IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 22, Issue 1 Ser. 2 (Jan. – Feb. 2025), PP 31-36
www.iosrjournals.org

Optimising The Performance Of Concrete With Gravel Aggregates: The Role Of Sand And Cement Types In Strength Enhancement

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Abstract
This article focuses on improving the mechanical properties of concrete made from natural uncrushed aggregates, a variant of aggregates commonly used in the city of Goma. The primary objective is to determine the optimal composition to enhance the concrete's compressive strength. So that this could happen, the aggregates (natural uncrushed aggregates, rolled sand, and crushed sand) were carefully studied. Next, the Bolomey method was used to refer to the concrete mix. This reference concrete consists of natural uncrushed aggregates, rolled sand, and CEM IV B-P 32.5N cement, a composition frequently used in Goma. The compressive strength of different types of concrete was tested. The types of sand used were rolled or crushed, and the types of cement used were CEM IV B-P 32.5N, CEM II B(P) 32.5N, and CEM II A(P) 42.5N. One type of concrete (B1) had a compressive strength of 7.4 MPa, while another type (B3') made with crushed sand and CEM II A(P) 42.5N cement had a strength of 20.2 MPa. These findings show that the type of cement and the nature of the sand used together have a big impact on how well natural uncrushed aggregate-based concrete works mechanically.
Keywords: *Concrete; Aggregates; Compressive strength; Crushed gravel; natural uncrushed aggregates.*

Date of Submission: 12-02-2025 Date of Acceptance: 22-02-2025

I. Introduction

Concrete is a fundamental construction material, esteemed for its various attributes, such as durability, strength, and versatility. This substance, derived from the solidification of a blend of binder, water, and aggregates, constitutes the foundation of contemporary construction. Without concrete, the construction of a substantial segment of contemporary infrastructure, including edifices, bridges, tunnels, and dams, would be unfeasible. Concrete, as a cost-effective material, can fulfil the diverse requirements of the construction and public works industries, in both terrestrial and aquatic settings[1].

Aggregates, constituting approximately 80% of concrete's total weight, are essential to its mechanical qualities, especially its compressive strength. The most often utilised aggregates are natural aggregates derived from several mineralogical sources, including sedimentary, metamorphic, or igneous rocks[2]. These aggregates can be classified into two main categories: rolled aggregates and crushed aggregates, which must meet established quality standards, particularly the [3] standard.

In the city of Goma, a distinctive approach is the utilisation of natural uncrushed aggregates. These aggregates, typically sourced locally and occasionally manually crushed, are commonly utilised in concrete production for regional construction projects. Even though concrete produced with these natural uncrushed aggregates often exhibits worse mechanical strength relative to that prepared with conventional aggregates, their reduced cost renders them a favoured option in the region[4].

This study seeks to enhance the performance of concrete composed of natural uncrushed aggregates by examining the effects of sand type (rolled or crushed) and cement type (CEM IV 32.5N, CEM II 32.5N, and CEM II 42.5N) on its mechanical properties. A sequence of aggregate characterisations, concrete formulations, and concrete evaluations were performed to achieve this. The employed method facilitates the identification of the composition that provides optimal compressive strength at 28 days, a critical criterion for assessing concrete quality. The aggregate and concrete characterisation tests were conducted in the materials laboratories of the Civil Engineering Department at the Faculty of Applied Sciences and Technologies of the Free University of the Great Lakes Region.

II. Materials And Methods

Nature And Origin Of The Materials

The cement utilised in our investigations includes CEM IV 32.5N, CEM II 32.5N, and CEM II 42.5N, distinguished by its grey hue and a density of around 3 g/cm³.

The mixing water utilised is potable water provided by the Water Distribution Authority (REGIDESO). It is obtained directly from the tap and is devoid of contaminants that could undermine the integrity of the concrete, including organic or chemical agents. Potable water guarantees that the concrete remains free from pollutants and provide sufficient hydration for the cement.

The aggregates utilised in this investigation are of many forms and sources. Two types of sand were utilised: river sand from Idjwi Island and crushed sand (0/5) derived from basaltic rock. The gravel, conversely, comprises natural uncrushed aggregates sourced from the city of Goma, gathered in accordance with local customs. Figure 1 provides a visual overview of the different aggregates utilised.

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Figure 1. Aggregates Used: (1) Crushed sand, (2) Idjwi Sand, and (3) natural uncrushed aggregates

Experimental Plan

This study's experimental strategy seeks to enhance the performance of concrete composed of natural uncrushed aggregates by investigating the effects of sand type (rolled or crushed) and cement type (CEM IV B-P 32.5N, CEM II B(P) 32.5N, and CEM II A(P) 42.5N) on their mechanical properties. Six concrete formulations will be developed to do this. Concrete B1 (reference) comprises natural uncrushed aggregates, rolled sand, and CEM IV B-P 32.5N cement; Concrete B2 consists of natural uncrushed aggregates, rolled sand, and CEM II B(P) 32.5N cement; Concrete B3 includes natural uncrushed aggregates, rolled sand, and CEM II A(P) 42.5N cement; Concrete B1' features natural uncrushed aggregates, crushed sand, and CEM IV B-P 32.5N cement; Concrete B2' contains natural uncrushed aggregates, crushed sand, and CEM II B(P) 32.5N cement; and Concrete B3' incorporates natural uncrushed aggregates, crushed sand, and CEM II A(P) 42.5N cement. The mixes will be formulated utilizing the Bolomey method to ascertain the ideal proportions. Following a curing duration of 28 days, compression tests will be conducted on the samples to assess their mechanical strength. The analysis of the results will provide a comparison of the performances of various formulations and the determination of the optimal mix to enhance the compressive strength of all-in gravel-based concrete in Goma..

Characterization of materials

This study involves conducting various laboratory tests to characterise the materials utilised, specifically aggregates and cement, and evaluate their qualities critical for concrete production. Before executing the tests, a meticulous sampling procedure is undertaken to guarantee that the samples accurately represent the components utilised in concrete manufacturing.

Grain Size Analysis: This analysis is conducted to ascertain the distribution of grain sizes within a sample of aggregates, facilitating the evaluation of their appropriateness for concrete composition. The sample is subjected to a series of sieves with progressively smaller mesh sizes, and the mass of each fraction is recorded to create a grain size curve, which offers insights into the compaction and workability of the concrete. The examination was performed following the stipulations of the [5] standard, which delineates the criteria for executing and interpreting the grain size analysis of aggregates.

The Sand Equivalent Test evaluates sand purity by quantifying the presence of tiny particles. The sand sample is stirred with a flocculating solution in a graduated cylinder, and the sand equivalent is determined by the ratio of the visible sand height to the total height in the cylinder.

The examination was performed following the[2] standard, which delineates the methodologies for assessing sand equivalent and categorising sand purity.

Absolute Density: This test measures the mass of grains per unit volume, omitting the voids between the grains. The volume alteration following the immersion of the dry aggregate sample in a liquid is assessed to determine the absolute density, which affects the compaction of the aggregates and, subsequently, the concrete formulation. The examination was performed following the stipulations of the [3] standard, which delineate methodologies for ascertaining the absolute density of aggregates.

Absorption Rate: This assessment evaluates the capacity of aggregates to hold water within their pores, which is especially significant for porous aggregates. The specimen is submerged in water for 24 hours, and the mass increment is recorded to determine the absorption rate. The examination was performed following the stipulations of the [3] standard, which delineate the procedure for assessing the absorption rate of aggregates.

The Abrams Cone Slump Test evaluates the consistency of fresh concrete, which is a crucial determinant of its workability. The concrete is positioned in an Abrams cone, and the slump is assessed post-removal of the cone to evaluate the fluidity of the concrete and its appropriateness for placement. The test was performed following the [7] standard, which specifies the process for measuring the slump of fresh concrete with the Abrams cone.

Compressive Strength: The compressive strength of hardened concrete is assessed by applying axial pressure to cylindrical specimens until failure occurs. The strength is determined by the maximum force the specimen can withstand, and this test facilitates the verification of the concrete's adherence to strength specifications. The examination was performed following the [8] standard, which delineates the criteria and methodologies for assessing the compressive strength of hardened concrete.

IV. Presentation And Interpretation Of Results

Aggregate Characteristics

Figure 2 presents the particle size distribution of the aggregates used, while Table 1 provides the grading parameters, including the uniformity coefficient (Cu), the curvature coefficient (Cz), and the Fineness Modulus.

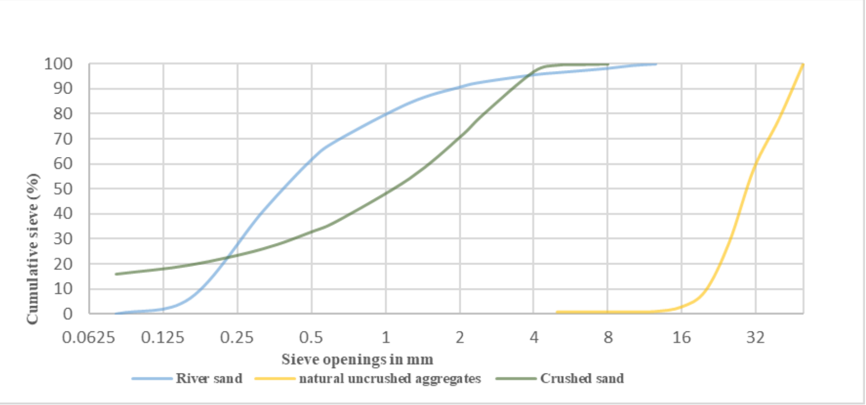

Figure 2. Particle Size Distribution of the Aggregates

The uniformity coefficient (Cu) and the curvature coefficient (Cz) for the all-in gravel are 1.6 and 0.9, respectively. Since Cu is less than 3, the particle size distribution of the gravel used is considered narrow or uniform. As for the curvature coefficient (Cz), its low value indicates the absence of certain diameters between the effective diameters D10 and D60, which suggests that the particle size distribution is poorly graded.

Table 1 presents the physical properties of the aggregates, including the absolute density, bulk density, absorption coefficient, porosity, and the Los Angeles abrasion coefficient.

Table 1. Physical properties of aggregates

	Absolute Density	Bulk density	Absorption coefficient	ES
	(g/cm3)	(g/cm3)	(%)	%
River sand	2.53	1.55	-	**91,2**
Crushed sand	2.89	1.58	2,3	89
natural uncrushed aggregates	2,46	1,07	2,52	-

Following the [3] standard, which defines the methods for measuring bulk density, porosity, absorption coefficient, and moisture content of aggregates such as gravel and sand, the aggregates used are exclusively standard. The obtained equivalent highlights that the sand used is clean and suitable for concrete mix formulation.

Concrete Mix Design

The composition of the different concretes derived from the Bolomey formulation is presented in Table 2.

Table 2. Constituent dosing of the concretes

	B1	**B2**	**B3**	**B1'**	**B2'**	**B3'**
Cement (Kg)	350	350	350	350	350	350
Sand (Kg)	1011.1	983.3	917.5	812.1	882.2	889.4
Gravel (Kg)	380.7	370.2	345.4	551.2	598.8	603.7
Water (l)	359.3	375.5	419.5	414.0	362.1	359.4

Through this table, it is evident that all the concretes have a cement content of 350 kg/m³. Furthermore, the differences in composition are primarily related to the particle size distribution and the bulk density of the aggregates used.

Properties of Fresh Concrete

Figure 3 shows the slump test results in centimetres for the six concrete mixes formulated.

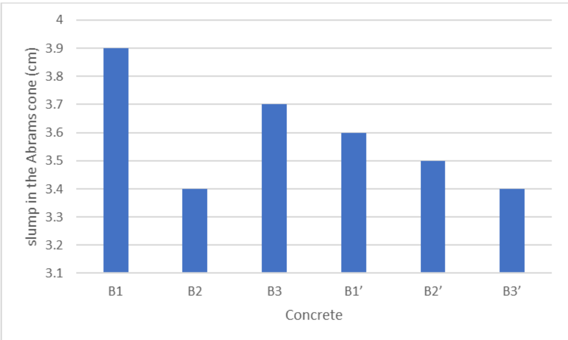

Figure 3. slump in the Abrams cone (cm)

The different slump values obtained, less than 5 cm, indicate that the concretes have a stiff consistency.

Properties of Hardened Concrete

Figure 4 shows the density of hardened concrete obtained from specimens at 28 days of age.

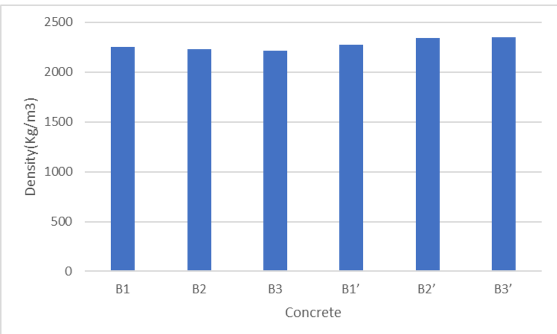

Figure 4. Density of concrete in kg/cm3

Based on this figure, all the concretes are considered normal concretes with a density ranging from 2200 kg/m³ to 2500 kg/m³, following the NF EN 12390-7 standard.
Figure 5 shows the different compressive strengths obtained from cylindrical specimens at 28 days of age.

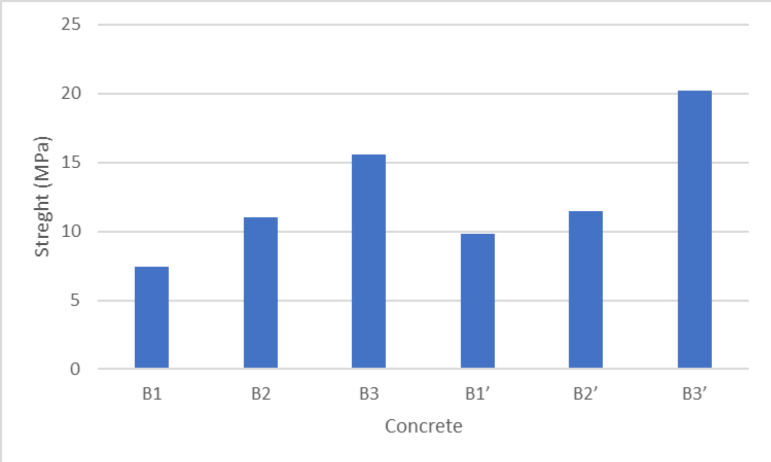

Figure 5. Compressive Strength of Concretes

This figure represents the different compressive strengths. The concretes B1, B2, B3, B1', B2', and B3' show compressive strengths at 28 days of 7 MPa, 11 MPa, 15.6 MPa, 9.8 MPa, 11.5 MPa, and 20.2 MPa, respectively. It follows that the combination of all-in gravel, crushed sand, and CEM II 42.5N cement results in a higher compressive strength compared to the reference formulation (B1). The optimal strength obtained is higher than the one achieved by [4].

V. Conclusion

This study underscores the significance of appropriate material selection to enhance the mechanical properties of concrete composed of natural uncrushed aggregates. Through comprehensive characterization of aggregates and variation of sand and cement types, we have shown that the compressive strength of concrete may be markedly improved. The findings indicate that a mixture of crushed sand and cement CEM II A(P) 42.5N attains a compressive strength of 20.2 MPa at 28 days, significantly surpassing that of the reference concrete. These findings facilitate improved exploitation of indigenous materials in Goma and offer opportunities for enhancing concrete performance in analogous environments. Enhancing concrete formulation according to the properties of accessible materials is a crucial strategy for sustainable and efficient construction in the area.

Regarding prospects, it would be advantageous to investigate the impact of additional variables, such as total moisture content and curing duration, on the characteristics of concrete. Furthermore, investigations into the durability of the formed concrete, especially its resistance to chemical assaults or abrasion, could yield essential insights for their prolonged utilization in extensive construction endeavours. It would be crucial to evaluate the viability of these formulations on an industrial scale, taking into account material costs and availability in various areas. Ultimately, the incorporation of modern technology, including eco-friendly cement and aggregate recycling methods, may enhance concrete performance while mitigating its environmental impact.

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