HUNGARIAN JOURNAL OF
INDUSTRY AND CHEMISTRY
Vol. 52(2) pp. 19–27 (2024)
hjic.mk.uni-pannon.hu
DOI: 10.33927/hjic-2024-15

REUSE OF FINE CONCRETE DEMOLITION WASTES AS A SUPPLEMENTARY CEMENTITIOUS MATERIAL IN CONCRETE

LYNDA KHEDDACHE[1], DJAMILA ABOUTALEB[1], BRAHIM SAFI[1*], SAMIR LECHEB[2], AHMED CHELLIL[2]
AND HAMZA MECHAKRA[2]

1 Research Unit Materials, Processes and Environment (URMPE), Faculty of Technology, M'hamed Bougara University of Boumerdes, Frantz Fanon City, Boumerdes, 35000, ALGERIA
2 Laboratory of Motor Dynamics and Vibroacoustics (LDMV), Faculty of Technology, M'hamed Bougara University of Boumerdes, Frantz Fanon City, Boumerdes, 35000, ALGERIA

Materials from demolition are only recycled if they are economically competitive on the one hand and technically acceptable on the other, meaning they can be implemented without risking disruption to the performance of the construction material. Among these materials are demolished concretes. This type of material (waste) is currently reused as recycled aggregate, commonly referred to as gravel. Indeed, the latter contains grains of anhydrous clinker, which may play a significant role in determining the properties of concrete. In the context of waste valorization, this study focuses solely on the influence of incorporating finely crushed concrete demolition waste (CDW) as an active additive or as a supplementary cementitious material in the cement matrix used to make concrete. The results showed that the addition of up to 10% of concrete demolition waste significantly improved physical properties such as the air void content and workability of fresh concrete. Furthermore, the compactness of hardened concrete also improved based on adding 10% of CDW as a result of increasing the speed of sound. Therefore, the compressive strength of concrete was also improved by 20% when 10% waste was added compared to the control concrete. This indicates that concrete demolition waste (finely crushed) can replace cement and therefore contribute to reducing binder consumption.

Keywords: Recycling wastes, concrete demolition wastes, cement paste, workability, mechanical strength analysis

1. Introduction

Materials for building construction are continuously being produced, which must either be disposed of or reused. A significant volume of waste materials such as demolished concrete and by-products is generated from various manufacturing processes, service industries and municipal solid waste management systems worldwide [1]-[6]. Consequently, solid waste management has emerged as a critical environmental issue globally. With growing environmental awareness, dwindling landfill space and rising disposal costs, the utilization of waste materials and by-products has emerged as an appealing alternative to traditional disposal methods. The high consumption of natural resources, substantial production of industrial waste and environmental pollution necessitate innovative solutions for sustainable development. In recent years, the emphasis on incorporating waste materials and by-products into construction materials has been increasing [5]-[10]. This utilization offers a partial solution to environmental and ecological challenges. Integrating these materials into cement, concrete and other construction materials not only reduces the cost of manufacturing but also yields several indirect benefits, including decreased landfill expenses, energy savings and the mitigation of potential environmental pollution. Moreover, their utilization can enhance the microstructure, mechanical strength as well as durability of mortar and concrete, aspects that are often challenging to achieve with conventional Portland cement alone [9]-[15].

Concrete production as well as the creation of construction and demolition waste are significant sources of ongoing carbon dioxide emissions. Numerous studies have examined the potential use of demolition waste as aggregates or mineral additives in concrete manufacturing. Recent studies have concentrated on improving the characteristics of recycled aggregate concrete by incorporating various supplementary materials. Some research suggests that incorporating recycled aggregates ranging from 30 to 50% can achieve strength levels comparable to those of natural aggregate concrete, particularly when combined with supplementary cementitious materials [10]-[16]. Nevertheless, further initiatives are required to establish

---

Received: 25 May 2024; Revised: 21 June 2024;
Accepted: 5 July 2024
*Correspondence: safi_b73@univ-boumerdes.dz

standards and effectively manage the challenges posed by hydrated cement paste adhering to the surface of crushed coarse aggregate in a cost-effective manner. Despite the potential of recycled aggregates (RA), their usage is constrained by the lack of structural standards for RA, limiting their application as substitutes for naturally sourced materials. The adoption of construction and demolition waste (CDW) materials as substitutes for natural aggregates has become a priority within the circular economy framework. Globally, the production of fresh concrete consumes about 20 billion tons of natural resources annually, a figure expected to triple over the next 20 to 30 years. However, the demolition of existing buildings generates a significant amount of solid waste, comprising 20 to 40% of total waste and posing a major environmental hazard. RA offers a sustainable solution to resource exploitation, land-space restoration and landfill waste reduction.

By replacing 5 to 30% of the mass of cement in mortar samples, researchers found that an optimal amount of recycled brick powder (RBP) could actually improve the mechanical properties of the mortar without significantly impacting its durability. Similarly, Li et al. explored the use of recycled concrete powder (RCP) as a substitute for 10 to 30% of the cement, yielding results comparable to those achieved with RBP. Nevertheless, some studies have suggested that using RCP/RBP as a partial substitute for cement could negatively impact the workability or compressive strength of the mortar/concrete mixtures. This decrease in workability or compressive strength becomes more pronounced, especially when RCP/RBP replaces more than 30% of the cement.

Past studies have shown that the effectiveness of mortar/concrete may drastically reduce when the quantity of construction and demolition waste (CDW) powder surpasses a specific limit [17]-[18]. Hence, when assessing the cost and carbon emissions associated with mortar/concrete when utilizing recycled concrete powder (RCP) or recycled brick powder (RBP), it is crucial to consider alterations in strength and additional properties like durability simultaneously. Several researchers have acknowledged this necessity and undertaken initial explorations in this regard.

In terms of environmental sustainability, incorporating demolition waste into concrete reduces the need for landfill space, alleviates the burden on natural resources by reducing the demand for virgin materials and mitigates carbon emissions associated with traditional concrete production. On the other hand, in order to preserve resources, an alternative must be sought. Fine concrete demolition wastes, when processed and utilized effectively, offer a sustainable alternative to traditional supplementary cementitious materials like fly ash and slag. This helps conserve natural resources and reduces the environmental impact of concrete production. Furthermore, to improve performance, properly processed demolition wastes can improve certain properties of concrete such as durability, workability and long-term strength. However, the effects may vary depending on factors like the composition and characteristics of the waste material as well as the concrete mix design.

The use of demolition wastes as supplementary cementitious materials (SCM) in concrete shows promise but presents several challenges. These include variability in material quality and composition, potential contaminants as well as the need for effective processing methods to ensure consistency and compatibility with concrete. Compliance with construction material regulations and standards through rigorous testing is crucial to ensure performance and safety. While incorporating demolition wastes as SCM can reduce costs compared to traditional materials, economic viability depends on waste availability, processing, logistics and the market demand for sustainable materials. Further research is necessary to optimize the use of fine concrete demolition wastes, address technical hurdles and establish guidelines for their integration into construction projects. Overall, utilizing these wastes could potentially enhance sustainability, performance and cost-effectiveness in construction assuming the careful management of processing, quality control, regulations and economic factors.

Our study aims to evaluate the influence of adding finely crushed concrete demolition waste on the physico-mechanical properties of concrete. The study investigates both the physical properties of the matrix and the concrete because it is too laborious to determine physical properties by only focusing on specific attributes (such as density, setting time, workability and air void content) as well as on the main mechanical properties (compressive strength). For this purpose, concrete mixtures have been studied by using concrete demolition wastes (CDW) as supplementary cementitious materials as a partial substitute for cement (0, 2.5, 5, 7.5, 10, 12.5, 15 and 20% by the weight of the cement) and as a mineral additive without substituting for cement (0, 2.5, 5, 7.5, 10, 12.5, 15 and 20% by the weight of the cement).

2. Experimental study

2.1. Materials used

Our study focuses on an ordinary concrete containing the components (cement, aggregates, mixing water and additives) used for construction with an envisaged compressive strength of 30 MPa using locally sourced materials (*Figures 1* and *2*). CEM II 42,5 Portland cement was used in this study in conformity with the European standards (EN). The chemical, physical, mineralogical and mechanical properties of this cement are given in *Table 1*. The fine aggregate used was a river sand. The coarse aggregates used are gravels of class 8/15, the characteristics of which are given in *Table 2*. The grain distribution of all the aggregates used is given in *Figure 3*.

Table 1: Characteristics of the Portland cement used

	Portland Cement (PC)
Chemical composition [%]	
SiO_2	22.97
Al_2O_3	5.76
Fe_2O_3	4.36
CaO	58.43
MgO	2.03
$K_2O + Na_2O$	1.11
SO_3	2.64
Mineralogical composition [%]	
C_3S	53
C_2S	27
C_3A	05
C_4AF	13
CaO_{free}	02
Physical Properties	
Specific surface area (cm^2/g)	3510
Density (specific gravity)	3.12
Setting times (Initial - Final) (min)	155-212
Mechanical Properties [MPa]	
Compressive strength after 2 days	17.20
Compressive strength after 28 days	40.60

Table 2: Physical properties of the aggregates

	Natural sand	Coarse aggregates G8/15
Apparent density (kg/m^3)	1450	1400
Absolute Density (kg/m^3)	2760	2560
Fineness modulus	3.20	2.47
Sand equivalent (%)	85	-

Table 3: Control concrete composition

Component [kg/m^3]	Portland Cement	Natural Sand	Gravel 8/15	Water
Control Concrete	400	761	1006	190

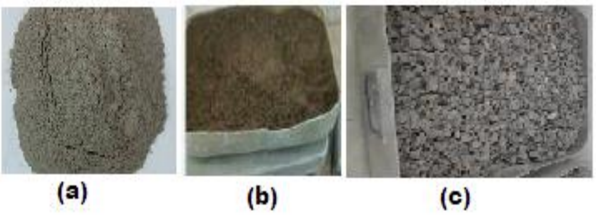

Figure 1: Materials used: (a) cement, (b) natural sand, (c) gravels

Figure 2: Concrete demolition wastes (CDW): (a) preparation zone, (b) CDW crushed finely

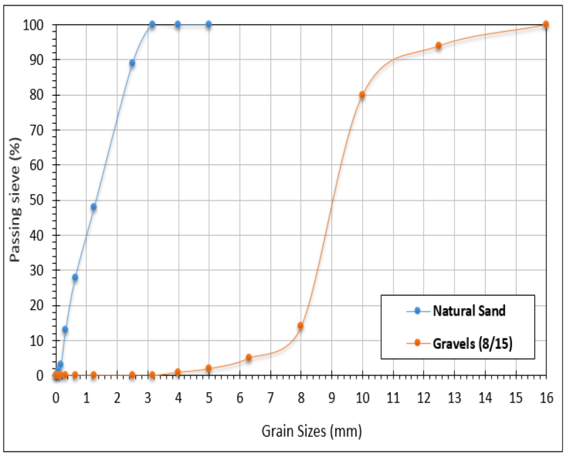

Figure 3: Particle size distribution of aggregates (sand and gravel)

2.2. Mix proportions of the studied concretes

The formulation of the concrete was determined using the Dreux-Gorisse method which offers a simple and rapid approach to obtain a composition with minimal variations to the studied concrete by taking into account the compressive strength and workability required for each type of construction. For our study, the compressive strength was fixed at 30 MPa using a plastic concrete.

The mix details of the control concrete are shown in Table 3. Other variants were obtained using Concrete Demolition Waste (CDW) as a supplementary cementitious material by partially substituting for cement (0, 2.5, 5, 7.5, 10, 12.5, 15 and 20% by the weight of the cement) and by adding CDW as a mineral additive without substituting for cement (0, 2.5, 5, 7.5, 10, 12.5, 15 and 20% by the weight of the cement). All the concrete mixtures of the studied cases are presented in Tables 4 and 5. The mixing method was kept constant for all mixtures of mortar.

All the mixtures were prepared in a concrete mixer. The waste was first mixed and homogenized with the cement. The aggregates (gravel and sand) were then introduced into the mixer, followed by the mixture of cement and waste. The entire mixture was mixed until it had become completely homogenized and dry. Subsequently, water was gradually added to the mixture and mixed until completely homogenized to obtain the concrete. For all formulations, tests on fresh concrete were conducted before being placed in the molds using a vibrator. Cylindrical specimens with the dimensions of 32 diameters and 16 heights (32Φ16) were prepared and placed in the curing tank according to the ENV standard. Demolding was performed after 24 hours of mixing. Mechanical tests were conducted after 3, 7 and 28 days of laboratory curing at 23°C.

Table 4: Mixture details of the studied concretes by substituting cement with concrete demolition waste (CDW)

Mix	CDW	PC	NS	G8/15	W
0 %	00	400	761	1006	190
2.5 %	10	390	761	1006	190
5 %	20	380	761	1006	190
7.5 %	30	370	761	1006	190
10 %	40	360	761	1006	190
12.5	50	350	761	1006	190
15 %	60	340	761	1006	190
20 %	80	320	761	1006	190

Table 5: Mixture details of the studied concretes by adding CDW (without substituting for cement)

Mix	CDW	PC	NS	G8/15	W
0 %	00	400	761	1006	190
2.5 %	10	400	761	1006	190
5 %	20	400	761	1006	190
7.5 %	30	400	761	1006	190
10 %	40	400	761	1006	190
12.5	50	400	761	1006	190
15 %	60	400	761	1006	190
20 %	80	400	761	1006	190

2.3. Preparation, curing of samples and test methods

Workability

The concrete slump test evaluates the viscosity of freshly mixed concrete prior to its hardening to assess the workability of newly prepared concrete, thereby determining its flowability. This workability test was carried out using a metal mold in the shape of a conical frustum known as a slump cone or Abrams cone (*Figure 4*) that is open at both ends and has attached handles (see *Figure 4a*). The workability of concrete can be measured using the following steps (*Figures 4b* and *4c*) by filling the cone in three layers packed with a pointed steel rod 16 mm in diameter at a rate of 25 strokes per layer before carefully lifting the mold and measuring the sag in cm.

Bulk density

The density of the hardened concrete was determined either by simple dimensional checks followed by weighing and calculating or by weight in air/water buoyancy methods. In this work, the density of hardened concrete specimens (cylindrical specimens 32Φ16) was measured by calculating the ratio of weight to volume of each specimen (*Figure 5*).

Air content

The air content measurement evaluates the amount of occluded air in the fresh concrete. The test is based on the compressibility of air bubbles contained in the fresh concrete. The standard device presented in *Figure 4* was made out of a 1 liter container in which mortar was placed in two layers and compacted by simply tamping it (the air content in the concrete is shown in *Figure 6*). The device directly measures the air content as a percentage.

Ultrasonic Pulse Velocity test

The Ultrasonic Pulse Velocity (UPV) test employs a non-

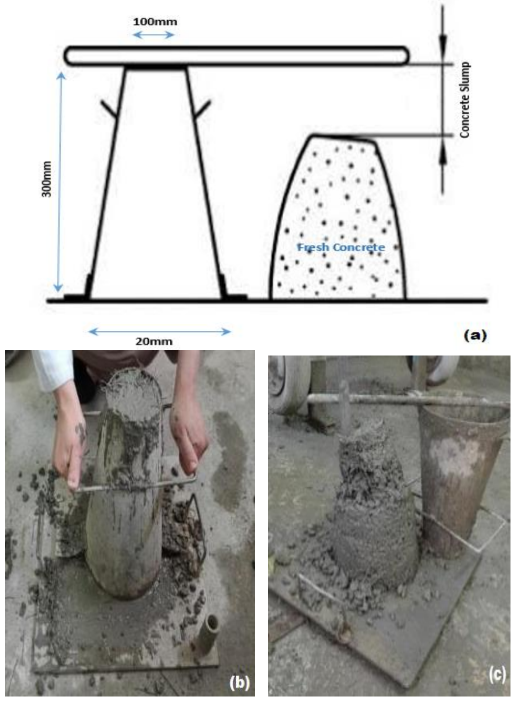

Figure 4: Concrete workability: (a) Abrams Cone and slump test, (b) Workability testing, (c) measuring concrete slump

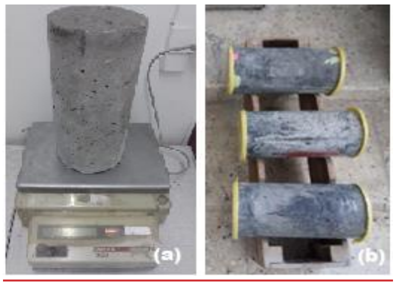

Figure 5: Concrete samples: (a) bulk density measurement, (b) cylindrical samples prepared for mechanical testing

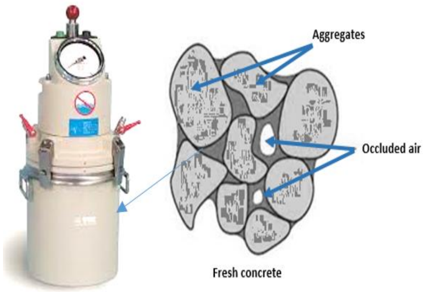

Figure 6: Air content measurement of the concrete (occluded air)

Table 6: Fresh characteristics of the studied concretes

	Mix	Occluded air (%)	Workability (cm)	Vibration time (s)
Concretes by substituting cement with CDW	0 %	2.1	0.5	40
	2.5 %	2.2	0.5	45
	5 %	2.2	1.0	39
	7.5 %	2.1	1.0	37
	10 %	1.2	1.0	35
	12.5	1.5	0.5	45
	15 %	1.5	0.5	48
	20 %	1.5	0.5	42
Concretes by adding CDW	0 %	2.1	0.5	40
	2.5 %	2.1	0.5	45
	5 %	2.0	1.0	36
	7.5 %	1.5	1.2	34
	10 %	1.2	1.5	33
	12.5	1.2	0.5	40
	15 %	1.0	0.5	42
	20 %	1,0	0,5	45

Figure 7: Ultrasonic Pulse Velocity test: (a) UPV device, (b) UPV testing of concrete sample

Figure 8: Mechanical testing: (a) Cylindrical specimens (32Φ16), (b) Uniaxial compressive strength tests

destructive approach, enabling the assessment of concrete structures without inducing any harm or disturbance. This method is invaluable for identifying defects as well as evaluating the general quality and uniformity of concrete materials. The method involves measuring the travel time of acoustic waves in a medium and correlating it with the elastic properties and density of the material. The travel time of ultrasonic waves reflects the internal state of the test zone. The test is commonly performed using transducers positioned at opposing ends of the concrete element under scrutiny, a setup referred to as through-transmission or direct configuration (*Figure 7*). The concrete compactness was estimated by measuring the speed of sound through concrete 28 days after curing.

Compressive strength

Compressive strength tests were carried out in accordance with ASTM C192/C192M [24]. Cylindrical specimens (32Φ16) for each mixture were stored one day after casting in water at 21±1°C (*Figure 8*). All uniaxial compressive strength tests were carried out 3, 7 and 28 days after hardening began.

3. Results and discussion

The main objective of our study was economic and technical by recycling as well as using concrete demolition waste (CDW). In order to determine the influence of the incorporation of CDW on the characteristics of concrete, the aim was to study the effect of using concrete demolition wastes (CDW) as a mineral additive on the fresh and hardened properties of concrete. The various results of the physico-mechanical tests on CDW-based concretes are presented in *Tables 6* and *7*.

3.1. Use of CDW by partially substituting for cement

a) Fresh properties: workability and content of occluded air

The fresh characteristics of the concretes studied based on concrete demolition wastes (CDW) are given in *Figures 9* and *10*. According to the obtained results, the following finding is observed.

A slight increase in the workability of the concrete was recorded when between 5 and 10% of the concrete was replaced (*Figure 9*). From a waste content of 12% upwards, an increase in the slump flow was recorded according to the Abrams cone test, which could be attributed to the fineness of the waste, thereby increasing the slump flow, and the presence of small hydrated grains.

When up to 7.5% of the cement was substituted by waste, no effect on the air void content of fresh concrete was noted. Beyond 10%, a slight decrease in this property was observed (*Figure 10*). This suggests that the CDW can fill voids.

b) Hardened properties: bulk density and compressive strength

The obtained results of the hardened characteristics, that is, bulk density and compressive strength, are given in *Table 7* and presented in *Figures 11* and *12*. It should be noted that: A slight increase of approximately 2.5% was

Table 7: Hardened characteristics of the studied concretes

	Mix	Bulk Density (kg/m^3)	UPV (m/s)	Compressive Strength (MPa)		
				3d	7d	28d
Concretes with cement substitution by CDW	0 %	2348	4413	13.44	27.25	32.00
	2.5 %	2364	4429	13.27	27.18	31.60
	5 %	2364	4442	12.13	25.82	30.03
	7.5 %	2379	4452	11.69	23.94	27.84
	10 %	2380	4456	11.04	22.52	26.19
	12.5	2379	4461	7.37	15.08	17.54
	15 %	2368	4461	7.31	14.96	17.40
	20 %	2365	4457	6.72	13.75	16.00
Concretes by CDW adding	0 %	2348	4413	13.44	27.25	32.00
	2.5 %	2400	4455	13.65	27.95	32.50
	5 %	2400	4450	14.58	29.80	34.60
	7.5 %	2400	4492	14.30	29.33	34.10
	10 %	2350	4468	15.18	31.00	36.20
	12.5	2400	4470	13.90	28.55	33.20
	15 %	2400	4487	12.60	25.80	30.00
	20 %	2400	4466	12.00	24.60	28.00

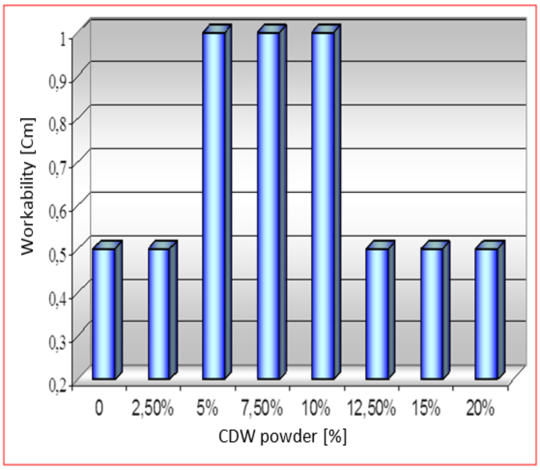

Figure 9: Workability of the studied concretes when cement was substituted by CDW

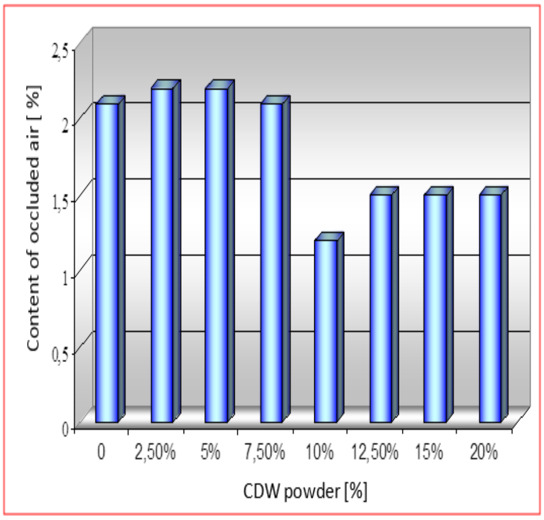

Figure 10: Content of occluded air of the studied concretes when cement was substituted by CDW

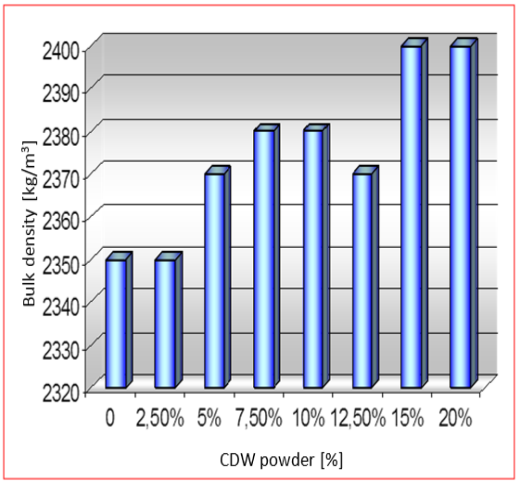

Figure 11: Bulk density of the studied concretes when cement was substituted by CDW

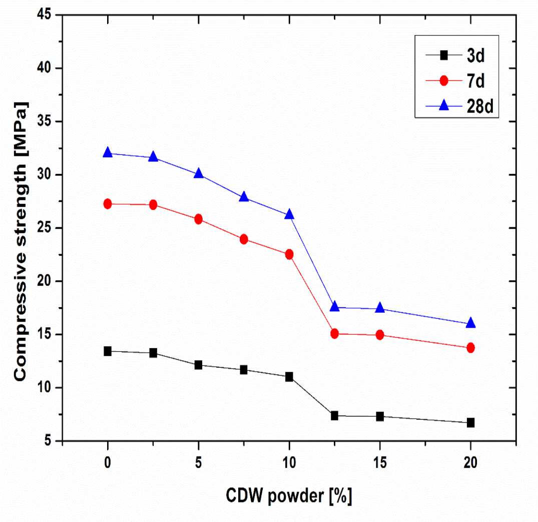

Figure 12: Change in the compressive strength of the studied concretes when cement was substituted by CDW

observed in the density of concrete made with recycled waste (crushed concrete waste) compared to the control concrete as the proportion of waste increased. However, this increase was not significant because the fineness and specific mass of the waste closely resembles that of cement (*Figure 11*).

The change in the compressive strength of concrete over time is highlighted. Indeed, the strength of concrete is determined by the strength of cement (the product of mineral hydration from clinker). It is clear from the curve in *Figure 12* that the compressive strength of concrete increased over 28 days of curing. However, a very slight reduction in compressive strength was noted, followed by a considerable and remarkable reduction when more than 10% of the cement was substituted by waste (*Figure 12*).

This is explained by the substitution of some cement with waste, resulting in a decrease in the production of CSH (calcium silicate hydrate), which determines its strength. However, the variations in strength are significant when the waste content exceeds 10%, [20], maybe because the waste contains grains of CSH. These grains act as nuclei during cement hydration and trigger direct crystallization of CSH from cement.

3.2. Adding CDW as a mineral additive

a) Fresh properties: workability and the content of occluded air

Regarding the use of CDW as a mineral additive without substitution for cement in concrete, the results of tests on samples of fresh concrete are given in *Figures 13* and *14*. It was noted that:

The addition of waste without substituting for cement improves the workability of these concrete mixes compared to the control concrete. An increase in slump as the rate at which waste is added increases is shown in *Figure 13*.

The filling of voids by the waste is also reflected in the reduction in the occluded air content (*Figure 14*), which is evident in the mixes prepared by adding waste [19-20,26].

b) Hardened properties: bulk density and compressive strength

The obtained results of the hardened characteristics, that is, bulk density and compressive strength, are given in *Figures 15* and *16*. It should be noted that:

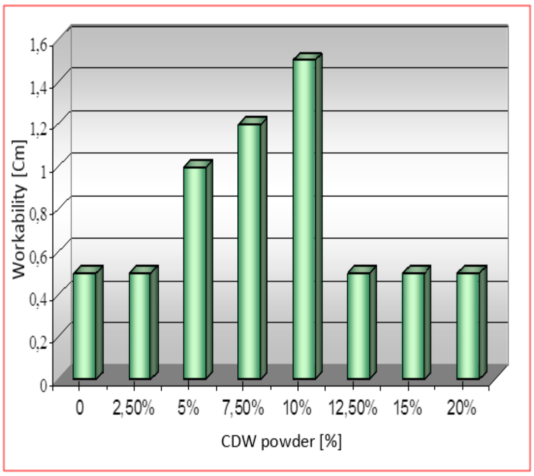

Figure 13: Workability of the occluded air of the studied concretes when CDW was added without substituting for cement

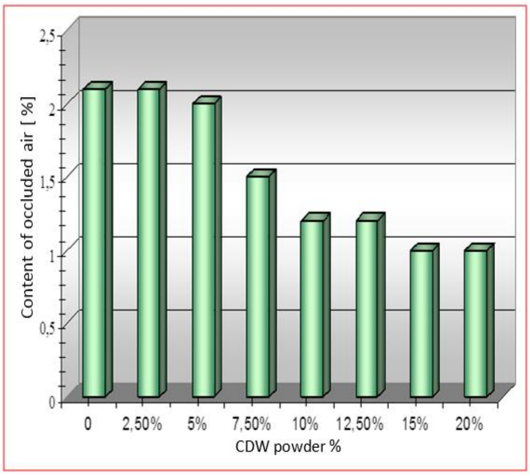

Figure 14: Content of occluded air of the studied concretes when CDW was added without substituting for cement

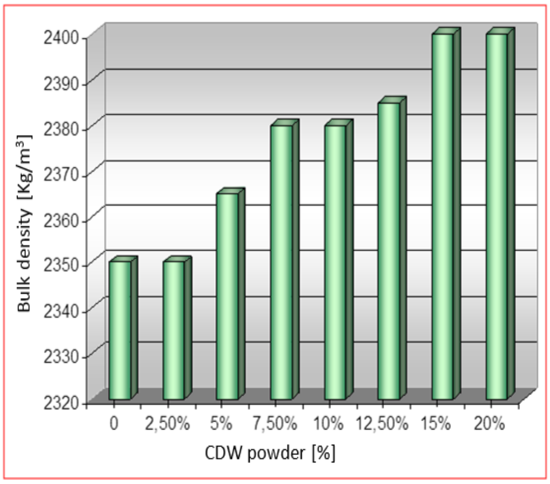

Figure 15: Bulk density of the studied concretes when CDW was added without substituting for cement

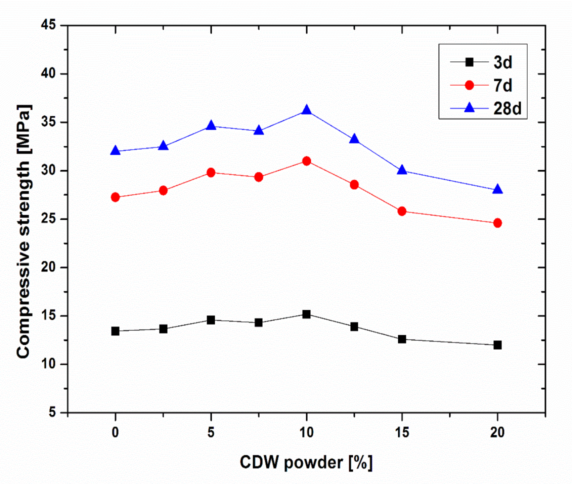

Figure 16: Compressive strength of the studied concretes when CDW was added without substituting for cement

A significant increase in the bulk density of concrete prepared by adding waste was observed. It is evident that the waste occupied and filled voids, thereby increasing the degree of matrix filling in the concrete (*Figure 15*).

Regarding the concretes prepared with a waste content of 10% without substituting for cement, a significant improvement in compressive strength of approximately 20% up to a waste content of 20% was observed as shown in *Figure 16*. It is noteworthy that the latter increased the compactness of the concrete in addition to the presence of unhydrated clinker grains. These grains contribute to the formation of CSH, thereby increasing the strength of the concrete [20,26-27].

3.3. Ultrasonic Pulse Velocity test

The curve depicted in *Figure 17* illustrates the change in the speed of sound through the concrete as a function of the rate at which waste was added. It is evident that the velocity of sound increases as the waste content increases. However, it is noteworthy that the velocity of sound of the hardened concrete made with waste was higher than that made by substituting cement with waste. It is clear here that the addition of waste increases the compactness of the concrete by filling voids, resulting in a reduced travel time. It is worth noting that the velocity is higher when the concrete is denser [19-20,26].

4. Conclusions

Our study focused firstly on the possibility of recycling and reusing concrete demolition waste as an active additive in concrete. Currently, this waste is used as aggregates for concrete in France but concrete made with rubble has shown inferior properties compared to regular concrete.

Secondly, our aim was to improve the physico-mechanical properties of concrete by incorporating finely crushed waste concrete. Through this work and the results obtained, the following conclusions were drawn:

Adding up to 10% of waste as a partial substitute for cement significantly improved physical properties such as the occluded air content and workability of fresh concrete, indicating that waste can partially replace cement, thereby reducing binder consumption. However, this waste degraded the mechanical properties of hardened concrete to some extent. Nonetheless, the compressive strength of concrete obtained with a waste content of 10% and even up to approximately 13% is satisfactory for building applications, surpassing the required standards.

Adding 10% of waste to the concrete mix as an active additive noticeably enhanced both the fresh and hardened properties of concrete. Because the waste is very fine and possesses physical properties like specific mass and surface area similar to those of cement, it fills the voids previously occupied by air, reducing the occluded air content and consequently increasing the density and compactness of fresh concrete. This increase in compactness is also observed in hardened concrete, as indicated by the increased speed of sound as the rate at which waste is added rises. Additionally, the compressive strength of concrete is improved by 20% by adding 10% of waste compared to the control concrete. This improvement is attributed to the interaction between concrete demolition waste and cement. Since the waste is very fine and contains unhydrated clinker grains, these grains hydrate and form CSH, strengthening the concrete structure.

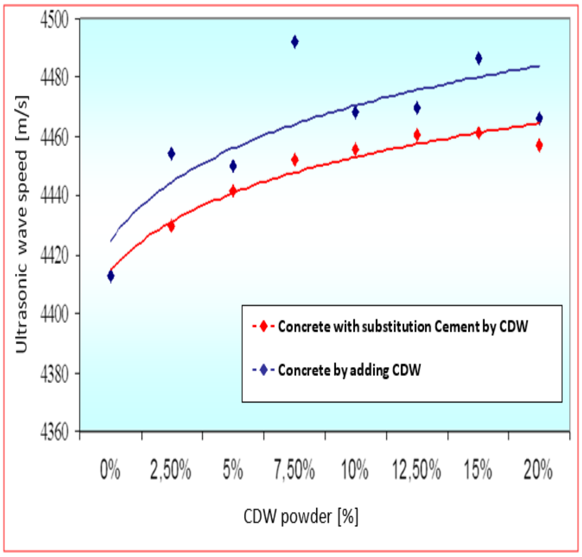

Figure 17: Change in the compactness of concrete estimated by the speed of sound

REFERENCES

[1] Hong, J.; Shen, G.Q.; Feng, Y.; Lau, W.S.-t.; Mao, C.: Greenhouse gas emissions during the construction phase of a building: a case study in China, *J. Clean. Prod.*, 2015, **103**, 249–259, DOI: 10.1016/j.jclepro.2014.11.023

[2] Tóth, E.; Bobek-Nagy, J.; Kurdi, R.: Investigation of regional differences in the organic fraction of municipal solid waste in Hungary, *Hung. J. Ind. Chem.*, 2023, **51**(1), 61–66, DOI: 10.33927/hjic-2023-09

[3] García-Segura, T.; Yepes, V.; Alcalá, J.: Life cycle greenhouse gas emissions of blended cement concrete including carbonation and durability, *Int. J. Life Cycle Assess.*, 2014, **19**(1), 3–12, DOI: 10.1007/s11367-013-0614-0

[4] Belaid, A.; Khaled, S.; Brahim, H.; Salim, K.; Brahim, S.; Mesrati, N.: Effect of metakaolin as partially cement replacement on the compressive strength of standard mortars, *Rom. J. Civ. Eng.*, 2021, **12**(2), 268–280, DOI: 10.37789/rjce.2021.12.2.6

[5] Fan, C.; Miller, S.A.: Reducing greenhouse gas emissions for prescribed concrete compressive strength, *Constr. Build. Mater.*, 2018, **167**, 918–928, DOI: 10.1016/j.conbuildmat.2018.02.092

[6] Sandanayake, M.; Lokuge, W.; Zhang, G.; Setunge, S.; Thushar, Q.: Greenhouse gas emissions during timber and concrete building construction - A scenario based comparative case study, *Sustain. Cities Soc.*, 2018, **38**, 91–97, DOI: 10.1016/j.scs.2017.12.017

[7] Huang, B.; Chen, Y.; McDowall, W.; Türkeli, S.; Bleischwitz, R.; Geng, Y.: Embodied GHG emissions of building materials in Shanghai, *J. Clean. Prod.*, 2019, **210**, 777–785, DOI: 10.1016/j.jclepro.2018.11.030

[8] Silva, R.V.; De Brito, J.; Dhir, R.K.: Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production, *Constr. Build. Mater.*, 2014, **65**, 201–217, DOI: 10.1016/j.conbuildmat.2014.04.117

[9] Rezaiee-Pajand, M.; Abad, J.M.N.; Karimipour, A.; Rezaiee-Pajand, A.: Propose new implement models to determine the compressive, tensile and flexural strengths of recycled coarse aggregate concrete via imperialist competitive algorithm, *J. Build. Eng.*, 2021, **40**, 102337, DOI: 10.1016/j.jobe.2021.102337

[10] Chen, S.-C.; Zou, S.-Y.; Hsu, H.-M.: Effects of recycled fine aggregates and inorganic crystalline materials on the strength and pore structures of cement-based composites, *Crystals*, 2021, **11**(6), 587, DOI: 10.3390/cryst11060587

[11] Joseph, H.S.; Pachiappan, T.; Avudaiappan, S.; Flores, E.I.S.: A study on mechanical and microstructural characteristics of concrete using recycled aggregate, *Materials*, 2022, **15**(21), 7535, DOI: 10.3390/ma15217535

[12] Ju, H.; Yerzhanov, M.; Serik, A.; Lee, D.; Kim, J.R.: Statistical and reliability study on shear strength of recycled coarse aggregate reinforced concrete beams, *Materials*, 2021, **14**(12), 3321, DOI: 10.3390/ma14123321

[13] Jian, S.-M.; Wu, B.: Compressive behavior of compound concrete containing demolished concrete lumps and recycled aggregate concrete, *Constr. Build. Mater.*, 2021, **272**, 121624, DOI: 10.1016/j.conbuildmat.2020.121624

[14] Ahmed, H.; Tiznobaik, M.; Huda, S.B.; Islam, M.S.; Alam, M.S.: Recycled aggregate concrete from large-scale production to sustainable field application, *Constr. Build. Mater.*, 2020, **262**, 119979, DOI: 10.1016/j.conbuildmat.2020.119979

[15] Makul, N.; Fediuk, R.; Amran, M.; Zeyad, A.M.; Murali, G.; Vatin, N.; Klyuev, S.; Ozbakkaloglu, T.; Vasilev, Y.: Use of recycled concrete aggregates in production of green cement-based concrete composites: A review, *Crystals*, 2021, **11**(3), 232, DOI: 10.3390/cryst11030232

[16] Ariyachandra, E.; Peethamparan, S.; Patel, S.; Orlov, A.: Effect of NO_2 sequestered recycled concrete aggregate (NRCA) on mechanical and durability performance of concrete, *Cem. Concr. Res.*, 2020, **137**, 106210, DOI: 10.1016/j.cemconres.2020.106210

[17] Xiao, J.; Ma, Z.; Sui, T.; Akbarnezhad, A.; Duan, Z.: Mechanical properties of concrete mixed with recycled powder produced from construction and demolition waste, *J. Clean. Prod.*, 2018, **188**, 720–731, DOI: 10.1016/j.jclepro.2018.03.277

[18] Wang, X.; Yang, X.; Ren, J.; Han, N.; Xing, F.: A novel treatment method for recycled aggregate and the mechanical properties of recycled aggregate concrete, *J. Mater. Res. Technol.*, 2021, **10**, 1389–1401, DOI: 10.1016/j.jmrt.2020.12.095

[19] Liu, Q.; Tong, T.; Liu, S.; Yang, D.; Yu, Q.: Investigation of using hybrid recycled powder from demolished concrete solids and clay bricks as a pozzolanic supplement for cement, *Constr. Build. Mater.*, 2014, **73**, 754–763, DOI: 10.1016/j.conbuildmat.2014.09.066

[20] Wu, H.; Yang, D.; Ma, Z.: Micro-structure, mechanical and transport properties of cementitious materials with high-volume waste concrete powder and thermal modification, *Constr. Build. Mater.*, 2021, **313**, 125477, DOI: 10.1016/j.conbuildmat.2021.125477

[21] Kim, Y.J.; Choi, Y.W.: Utilization of waste concrete powder as a substitution material for cement, *Constr. Build. Mater.*, 2012, **30**, 500–504, DOI: 10.1016/j.conbuildmat.2011.11.042

[22] Kumar, G.S.: Synergetic effect of a chemical activator and blast-furnace slag on enhancing recycled aggregate mortar, *Mag. Concr. Res.*, 2020, **72**(9), 471–485, DOI: 10.1680/jmacr.19.00280

[23] Saidi, M.; Ait-Medjber, F.; Safi, B.; Samar, M.: Recycling of aggregates from construction demolition wastes in concrete: Study of physical and mechanical properties, *Int. J. Archit. Civ. Constr. Sci.*, 2014, **8**(12), 1307–1311

[24] Kumar, S.; Saini, P.K.; Karade, S.R.: Impact of mixing approaches on properties of recycled aggregate mortar, *ACI Mater. J.*, 2020, **117**(6), 201–214, DOI: 10.14359/51728129

[25] Bao, J.; Li, S.; Zhang, P.; Ding, X.; Xue, S.; Cui, Y.; Zhao, T.: Influence of the incorporation of recycled coarse aggregate on water absorption and chloride penetration into concrete, *Constr. Build. Mater.*, 2020, **239**, 117845, DOI: 10.1016/j.conbuildmat.2019.117845

[26] Rattanachu, P.; Toolkasikorn, P.; Tangchirapat, W.; Chindaprasirt, P.; Jaturapitakkul, C.: Performance of recycled aggregate concrete with rice husk ash as cement binder, *Cem. Concr. Compos.*, 2020, **108**, 103533, DOI: 10.1016/j.cemconcomp.2020.103533

[27] Tang, Q.; Ma, Z.; Wu, H.; Wang, W.: The utilization of eco-friendly recycled powder from concrete and brick waste in new concrete: A critical review, *Cem. Concr. Compos.*, 2020, **114**, 103807, DOI: 10.1016/j.cemconcomp.2020.103807