

Proposal for Ordinary Concrete Formulation from Different Cements of Strength Class 42.5R for the Informal Construction Sector

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Abstract

Faced with the recurring collapses of residential buildings affecting the civil engineering sector in Côte d'Ivoire, this study aims to evaluate and compare the performance of 42.5R strength class cement produced by four local cement plants (BEL, CIM, CUR and GUE) within the framework of a standardized, ordinary concrete mix design (class C20/25 to C30/35). The experimental protocol consisted of the determination of the physical properties (water porosity, water absorption and dry density) and mechanical properties (splitting tensile tests, 3-point bending tensile tests and compressive strength) carried out on concrete specimens at 7, 14 and 28 days. The results show that the concretes formulated with the different cements meet the mechanical strength criteria of ordinary concretes. A comparative analysis of the results highlighted distinct performance characteristics: concrete formulated with GUE cement provided the best mechanical strength at all ages, followed by concrete made with BEL cement, which stood out for its high long-term performance. Concrete made with CIM and CUR cements also demonstrated satisfactory results, confirming their compliance with the required standards. These performance variations are attributed to differences in mineralogical composition and grind fineness of the different cements. These formulations can provide a reliable source for concrete manufacturers in the informal construction sector. This study demonstrated that local 42.5R strength class cements can indeed be used for the formulation of ordinary concrete, providing a viable and standard-compliant solution for improving the quality and durability of construction.

Keywords

Formulation, Concrete, Aggregates, Cement, Physical and Mechanical

1. Introduction

The construction sector is growing rapidly in view of the accelerated urbanization of major African cities and their demographics [1]. In Côte d'Ivoire, the housing deficit is estimated at nearly 500,000 housing units and is increasing by approximately 40,000 units each year [2]. To meet the demand for housing, many construction companies (formal and informal) have emerged and there is a development of self-construction in the production of private buildings. Most buildings constructed use concrete (concrete, reinforced concrete, self-compacting concrete, etc.) as the main material. This is justified by the fact that this manufactured material is the most used in the world [3]. To meet the demand for housing, many construction companies (formal and informal) have emerged and there is a development of self-construction in the production of private buildings. Unfortunately, most informal construction companies don't have competent human resources (lack of civil engineers and specialized senior technicians), which leads to a lack of professional oversight on their construction sites. Furthermore, these companies do not have the material resources to guarantee the quality of the concrete formulations used (lack of laboratory on the construction sites, lack of quality controllers on the construction sites, etc.). In Côte d'Ivoire, more than ten cement factories have been created, each offering a wide range of cements (CEM I, CEM II, CEM III, etc.). For informal construction companies, this proliferation of cement factories (and cement) constitutes a real imbroglio in terms of concrete formulation.

Unfortunately, in recent years, the construction sector has been faced with numerous collapses of buildings completed or under construction in Ivory Coast [4]. The work of Bakayoko *et al.* [5] has shown that the building collapses observed recently are partly due to the quality of the concrete used, particularly linked to its low mechanical strength (less than 25 MPa). Several works [6]-[8] have indicated that the quality of concrete is strongly linked to its formulation and the materials used. The purpose of formulating concrete is to select the constituents of the concrete and to choose their proportion in order to meet a well-defined specification. The minimum specifications imposed may concern mechanical resistance, handling and durability of concrete [9]. This formulation of concrete depends on technical, normative and also economic criteria such as the geometric characteristics of the structure and its environment during its operation [10]. However, developing suitable concrete can be tricky. Contemporary concrete is made from a mixture of cement (the result of baking clinker and gypsum with possible additions), water and aggregates. Thus, the recurrence of collapses of structures in Abidjan leads to finding an effective formulation of ordinary concretes for cements of resistance class 42.5R used on the majority of building sites

in the Ivory Coast [11].

This paper presents a study on the formulation of ordinary concretes from locally produced cements of class 42.5R. The compressive strength of concretes is estimated between 20 and 30 MPa, intended for use in the informal construction sector, with materials collected locally in the Abidjan region. The aim is to evaluate the influence of cement on the mechanical strength and durability of the formulated concrete.

2. Materials and Methods

2.1. Raw Materials

2.1.1. Aggregates

The gravel used for making concrete is crushed granite from an industrial quarry in the Abidjan region. The gravel is granular class 5/15. The sand used for making concrete is extracted from the Ebrie lagoon by dredging and is generally used in building construction work in the city of Abidjan [12]. The granular class of the sand is 0/1. Physical and mechanical characteristics of the aggregates used are presented in **Table 1**. The granulometric analysis curves of sand and gravel are given in **Figure 1**.

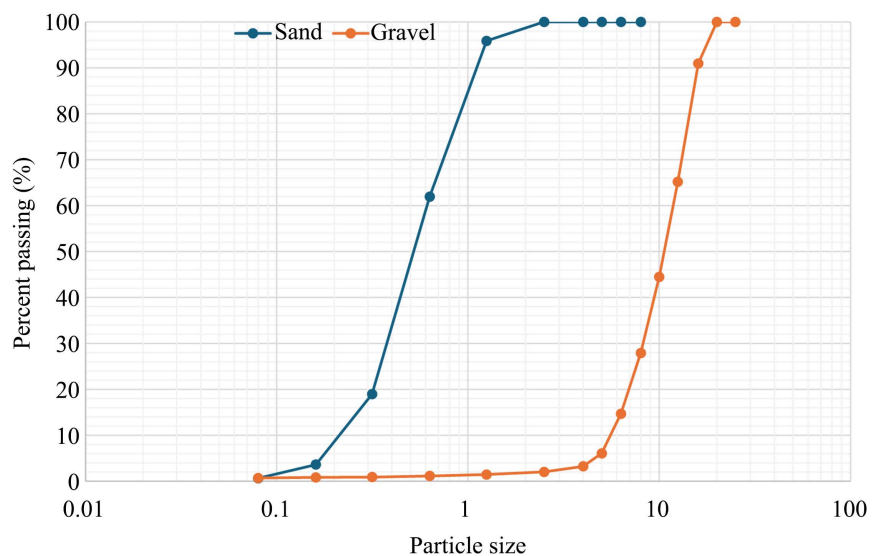


Figure 1. Granulometric analysis curves of aggregates.

Table 1. Physical and mechanical characteristics of the aggregates used.

Aggregates	Uniformity Coefficient (C_u)	Curvature Coefficient (C_c)	Fineness Modulus (M_f)	Sand Equivalent (E. S)	Specific weight (g/cm^3)	Los Angeles (LA)	Micro-Deval (MDE)
Sand (0/1)	2.6	1.03	2.20	84	2.60	-	-
Gravel (5/15)	2.0	0.04	-	-	2.62	30	7

2.1.2. Cements

In order to assess the impact of cements, cements used came from four (04) cement plants designated GUE, BEL, CUR and CIM. The physical and mechanical characteristics of these different cements are given in **Table 2**. All the cements used are class CPJ – CEM II/B 42.5 R (CPJ – CEM II/A 42.5 for CIM cement).

Table 2. Physical and mechanical characteristics of the cements used.

Cement plant	CaO (%)	SO ₃ (%)	Loss on ignition (%)	Insoluble Residues (%)	Blaine fineness (cm ² /g)	R _{c7} (MPa)	R _{c28} (MPa)
BEL	52.56	2.94	2.52	1.01	4185	33	44
CIM	52.17	2.63	2.83	1.2	4100	33.6	44.1
CUR	57.10	2.50	-	0.58	4122	32.1	46.4
GUE	50.48	2.60	3.21	-	4350	36	48

From the oxide composition of the cements and using the Bogue formula, the mineralogical composition of the cements is given in **Table 3** below:

Table 3. Mineralogic composition of the cements used.

Cement plant	CaO (%)	SiO ₂ (%)	Al ₂ O ₃ (%)	Fe ₂ O ₃ (%)	C ₃ S (%)	C ₂ S (%)
BEL	52.56	20.15	5.09	2.27	34.21	31.97
CIM	52.17	21.29	6.37	2.06	4.78	57.30
CUR	57.1	23.5	7.1	2.6	2.37	65.43
GUE	50.48	20.05	5.33	1.86	25.42	38.27

2.1.3. Water

The water used for concrete formulation is the tap water, this water is regulated by the French standard [13].

2.2. Concrete Formulation

The concrete mixes were formulated according to the modified Dreux-Gorisse method [11]. **Table 4** gives the mass composition for 1 m³ of concrete. The proportions of materials (cement, aggregates, water) are the same for the concretes of the four cement plants.

Table 4. Mass composition for 1 m³ of concrete.

Components	Gravel (kg)	Sand (kg)	Cement (kg)	Water (l)	Slump (cm)
Ordinary Concrete	1065.60	648.13	400	224.6	7 - 8

2.3. Specimens Casting and Curing

For each composition, prismatic (7 × 7 × 28 cm³) and cylindrical (φ11 × 22 cm³)

specimens were cast. Specimens were used to determine the physical and mechanical properties of concrete. All samples were cast in steel molds and compacted using a vibrating needle. After demolding, the specimens were kept in a basin containing water until the test dates (7, 14 and 28 days).

2.4. Physical and Mechanical Tests

Physical and mechanical characterization tests were carried out on the concrete specimens. According to specifications, in each case four samples were tested.

2.4.1. Determination of Physical Properties

For the determination of physical characteristics, hydrostatic weighing was carried out. This test allows the determination of the water porosity, dry density and water absorption of the concrete using the hydrostatic weighing device (**Figure 2**).

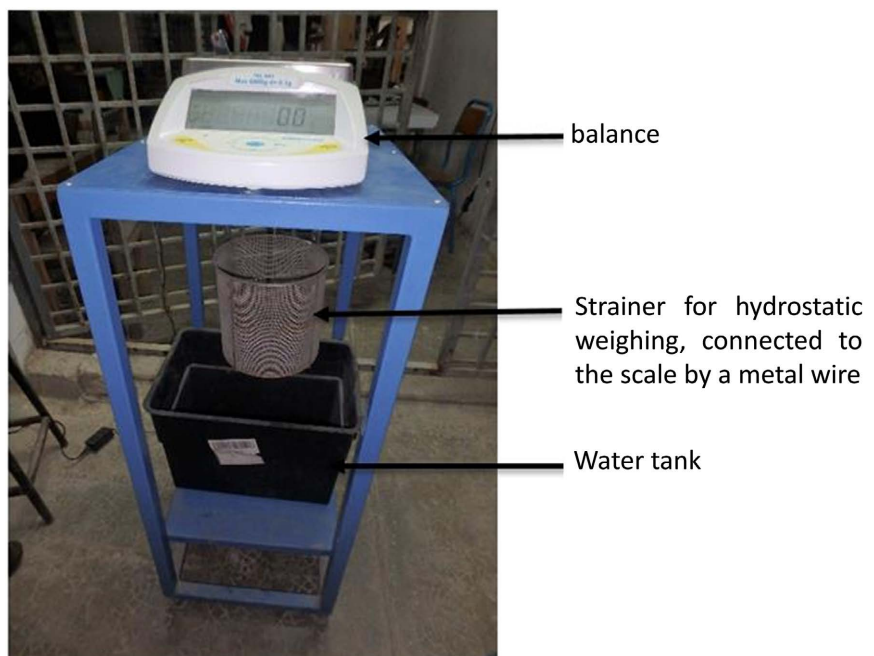


Figure 2. Hydrostatic weighing device.

The test is carried out in the following successive phases according to the AFPC-AFREM procedure [14]:

- **Phase 1** (Drying of the sample and dry mass): For each concrete, five (05) samples are taken and placed in the oven at 105°C for 24 hours. After 24 hours in the oven, the samples are weighed on an electronic balance to obtain the dry mass (M_s);
- **Phase 2** (Air weighing and air mass): After measuring the dry mass, the samples are immersed in water until they are saturated with water (obtaining a constant mass between two successive weighing). The water-saturated samples are wiped and weighed in air. This allows the saturated mass (M_a) to be obtained;

- **Phase 3** (Weighing in water and mass in water): After the second phase, each sample is placed in a strainer suspended from a hydrostatic balance. The strainer is immersed in a tank containing water, ensuring that its bottom is not in contact with the tank. The mass of the immersed sample (M_e) is thus determined.

At the end of these different hydrostatic weighing phases, the following physical characteristics are determined:

- o **Water porosity**: it is given by the following relationship:

$$\eta = \frac{M_a - M_s}{M_a - M_e} \cdot 100 \quad (1)$$

where η is the porosity to water, M_a is wet mass of sample, M_s is dry mass sample, M_e is submerged mass, so, $M_a - M_e = V \cdot \rho_w$, V volume of sample.

- o **Dry density**: it is given by the following formula:

$$\rho = \frac{M_a}{M_a - M_e} \cdot 100 \quad (2)$$

where ρ is dry density; M_a is wet mass in air; M_s is dry mass sample, M_e is submerged mass, so $M_a - M_e = V \cdot \rho_w$.

- o **Water absorption**: is given by the formula:

$$w = \frac{M_a - M_s}{M_s} \cdot 100 \quad (3)$$

With w : water absorption; M_a : wet mass in air; M_s : dry mass.

2.4.2. Determination of Mechanical Properties

These are the following tests:

- **Compressive strength test**: The compression test was carried out on prismatic concrete specimens ($7 \times 7 \times 14 \text{ cm}^3$) according to the French standard [15]. The compressive strength test was carried out by applying a load to the specimen until rupture using a hydraulic press with a capacity of 150 KN. The compressive strength is given by the following formula:

$$R_c = \frac{F}{S} \quad (4)$$

where R_c is the compressive strength in MPa, F is the load applied in N, S is the surface area of the specimen in mm^2 .

- **Bending tensile test**: The bending tensile test was carried out on prismatic specimens ($7 \times 7 \times 28 \text{ cm}^3$) according to the French standard [16]. The test determined the bending strength (3 points) of the specimens subjected to a centred force exerted using a hydraulic press. The bending strength was determined by the following relationship:

$$R_b = \frac{3 \cdot F \cdot L}{2 \cdot I \cdot e^2} \quad (5)$$

With, R_b the bending strength in MPa, L the length of the prism in mm, I the thickness in mm, e the height in mm and F the load in N.

- **Splitting tensile test:** The splitting tensile test is carried out using the French standard [17]. The test consisted of crushing the cylindrical specimens ($11 \times 22 \text{ cm}^3$) of concrete. The splitting tensile strength is given by the following formula:

$$R_f = \frac{2 \cdot F}{\pi \cdot L \cdot D} \quad (6)$$

where R_f is the splitting strength in MPa, F is the load applied in N, L is the length of the concrete cylinder in mm and D is the diameter of the concrete cylinder in mm.

3. Results and Discussion

Note: Each graph in the figures below corresponds to the mean value obtained for the various tests carried out. Error bars correspond to the standard deviation calculated for each average value.

3.1. Physical Properties

3.1.1. Porosity to Water

Figure 3 shows porosity to water versus age of concrete for different cement (BEL, CIM, CUR and GUE).

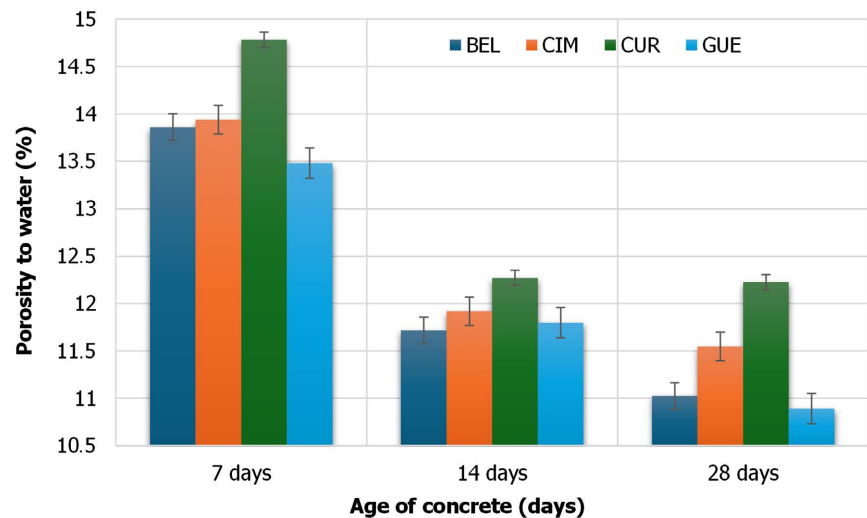


Figure 3. Porosity to water vs age of concrete from different cement.

Evolution of the concrete's porosity formulated with the four types of cements (BEL, CIM, CUR, and GUE) was monitored at 7, 14, and 28 days of curing. The results show a decrease in porosity over time, reflecting the progressive densification of the cement matrix. At 7 days, the lowest porosity is observed with GUE cement (13.48%), followed by BEL (13.86%), CIM (13.94%), and CUR (14.78%). This trend reflects a greater onset of densification for GUE cement, which appears to promote faster and more efficient hydration. At 14 days, the porosity decreases further for all cements. The values vary from 11.71% (BEL) to 12.27% (CUR). A

narrowing of the gaps is observed, but GUE and BEL have the lowest values, confirming more favorable hydration kinetics. As noted by [18], the reduction in porosity is linked to the progressive filling of capillary voids by calcium hydrates (C-S-H, CAH, etc.). However, calcium hydro-silicates and hydro-aluminates (CSH and CAH) which result from hydration reactions gradually reduce the porosity of the composite over time. This explains the decrease in porosity with curing time. This result is confirmed by [19] who noted that the hydrates formed favor a rearrangement progressively occupying the voids within the block. At 28 days, the concretes have porosities between 10.89% (GUE) to 12.22% (CUR). GUE and BEL cements are distinguished by the lowest values, reflecting a more closed and homogeneous microstructure. In fact, the hydration process and hardening based on compounds of cement give materials with hydrophilic character that is influenced by cement composition [20]. These results confirm the work of [21], according to which concretes with a porosity of less than 12% are more resistant to external aggressions, because reduced porosity improves durability.

3.1.2. Dry Density

The average measured values of concrete dry density are plotted against age of concrete on **Figure 4**.

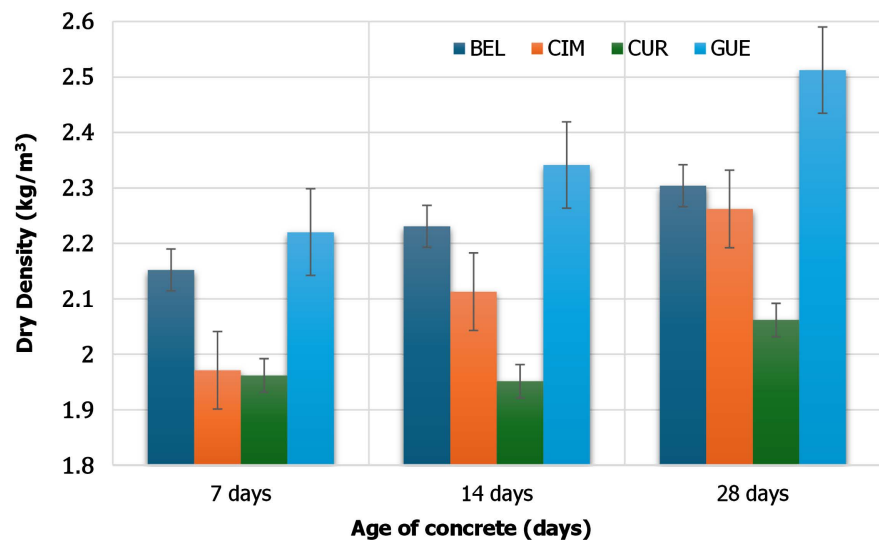


Figure 4. Dry density vs age of concrete from different cement.

Dry density results presented in **Figure 4** reveals a progressive increase in density for all concretes tested over time (the values are between 1.95 kg/m³ at 7 days for CUR cement and 2.51 kg/m³ at 28 days of curing for GUE cement). This trend is a direct consequence of cement hydration, where reaction products (primarily C-S-H gel) form and gradually fill the pore space left by water. A higher density indicates a more compact microstructure and low porosity. This fundamental relationship between density, hydration, and porosity has been a pillar of concrete research, as demonstrated by the work of [22], which established the foundations

of the hydrated cement paste theory.

Significant differences in density between samples are also noted. Concrete formulated with GUE cement exhibits the highest density (2.22 kg/m³ to 2.51 kg/m³) at all ages. This superiority is explained by faster and more complete hydration kinetics, which allow for more efficient formation of hydration products. This observation may be related to a higher content of reactive phases in the clinker. Concrete with BEL cement, although slightly less dense at the beginning (2.15 kg/m³ at 7 days of curing) shows a progression that keeps it close to GUE cement. This performance is characteristic of concretes containing cementitious additions that, through longer-term pozzolanic reactions, continue to densify the matrix. According to the studies of [23], these additions contribute to the formation of an additional and denser C-S-H gel, thus improving the microstructure and final density of the concrete. CIM and CUR concretes have similar and lower densities, which could indicate a composition with lower reactivity or a proportion of additions less effective for pore filling [24].

3.1.3. Water Absorption

The results of the water absorption test are shown in **Figure 5** versus age of concrete.

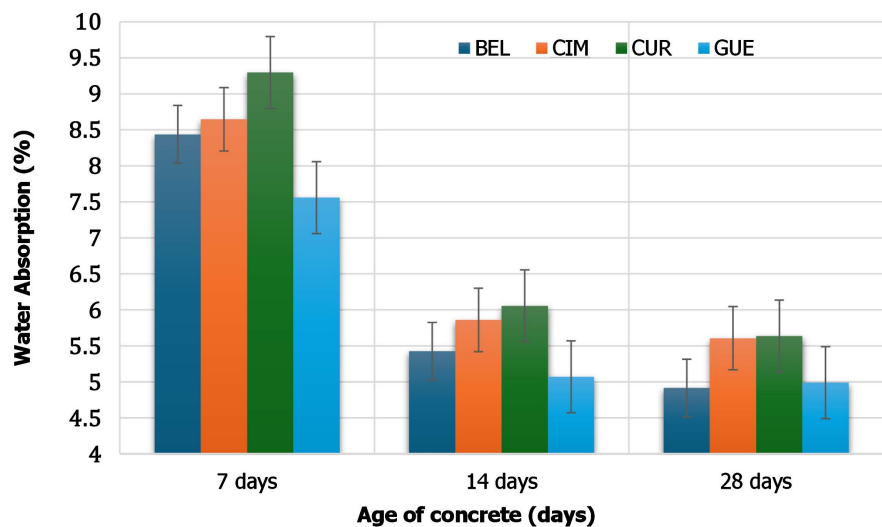


Figure 5. Water absorption vs age of concrete from different cement.

The results of the water absorption test, presented in **Figure 5**, reveal the densification kinetics of the microstructure of four concretes (BEL, CIM, CUR, GUE) over 28 days. Absorption values, which measure open porosity, decrease significantly over time for all formulations, reflecting the progression of the cement hydration reaction and pore filling.

At 7 days, the cements exhibit distinct behaviors. CUR cement shows the highest absorption (9.29%), while GUE cement has the lowest (7.56%). This initial difference is directly linked to the hydration kinetics of each type of cement. Faster hydration initially generates a more open microstructure, as suggested by Neville

[21] for similar formulations. At 14 days, all concretes show a clear reduction in absorption (25% to 40% compared to the 7-day values), reflecting a refinement of the microstructure and a reduction in capillary porosity. The decrease in absorption is generally correlated with changes in internal compactness, due to the progress of hydration [25].

At 28 days, the absorption values converge, confirming that the densification process is stabilizing. GUE cement maintains the lowest absorption (4.99%), while CIM cement has the highest (5.60%). This convergence of absorption values indicates an equivalent practical densification of the cement matrix, which suggests a similar potential long-term durability for the four concretes. This result corroborates the work of Taylor [26], which highlights the importance of densification for the final performance of concrete.

3.2. Mechanical Properties

3.2.1. Compressive Strength

Figure 6 presents the compressive strength results of concretes.

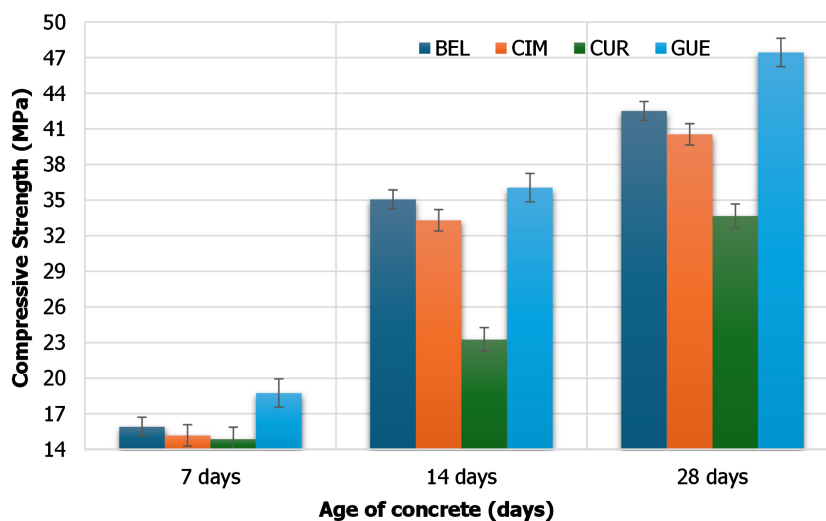


Figure 6. Compressive strength vs age of concrete from different cement.

The higher early strength of GUE cement (18.77 MPa) at 7 days is consistent with its high short-term reactivity. Beyond tricalcium silicates alone, it is important to note that cement fineness plays a major role in hydration rate. As demonstrated by previous authors [27] [28], a larger specific surface area of cement particles allows for a faster hydration reaction, which directly translates into increased compressive strength development at early ages. These results match with previous works [29] which indicate the existence of a relationship between compressive strength and density of concrete.

The high performance of BEL cement at 14 and 28 days (35.07 MPa and 42.52 MPa, respectively) can be attributed not only to the mineral composition of this cement but also to a better paste microstructure resulting from the reaction of cementitious additions. These additions form additional C-S-H and consume

some of the portlandite, thereby reducing the size and connectivity of the pores in the matrix. This mechanism is crucial for compressive strength. The work of Mehta and Monteiro [23] describes in detail how these additions can modify the morphology of hydration products and improve the overall density of concrete, which is the key factor in long-term compressive strength. The CIM and CUR samples, on the other hand, show comparable and consistent strength development, which could indicate similar mineral compositions.

3.2.2. Three-Point Bending Tensile Strength

The results of the three-point bending test as a function of curing time are presented in Figure 7.

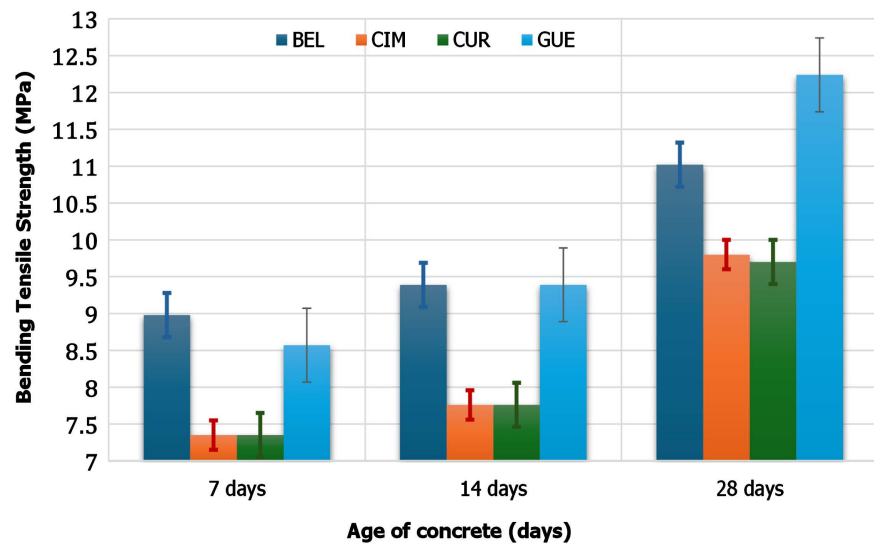


Figure 7. 3-point bending tensile strength vs age of concrete from different cement.

These results reveal an evolution of strengths for all the cements tested, with notable differences in performance. The high initial strength of GUE cement at 7 days is typical of cements with a high C3S (tricalcium silicate) content, whose hydration kinetics are rapid, producing a significant amount of C-S-H (Calcium Silicate Hydrate) and portlandite in the first hours. This behavior is well documented and has been studied in detail by researchers such as Mindess and Young [30] who emphasize the impact of mineralogy on the development of mechanical properties. At 14 days, GUE cement begins to exceed BEL, confirming its superiority at 28 days. This slower but more sustained progression is characteristic of cements containing mineral additions, which require more time to initiate their pozzolanic reaction. These additions not only contribute to final strength, but can also improve the microstructure of the cement paste by reducing porosity, a mechanism highlighted by Taylor [26]. This increased density results in better flexural strength; a parameter intrinsically linked to the quality of the cement matrix. CIM and CUR cements, for their part, show comparable strength development, which could be explained by the use of a similar formulation or additions with comparable reac-

tivity.

3.2.3. Splitting Tensile Strength

Figure 8 shows the results of the splitting tensile test carried out on the concrete specimens. The results obtained show an increase in strength for all the concretes with curing time.

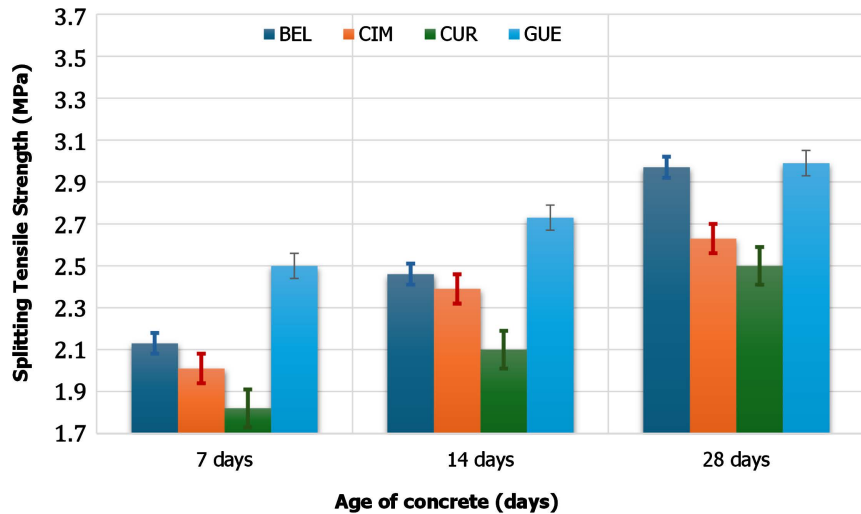


Figure 8. Splitting tensile strength vs age of concrete from different cement.

The splitting tensile test results, presented in **Figure 8**, reveal an increase (16% to 28% increase) in splitting tensile strength for all samples over time. GUE cement gives a higher value of strength, 2.5 MPa at 7 days compared to 1.82 MPa, 2.01 MPa and 2.13 MPa for CUR, CIM and BEL cements respectively. This good early age strength can be attributed not only to a high tricalcium silicate (C3S) content, but also to optimal grinding fineness (the Blaine surface area of GUE cement is higher than that of other cements (**Table 1**) and to a homogeneous particle size distribution.

As highlighted in studies such as those of Soroka and Gjørsv [27], the particle size distribution of cement particles plays a decisive role in increasing the specific surface area available for hydration, which directly translates into rapid development of hydration products and, consequently, mechanical strength at early ages.

At 28 days, GUE and BEL cements display identical strength values (2.99 MPa), exceeding the other samples (a difference of more than 13%). This long-term behavior is particularly indicative of the quality of the cement paste microstructure. Splitting tension, being more sensitive to the internal microstructure than to compression, directly reflects the quality of the matrix and the interfacial transition zone (ITZ) [31] [32]. Indeed, the work of Konin *et al.* [33] showed that even in the case of high-performance concrete, the paste-aggregate transition zone is a zone of low strength, due to its high porosity. And as the concrete becomes more porous and less resistant, the values obtained were predictable.

The gradual increase in strength of the BEL sample (approximately 28% strength

gain from 7 days to 28 days) can be attributed to mineral additions that, by reacting more slowly, refine the pore network. Portlandite consumption and the formation of additional hydration products fill the pores, reducing their size and connectivity. This microstructural modification is a key mechanism, detailed by authors such as Zhang *et al.* [34], and results in increased long-term strength. CIM and CUR cements, on the other hand, show lower strength. (2.01 MPa and 1.82 MPa at 7 days), which could be explained by a less reactive composition or the presence of additions which do not contribute as much to the refinement of the porosity.

4. Conclusions

This study comparatively assessed the influence of four types of local cements (BEL, CIM, CUR, and GUE) on the physical and mechanical properties of concrete at 7, 14, and 28 days. The specimens were prepared using an identical formulation and subjected to the same implementation and curing conditions to ensure a rigorous and objective analysis.

On the one hand, the measurement of physical characteristics (water porosity, dry density, and water absorption) showed that concretes formulated with GUE cement and, to a lesser extent, BEL cement, yielded the best results for all physical properties, regardless of the age of these concretes. At 28 days, the dry density of concretes formulated with GUE and BEL was 2.51 and 2.30, respectively (and water porosities of 10.89 and 11.71), compared to 2.26 and 2.06 for CIM and CUR concretes (and water porosities of 11.91 and 12.25, respectively). This indicates that GUE and BEL concretes are more compact and less porous than CIM and CUR concretes, which may lead to better long-term durability of these concretes. These performance variations can be attributed to differences in chemical composition, grind fineness, and clinker mineralogy between the cements.

Furthermore, the determination of mechanical strengths (compressive strength, tensile strength by splitting, and tensile strength by 3-point bending) revealed that the cements from the four cement plants achieve satisfactory performance for a usual class of concrete at 28 days (the compressive strength values are greater than 30 MPa for all the concretes produced). A detailed comparison confirmed the trends observed in the physical properties, namely that GUE cement provided the highest mechanical strengths at all curing ages (compressive strength of 18.74 MPa, 36.05 MPa and 47.45 MPa at 7, 14 and 28 days respectively), followed by BEL cement (compressive strength of 15.92 MPa, 35.07 MPa and 42.52 MPa at 7, 14 and 28 days respectively). CIM cements (compressive strength of 15.17 MPa, 33.30 MPa and 40.54 MPa at 7, 14 and 28 days respectively) and CUR cements (compressive strength of 14.86 MPa, 23.27 MPa, and 33.67 MPa at 7, 14, and 28 days, respectively) also yielded satisfactory results, falling within the strength range required for ordinary concrete.

Indeed, although the four 42.5R cements studied are suitable for use in ordinary concrete, this study recommends that companies in the informal construction sector use GUE and BEL cements for uses requiring good mechanical performance

at early ages (and in the long term) and CUR and CIM cements to a lesser extent when only long-term mechanical performance is required.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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