



RESEARCH ARTICLE

INFLUENCE OF GRANITE POWDER ON THE MECHANICAL BEHAVIOR OF RECYCLED AGGREGATE (GRAVEL) CONCRETE

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ABSTRACT

Aggregates are granular materials used in construction, either bound with substances such as binders and bitumen to produce concrete, road concrete, etc., or unbound as in railway ballast or drainage systems. Old buildings are often demolished to make way for new ones. Demolition waste can be recycled into reusable aggregates for concrete production. Studies have shown that concretes produced with such aggregates require more water and exhibit a compressive strength reduced by 5 to 40% compared to concretes made with natural aggregates. To improve the properties of these materials, granite powder was added to the sand–recycled aggregate–cement mixture. Thus, 5%, 7%, 10%, 12%, and 15% granite powder were incorporated into recycled aggregate concretes, and 10% into natural aggregate concrete, then subjected to compression and sclerometer tests. The aim of this study is to investigate the influence of granite powder on the mechanical behavior of recycled aggregate concrete. The results obtained show that the compressive strength of recycled aggregate concretes remains lower than that of natural aggregate concretes. However, the addition of granite powder improves the strength of both natural and recycled concretes.

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INTRODUCTION

Concrete is an excellent composite material, as its matrix consists partly of aggregates of various sizes, cement, water, and additives. It is the essential element in industrial and residential buildings, as well as in retaining walls and civil engineering structures such as bridges, tunnels, dams, sidewalks, and airport runways (Makhlouf, 2010). The extensive use of concrete in different fields has led to intensive and sometimes abusive exploitation of aggregate quarries. This excessive exploitation will eventually result in the depletion of this natural resource in the coming years. To address this issue, another solution is available to researchers and policymakers in developing countries: recycling. Indeed, recycling industrial concrete waste and non-biodegradable materials can serve as an alternative to preserve natural resources (Serifou, 2013). Demolition materials from old buildings and large structure are discarded daily in landfills. They represent an economic burden in terms of transportation and are often sources of unpleasant odors and mosquito breeding grounds, which contribute to the spread of malaria. However, these wastes can be recycled and reused as aggregates for road construction or building projects. The use of recycled aggregates in concrete production has already been the subject of several studies, which have highlighted a mechanical strength generally lower than that of concretes made with natural aggregates.

Berredjem *et al.* (2015) notably showed that incorporating recycled aggregates from demolition concrete leads to a significant decrease in mechanical performance compared to natural aggregates, confirming the need to optimize formulations to improve their properties. To overcome this weakness, adding granite powder to the recycled aggregate–sand–cement mixture appears to be a promising solution. Sellaf and Adda (2020) demonstrated that incorporating granite powder as a partial substitute for cement improves the compressive strength of concrete up to an optimal threshold of 10%, before decreasing beyond this proportion. Similarly, Moisson (2005) showed that the addition of fine aggregates contributes to increased compactness and strength of concrete, particularly in controlling the alkali-silica reaction.

This study follows this perspective and aims to propose a formulation of recycled aggregate concrete whose mechanical performance approaches that of conventional concrete.

MATERIALS AND METHODS

Matériels

Raw materials: The recycled aggregate used for concrete production was obtained from the demolition of ruined

buildings. These aggregates were mixed with sand collected from the lagoons of the Yopougon district. The cement used to stabilize the aggregate–sand mixture was of the Béliér brand. The granite powder added to the mixture came from the granite crushing quarries at PK24 on the Northern Highway. The entire mixture was prepared using tap water.

Equipment: A balance, graduated cylinders, cylindrical molds of 16 cm in diameter, 32 cm in height, and 200 cm² in cross-sectional area, a sclerometer, and an electronic compression press were used.

Method

Preparation of raw materials: Natural gravel was obtained by crushing granite. Recycled concrete gravel, on the other hand, came from the demolition of old buildings. Its composition differs from that of conventional gravel due to the presence of cement mortar on its surface. These demolition wastes are therefore considered secondary aggregates.

Sample preparation: For the preparation of samples, the water-to-cement ratio was fixed at 0.6, and the quantities of natural sand, gravel, and cement were kept constant. Only the granite powder was progressively introduced at dosages of 5%, 7%, 10%, 12%, and 15% relative to the mass of gravel. Two series of concretes were thus prepared: the first with natural aggregates (BN), including two reference concretes—one without granite powder (0%) and the other with 10% granite powder; the second with recycled aggregates from demolished buildings (BR), in which the granite powder content varied from 0% to 15%. The mechanical performance of these formulations was evaluated through compressive strength tests conducted after 28 days of curing in immersion, as well as surface hardness determination using the sclerometer. Table I presents the detailed composition of the concretes produced.

Tableau I. Composition des différents bétons formulés

Concretes	Gravel (kg)	Granite powder (%)	Sand (kg)	Cement (kg)	Water (l)
BN 0%	23,82	0	11,92	6	3,8
BN10%	23,82	10	11,92	6	3,8
BR 0%	23,82	0	11,92	6	3,8
BR 5%	23,82	5	11,92	6	3,8
BR 7%	23,82	7	11,92	6	3,8
BR 10%	23,82	10	11,92	6	3,8
BR 12%	23,82	12	11,92	6	3,8
BR 15%	23,82	15	11,92	6	3,8

BN = Natural concrete; BR = Recycled concrete

Concrete Characterization

Sclerometer: The sclerometer used was the standard NR-type aluminum housing sclerometer (Fig. 1). The characterization of a cylindrical concrete specimen measuring 16 × 32 cm with a sclerometer is based on a non-destructive test that estimates the mechanical strength of concrete, particularly its compressive strength. It allows the determination of the “impact hardness” of the concrete near the surface (sclerometric index). From this index, charts can be used to establish a correlation with compressive strength. The sclerometer (or Schmidt hammer) projects a mass against a compressed spring. This mass strikes a piston in contact with the concrete surface, and the rebound energy is measured. The harder the concrete, the greater the rebound. This measurement

is expressed as a rebound index (R), which is then correlated to an estimated compressive strength using a calibration curve. The specimen is positioned vertically (as in the compression test). At least 10 to 12 impacts are performed, distributed across the lateral surface, avoiding edges and damaged areas. Outliers are eliminated, and the average rebound index is calculated. Using a calibration curve specific to the type of concrete, the estimated strength is then determined.

Compression Machine: The machine used for compression testing was a 1500 kN testing press (Fig. 2). This CONTROLAB press is equipped with a control console, a hydraulic system, and a frame.



Figure 1. Standard NR-type sclerometer

The compression test is a destructive test carried out to determine the compressive strength of concrete. The crushing strength is obtained by applying a progressive load at a rate of 0.5 MPa/s until failure. The ratio between the failure load and the cross-sectional area of the specimen gives the compressive strength.



Figure 2. Electronic press, CONTROLAB brand

RESULTS AND DISCUSSION

Effect of Granite Powder on the Compressive Strength of Reference Concretes: Table II summarizes the strength results obtained for natural concretes with 0% and 10% granite powder.

Table II. Compressive Strength of Concretes

Concretes	BN 0%	BN 10%
E1 (MPa)	21	23,37
E2 (MPa)	20,11	22,79
E3 (MPa)	20,22	23,67
Average strength (MPa)	20,44	23,27

Table III. Compressive strength of recycled concretes (BR)

Concretes	BR 0%	BR 5%	BR 7%	BR 10%	BR 12%	BR 15%
E ₁ (MPa)	8,96	10,46	12,73	13,80	16,34	14,01
E ₂ (MPa)	9,31	10,21	12,11	12,91	16,50	14,13
E ₃ (MPa)	9,18	9,45	12,46	13,24	16,88	14,09
Average strength (MPa)	9,15	10,04	12,43	13,31	16,57	14,07

The tests were carried out on natural aggregate concretes (BN) with 0 and 10% granite powder. In general, the compressive strength of natural concretes (BN) is greater than 20 MPa.

A value of 23 MPa is observed with the addition of 10% granite powder. The addition of granite powder improves the strength of the reference concrete. This improvement in concrete strength by adding granite powder could be explained by the fact that the powder fills the voids left by the gravel and sand. The material becomes more compact, hence the increase in strength. These results are consistent with those of Moisson (2005), who showed in his work that the addition of fine aggregates improves the strength of concrete.

Effect of the progressive addition of granite powder on the compressive strength of recycled concretes (BR): Table III presents the results of compressive strength obtained on recycled aggregate concretes. The results indicate that the compressive strength of concretes increases with the addition of granite powder. Thus, when moving from 0 to 12% granite powder addition, the compressive strength increases from 9.15 to 16.57 MPa. However, beyond this threshold of 12%, a decrease is observed at 15% (14.07 MPa), reflecting excessive dilution of the cement and a reduction in mechanical performance. This improvement in the strength of concretes from 0 to 12% granite powder addition is linked to a good distribution of the granite powder in the cementitious matrix. As shown by (Sellaf, 2020) and (Moisson, 2005), fine particles in significant quantities perfectly occupy the spaces between the recycled aggregates.

This increase in strength could also be explained by the physical effect of granite powder, which adjusts the cement particle size distribution, thereby increasing the compactness and density of the paste. Furthermore, the work of (Rahmani *et al.*, 2015) confirms that this redistribution of particles improves internal bonding, while (Neville, 1995) highlights the filling effect of fines in reducing porosity. Indeed, the mixture of granite powder allows a redistribution of particles, which enhances the mechanical properties of recycled concretes. At 5%, the amount of powder becomes sufficient to fill the voids left by sand and cement. In addition, the hydrates formed between these different particles are present in significant quantities to strengthen the bonds between the material's particles, thus increasing the concrete's strength. However, an excess of non-reactive powder reduces the proportion of available hydraulic binder, which explains the drop in strength beyond 12%. Similar studies corroborate this interpretation. (Sellaf, 2020) showed that the incorporation of granite powder as a partial substitute for cement improves strength up to an optimal threshold of 10%, before decreasing. Thus, the optimum performance for recycled concretes lies between 10 and 12% granite powder, confirming that this material constitutes an effective solution for improving the mechanical properties of concretes made from demolition aggregates. Figure 4 illustrates a typical vertical cracking observed on concrete specimens after compressive failure. This cracking mode, from top to bottom, is characteristic of cementitious

materials subjected to axial stresses. It reflects the low deformation capacity of concrete, particularly under the effect of shrinkage and load concentration (Serifou, 2008). According to (Neville, 1995), this failure is linked to the low toughness of concrete, which promotes the appearance of cracks as soon as stresses exceed local strength (Sellaf, 2020) emphasizes that the addition of fines, such as granite powder, improves compactness and reduces porosity, but does not fundamentally alter the failure mode. Moreover, (Sellaf, 2020) and (Rahmani, 2015) confirm that the redistribution of fine particles enhances internal bonding, strengthening resistance without eliminating sensitivity to cracking. Thus, this image confirms that, despite the mechanical improvement provided by granite powder, recycled concrete retains a fragile structure, prone to typical vertical failure of low-deformability concretes.

**Figure 4. Failure of the specimen under compression****Table IV. Rebound hammer strengths of concretes**

Concrete	Compressive strength (MPa)	Rebound hammer strength (MPa)
BN 0 %	20,44	21,03
BN 10 %	23,27	24,08
BR 0 %	09,15	08,96
BR 5 %	10,04	10,81
BR 7 %	12,43	12,76
BR 10 %	13,31	13,65
BR 12 %	16,57	16,06
BR 15 %	14,07	15,34

Influence of granite powder on the surface strength of concretes: Table IV presents the strength results obtained from the rebound hammer indices of natural aggregate concretes and recycled aggregate concretes. Overall, the rebound hammer strengths of natural concretes are higher than those of recycled aggregate concretes. The results obtained show that the studied addition influences the mechanical performance of BN and BR concretes differently. For BN, the incorporation of 10% leads to a notable improvement in compressive strength (from 20.44 to 23.27 MPa) and rebound hammer strength (from 21.03 to 24.08 MPa), reflecting better compactness and density of the cementitious matrix. In contrast, BR exhibits a progressive increase in strength up to an optimal threshold at 12% (16.57

MPa in compression and 16.06 MPa with the rebound hammer), beyond which performance decreases, probably due to excessive substitution that weakens the structure. Overall, rebound hammer measurements confirm the trends observed in compression, validating the consistency of the results. Thus, the addition is beneficial for BN at 10%, while for BR, an optimal dosage of 12% is necessary to maximize strength before it declines.

CONCLUSION

At the end of our study, it appears that it is possible to formulate concretes using aggregates derived from the demolition of old buildings. The tests carried out show that the mechanical strength of recycled aggregate concretes remains lower than that of natural aggregate concretes. However, the incorporation of granite powder significantly improves their performance. For natural concretes, the addition of 10% granite powder increased the average compressive strength from 20.44 to 23.27 MPa. As for recycled concretes, the strength increased from 9.15 MPa without addition to 16.57 MPa with 12% granite powder. Rebound hammer measurements confirm this trend, indicating a parallel improvement in surface hardness. This progression is attributed to the increased compactness of the cementitious matrix and the redistribution of fine particles, which strengthen the internal bonds of the material. Thus, the addition of granite powder constitutes an effective means of valorizing demolition waste and producing recycled concretes with significantly improved mechanical properties.

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