR		
	Sand	Stone dust	Lower	Upper
10	100	100	100	100
4.75	95.4	74.98	90	100
2.36	78.64	73.3	75	100
1.18	59.84	64.31	55	90
0.6	38.12	43.65	35	59
0.3	12.38	20.92	8	30
0.15	2.09	7.7	0	10
FM	3.86	3.85		

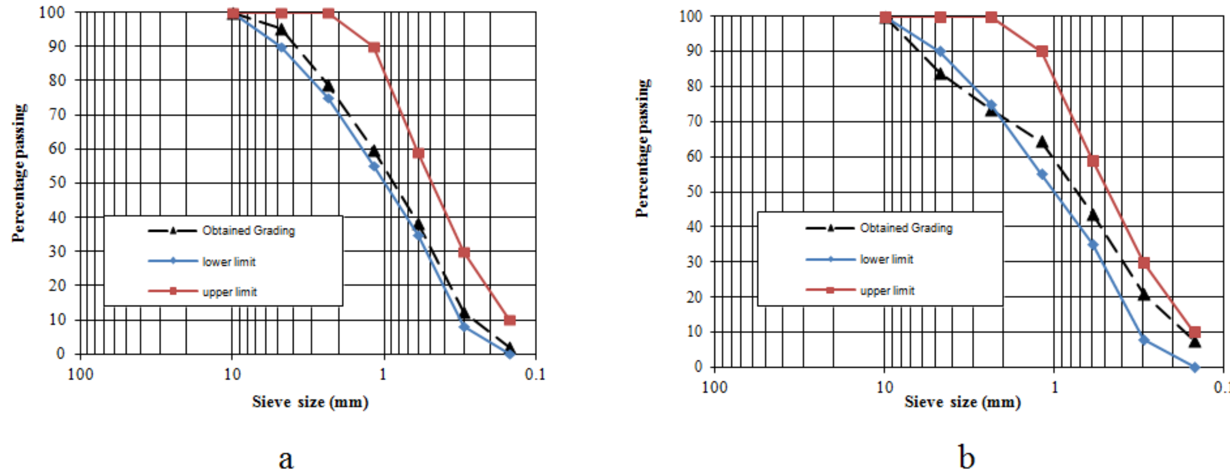

Figure 1: (a) Gradation analysis for sand, and (b) Gradation analysis for stone dust

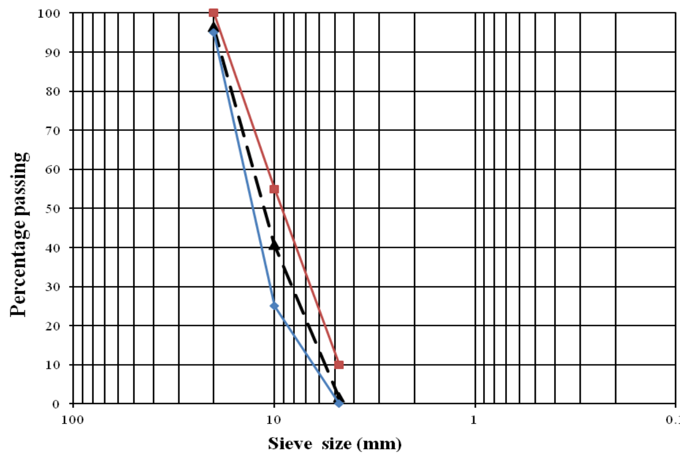

Figure 2: Gradation analysis for coarse aggregate

Physical and mechanical properties of aggregate: The physical and mechanical properties of the aggregate are presented in the Table 7.

Table 7: Physical and mechanical properties of aggregate

Properties	Sand	Stone dust	Coarse Aggregate
Specific gravity	2.64	2.5	2.71
Water absorption coefficient	1.103	0.502	–
Bulking (%)	21.22	25.53	_
Impact Strength (%)	_	_	20.91
Crushing Strength (%)	_	_	24.03
Los Angles abrasion value (%)	_	_	27.44

The specific gravity of all aggregate sources is within the standard range as per IS 2386 (Part III)-1963 and specifications proposed by the Department of Roads (DoR). The coarse aggregate impact values are within the limits of the IS 2386 (Part IV)-1963 code, and all samples are suitable for use in building projects. The crushing value of the coarse aggregate sample is within the limits of the IS 2386 (Part IV)-1963 code which means that the whole sample is suitable for use in building activities. In accordance with IS 2386 (Part IV)–1963 code and specifications proposed by the Department of Roads (DoR), the abrasion values of coarse aggregate samples are within acceptable limits, and hence all samples are suitable for use in construction activities.

`3.2 Test of cement:

Cement is the binding material largely used in concrete production. There are various brands of cement that are being manufactured and imported to use in infrastructure construction. The Shivam OPC cement was used for concrete production during my research. The following general tests were conducted and compared with Nepal Standards (N.S.), and the results are presented in Table 8.

Table 8: Properties of cement

Properties	Test Result	N.S. Norms
Initial setting time (Minutes)	200	45 Minimum
Maximum final setting time (Minutes)	275	600 Maximum

The initial setting time of cement was found to be much higher than that specified by NS specifications, while the final setting time of the cement was found to be within the safe limit allowed by NS specifications.

3.3 Properties of fresh concrete:

The evaluation of the properties of fresh concrete has been done based on workability, density, and compressive strength at varying proportions of sand and stone dust. The results of the test have been presented in Table 9, Table 10, Table 11, Figure 3, Figure 4, Figure 5, and Figure 6.

Workability:

Table 9:Workability of fresh concrete at different proportions

Mix proportion (% replacement)	Workability (mm)	
	M_{20}	M_{25}
0	70	74
20	66	69
40	60	65
50	53	58
80	43	47
100	38	40

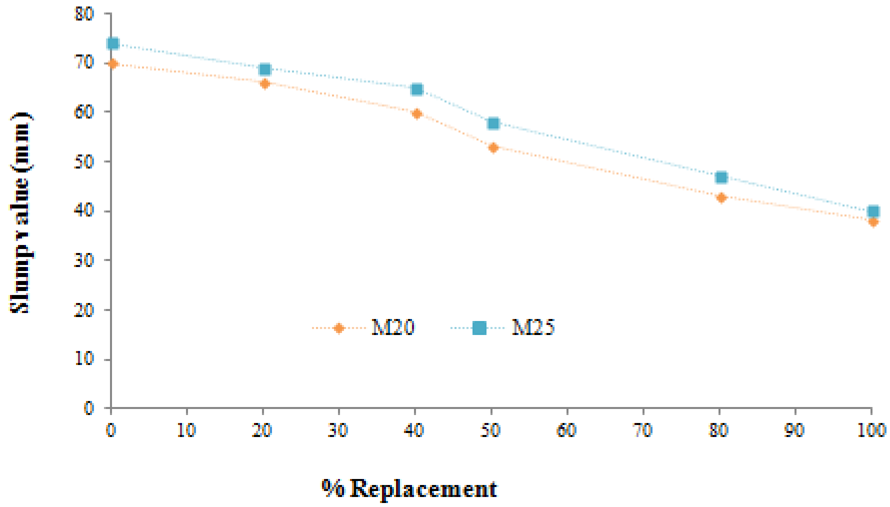

Figure 3: Slump value M_{20} and M_{25} Concrete at different proportions at different proportions

The previous study has shown that the use of stone dust above 20% can decrease the slump of normal-strength concrete and high-strength concrete [21]. The mono-crushed sand could replace the mono-river sand in making concrete, with notable improvements in workability by a 22% increment [22].

Table 9 indicates that at 0% replacement, the concrete has the greatest slump value, while concrete with 100% replacement has the lowest slump value. According to IS 456–2000, the slump value of concrete with varying mix proportions of fine aggregates and stone dust should be within the range of 25–75 mm, which satisfied the specification with a lower value.

Figure 3 illustrates that 0% replacement has a higher degree of workability than other percentages of replacement on all testing days, which means minimal effort is required for placement and compaction of sand and stone dust. In general, SD contains more angular particles with a rougher surface texture and flatter faces than normal sand, which causes a decrease in slump value. Moreover, due to the presence of more voids and moisture content in 0% replacement than in other percentages of replacement, this increases the workability of fresh concrete. In this study, the % increase in SD resulted in a decrease in slump value, producing less workable concrete since it requires higher water content, while a similar study showed that there is no clear representation of slump value for sand replacement [23]. Similarly, another similar study indicated that the increase in SD requires extra water to make workable concrete, which is due to the high-water absorption of SD. A similar result was found in our study [24].

The bleeding was not observed during the concrete production due to the presence of fewer voids than natural sand, which resulted in a reduction in segregation in the concrete due to the higher bonding due to interlocking capacity.

Density:

The density of concrete measures its unit weight and solidity, which are used to evaluate strength. The results of the density of concrete at different proportions have been presented in Table 10 and Figure 4.

Table 10: Density of fresh concrete at different proportions

	Density of concrete (kg/m^3)	
Mix proportion (% replacement)	M_{20}	M_{25}
0	2538.72	2535.31
20	2531.95	2539.85
40	2543.01	2540.84
50	2534.42	2530.27
80	2536.49	2532.64
100	2528.84	2529.33

The density of 40% replacement in M_{20} and M_{25} has the highest value, and 100% replacement in M_{20} and M_{25} has the lowest value.

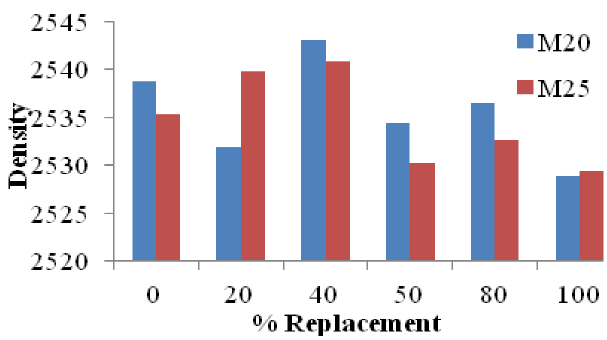

Figure 4: Density of M_{20} and M_{25} Concrete at different proportions

Figure 4 evidently shows that the density at 40% replacement for M_{20} concrete is higher than the other percentage replacement. Fine aggregate, stone dust, and coarse aggregates have different specific gravity and water absorption values, but at 40% replacement at M_{20}, fine aggregate, stone dust, and coarse aggregates have higher specific gravity and lower water absorption than the corresponding percent of replacement, which increases the density of the concrete. Also, the density at 40% replacement of M_{25} has a highest value than the other percentage replacement because of the high specific gravity and low water absorption of sand, stone dust, and coarse aggregates.

Compressive strength:

The compressive strength of cube and cylinder samples is tested as per standards, and the obtained results from the sampled sources are presented below. The experimental results of the M_{20} and M_{25} grades of the concrete cube with different sources of aggregate are given, and other individual results have been presented in Table 11, Figure 5, and Figure 6.

Table 11: Compressive strength of fresh concrete at different proportions

% Replacement	Compressive Strength of Concrete, M_{20} (MPa)		Compressive Strength of Concrete, M_{25} (MPa)	
	7 Days	28 Days	7 Days	28 Days
0	17.06	23	21.7	25.99
20	16.3	23.12	21.1	26.58
40	15.78	24.29	20.49	26.66
50	15.16	22.89	20.11	25.63
80	14.56	22.01	19.5	25.11
100	13.64	20.54	18.82	24.59

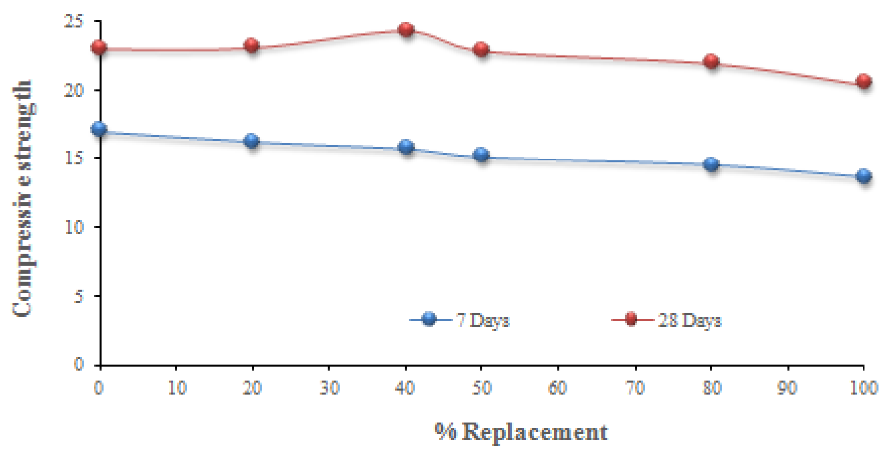

Figure 5: Compressive strength of M_{20} concrete at different proportions

Table 11 and Figure 5 evidently show that the compressive strength of M_{20} grade concrete at 28 days for different proportions of sand and stone dust was figured out, and all the mix proportions samples did not satisfy the specifications (24 MPa) except at 40% replacement of M_{20} grade concrete, though it had gained reasonable strength. The maximum strength was observed at 40% replacement, having a value of 24.29 MPa; it goes down, having a minimum value of 20.54 MPa at 100% replacement. Hence, the higher compressive strength is due to good bondage and fewer voids in the concrete matrix.

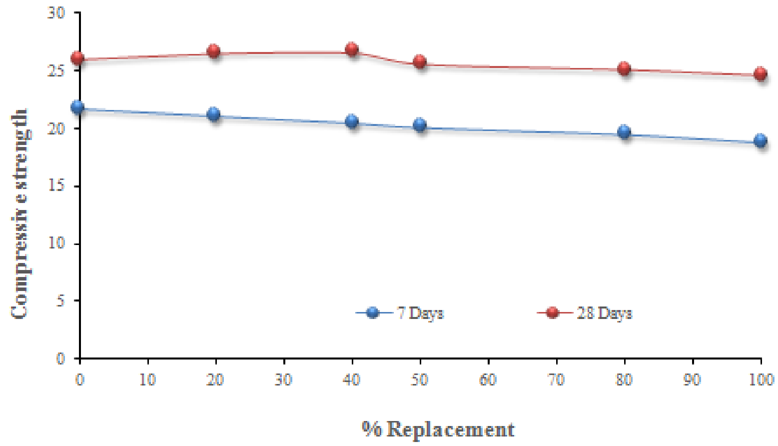

Figure 6: Compressive strength of M_{25} concrete at different proportions

Similarly, Table 11 and Figure 6 reveal that the compressive strength of M_{25} grade concrete at 28 days for different proportions of sand and stone dust was figured out, and all the mix proportions samples did not satisfy the specifications (29 MPa) of M_{25} grade concrete, though it had gained reasonable strength. The maximum strength was observed at 40% replacement, having a value of 26.66 MPa; it goes down, having a minimum value of 24.59 MPa at 100% replacement. Hence, the higher compressive strength is due to good bondage and fewer voids in the concrete matrix. A similar study reveals that a 40% replacement result shows that the compressive strength value has a maximum, and it goes down with a higher percentage replacement of sand by stone dust [23]. The difference in this study was that the replacement of sand has been done at 20%, 30%, 40%, and 50% only for M_{20}, M_{25}, and M_{30}. The compressive strength of the concrete increased up to 40% in this study, but in the previous study, the compressive strength remained almost constant up to 40% replacement. The maximum compressive strength was found at 40% replacement, while the value was decreased beyond 40% in both studies. A similar previous result also indicated that with 7.5% partial stone dust replacement, there was an increase in compressive strength of 14.42% at 28 days [22]. The previous study indicates that the replacement content of 30% in relation to the natural sand presented a satisfactory performance in relation to compressive strength, which is not true in our case, i.e., even the 100% replacement has a satisfactory performance in relation to the compressive strength of concrete [25].

Cost comparison:

The cost comparison for the unit volume of concrete has been done for natural concrete and 40% sand replacement. The maximum compressive strength was found at 40% sand replacement by stone dust, so the cost has been compared with 0% replacement and 40% replacement. The result of the cost has been presented in Table 12.

Table 12: Cost comparison of concrete

Mix proportion (% replacement)	Cost of Concrete (NPR.)	
	M_{20}	M_{25}
0	13992.06	15068.47
40	12841.03	13920.2
% Variation	8.23	7.62

4. CONCLUSIONS

In this study, the effect of using stone dust as a replacement for natural fine aggregates on M_{20} and M_{25} grade nominal mix concrete compressive strengths was investigated comparatively. In this context, the following important results were obtained in the study:

i. The specific gravity of fine aggregate (sand) and stone dust is 2.64 and 2.50, respectively, in comparison to coarse aggregate, which is 2.71. Fine aggregate (sand) and stone dust have water absorption coefficients of 1.103 and 0.502, respectively. It has been determined that the specific gravity of measured stone dust is lower than that of the corresponding sand because of its lower water absorption than that of the corresponding sand. The bulking of sand and stone dust was 21.22% and 25.53%, which were less than 30%, so the percentage value lies within the limit of Standard Specification for Road and Bridge 2073 recommended by the Department of Roads (DoR).

ii. The compressive strength of concrete has the greatest value at 40% replacement of fine aggregate (sand) by stone dust, which has decreased at a higher percentage replacement. It has been determined that stone dust may be used in place of sand in low-grade concrete since all the mix proportions in M_{20} and M_{25} concrete have not satisfied the specification of the specified grade of concrete except at 40% replacement, though it has gained reasonable strength. Both instances (M_{20} and M_{25}) show that varying amounts of sand and stone dust provide better outcomes than a single percentage of sand. The 40% replacement result for M_{20} showed that the 28-day compressive strength of stone dust concrete is 21.45% higher (24.29 MPa) than that of natural aggregate concrete (20 MPa). Similarly, the 40% replacement result for M_{25} shows that the 28-day compressive strength is 6.64% (26.66 MPa) higher than that of natural concrete.

iii. The cost comparison for unit volume of concrete has been done for natural concrete and 40% sand replacement and found that the cost savings for M_{20} and M_{25} are 8.23% and 7.62%, respectively.

iv. For low- and medium-strength concrete, 40% replacement of sand by stone dust becomes technically and economically feasible and sustainable, which may lead to environmental protection.

Recommendations

The research has been done on M_{20} and M_{25}-grade nominal mix concrete only at a fixed W/C ratio. It is recommended that a similar study be conducted for other mix design-grade concrete at varying W/C ratios so that the general equation can be derived for varying proportions of stone dust and W/C ratios. The study has been conducted using processed aggregate from the Kotre and Hemja areas, so it is recommended to study the other sources for a better understanding of the impact of these sources on the compressive strength of concrete. A detailed feasibility study of the availability of materials and stone dust production should be conducted for its sustainability.

The research has been done on M_{20} and M_{25} grade nominal mix concrete only at fixed W/C ratio. It is recommended that the similar study should be conducted for other mix design grade concrete at varying W/C ratio so that the general equation can be derived for varying proportion of stone dust and W/C ratio. The study has been conducted using processed aggregate from the Kotre and Hemja areas, so it is recommended to study the other sources for a better understanding of the impact of these sources on the compressive strength of concrete. The detailed feasibility study of availability of material and stone dust production should be conducted for its sustainability.

CONFLICTS OF INTEREST

The authors have declared that no competing interests exist. The data used for this research are commonly and predominantly used in our area of research and country. There is no conflict of interest between the authors and other stakeholders because we do not intend to use these products as an avenue for litigation but for the advancement of knowledge. Also, the research was not funded by any authorities; rather, it was funded by the personal efforts of the authors.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available to the main author, upon reasonable request.

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