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Mechanical, physical and environmental performance of sustainable concrete containing marble wastes

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Abstract. Background: Today, Construction and Demolition Wastes (CDW) are undoubtedly the most studied materials in sustainable construction. **Objective:** This paper examines the effect of Recycled Marble Aggregates (RMA) on the mechanical, physical and environmental performance of concrete. In this context, natural aggregates (fine, coarse or both) were totally replaced (100%) with RMA. **Method:** The paper discussed some mechanical and physical parameters of the hardened concrete, such as Ultrasonic Pulse Velocity (UPV), Dynamic Elastic Modulus (E_{dy}), Density (D) and Compressive Strength (f_S) after 14 and 28 days of water curing. Additionally, the environmental impacts including global warming (GWP), acidification (AP), eutrophication (EP) and photochemical oxidant formation (POCP) of concrete with and without RMA were assessed. **Result:** Replacement of RMA causes a decrease in f_S and E_{dy} of all mixtures and its effect on UPV and D was slightly insignificant. **Conclusion:** Despite the performance of concrete made with RMA decreased, this paper shows that the use of RMA in the production of new concrete can lead to a more verdant environment and even pave the way for green concrete. On the other hand, it is recommended to use 100% of RMA in the production of concrete in non-structural elements.

Keywords. Recycled marble, Aggregates, wastes, sustainable construction, environmental impacts.

1. Introduction

It is known that concrete is the most widely used building material in the world due to the availability of its raw materials and ease of manufacture. Aggregates and cement are the main components of concrete that are extracted from nature. Therefore, the unrestricted use of natural resources in the manufacture of concrete is unsustainable from the point of view of preserving the environment. In the past few years, rapid development, the growth of the world's population, wars and natural disasters have caused an increasing amount of construction and demolition waste. This situation is encouraging governments around the world to use green concrete as it enhances sustainable development. Therefore, green concrete is characterized by the recycling of CDW to reduce environmental burdens and save natural resources [1].

2. Literature review

The literature review concentrates on the characteristics of recycled aggregates, properties of concrete containing recycled aggregates and use of RMA in concrete production.

2.1. Characteristics of recycled aggregates

In general, the physical properties of recycled aggregates are inferior to those of natural aggregates. Hachemi and Ounis [2] found that the absolute density of recycled coarse brick (2.22 g/cm^3) is lower than that of natural coarse aggregates (2.6 g/cm^3). Similar results were also noted by Bui et al. [3]. Regarding the water absorption, Khattab [4] found that the water absorption of natural coarse aggregate is about 0.26%, while it is about 7.45% for recycled coarse refractory brick. The author concluded that the high porosity of recycled coarse refractory brick increases its water absorption. Debieb and Kena [5] also found that the water absorption of fine recycled ceramic aggregates (14%) was significantly higher than that of fine natural aggregates (1%). Furthermore, the resistance to fragmentation of recycled aggregates is lower when compared to natural aggregates [6-9]. The inferior quality of the recycled aggregates has an immediate effect on the performance of concrete.

2.2. Performance of concrete containing recycled aggregates

In the literature, many research efforts have focused on the use of recycled aggregates in sustainable concrete in the form of aggregates [10-18]. In fact, these studies found that the concrete produced with recycled aggregates behaves differently from conventional concrete. Concrete made with recycled aggregates is characterized by lower physical and mechanical properties than that conventional concrete [6, 15]. Moreover, the use of high amount of recycled aggregates has a negative effect on the performance of concrete [9, 16]. On the other hand, several researchers found that the recycled aggregates could be used as aggregates with a replacement rate up to 30% in the production of concrete with acceptable properties [17-19].

2.3. Using Marble waste as aggregates

Among the CDW, Recycled Marble Aggregates (RMA) can be used in concrete in the form of aggregates (coarse and fine) or additions (powder) to improve concrete performance. In this regard, about 40% of marble waste is small pieces that are usually dumped in landfills [20].

2.3.1. Using RMA as fine aggregates

Using RMA as fine aggregates, several researchers have found that RMA could be used as fine aggregates in production of concrete [21, 22] and mortars [23, 24]. Vardhan et al. [25] stated that with inclusion of marble waste as fine aggregates, the concrete compressive strength was improved at 20% substitution level, where maximum performance was achieved at 40% substitution level. Gameiro et al. [26] reported that when 20% of natural sand was replaced with marble dust, the durability performance of concrete was improved.

2.3.2. Using RMA as coarse aggregates

Additionally, RMA was used as coarse aggregates. The results obtained by Kore and Vyas [27] indicate that RMA could be used as coarse aggregates to improve the concrete performance. Binici et al. [28] reported that the mixtures prepared with RMA as coarse aggregates had better durability properties. André et al. [29] used RMA as coarse aggregate in concrete in ratios of 0%, 20%, 50% and 100%. The results obtained by the authors illustrated that RMA can be used as coarse aggregates for concrete, without influencing the fundamental properties of concrete. A study by Hebhoub et al. [22] tested replacement ratios of 20%, 50%,75% and 100% of coarse natural aggregates by coarse RMA to determine the compressive and tensile strength of concrete. According to their results, they found that with the use of RMA as a replacement for coarse natural aggregates by up to 75%, the compressive and tensile strength of the mixtures were improved.

3. Research Significance

The use of RMA as coarse and fine aggregate or as a cement replacement for conventional concrete in research investigations has been exponentially growing. However, experimental investigations that examine the combined effect of coarse and fine RMA in concrete production have not been studied in the literature. For this reason, the objective of this work is to reduce the use of coarse and fine natural aggregates and understand the behaviour of sustainable concrete produced with RMA.

3.1. Objectives

The objectives of this study are as follows:

1- To evaluate the influence of total replacement (100%) of natural aggregates (coarse, fine or both) by RMA on mechanical and physical properties of concrete.

2- To evaluate the environmental impacts of the use of RMA in the concrete production in comparison to natural aggregates.

An experimental program was defined that included the characterization of hardened properties of concrete produced with 100% of RMA including density, UPV, dynamic elastic modulus and compressive strength. Results obtained were compared with conventional concrete made with 100% of coarse and fine natural aggregates. Moreover, the global warming (GWP), acidification (AP), eutrophication (EP) and photochemical oxidant formation (POCP) of concrete containing RMA were evaluated and compared with the conventional concrete.

4. Methodology and experimental details

4.1. Materials employed

4.1.1. Cement

The Portland-Pozzolana cement (CEMI/A-P 42.5 N) was used as a binder for the preparation of all concrete mixes.

4.1.2. Coarse aggregates

In this study two types of coarse aggregates were used, Natural Aggregates (NA) and Recycled Marble Aggregates (RMA). The coarse NA used was white calcareous aggregates with granular class 5/25 mm, while the coarse RMA used in this study was obtained from a marble quarry in Jerash /Jordan, see Figure1. The RMA was crushed in the laboratory using a Los Angeles abrasion machine to obtain 0/25 mm grain fractions. Then, the crushed RMA was sieved to obtain coarse RMA with granular class 5/25 mm (see Figure 2). The standard used and the physical properties of coarse NA and RMA are listed in Table 1.

Figure 1. Marble waste used in this study before crushing.

Figure 2. Coarse RMA after crushing.

Table 1. Physical properties of coarse NA and coarse RMA.

Physical properties	**Abbreviations**	**Standard used**	**Coarse NA**		**Coarse RMA**	
			15/25 mm	**5/15 mm**	**15/25 mm**	**5/15 mm**
Apparent Density (g/cm^3)	D	NF P 18-554 [30]	1.36	1.40	1.35	1.39
Absolute Density (g/cm^3)			2.63	2.61	2.66	2.66
Water Absorption (%)	WA		1.32	1.30	1.35	1.33
Porosity (%)	P		1.91	1.91	1.98	1.98
Los Angeles abrasion (%)	LA	NF P 18-573 [31]	28		31	

4.1.3. Fine aggregates

The fine NA used in this study was calcareous sand with granular class 0/5 mm. On the other hand, the RMA obtained after being crushed using a Los Angeles abrasion machine was sieved to obtain fine RMA with the same granular class of calcareous sand (0/5mm), see Figure 3. The standard used and physical properties of fine NA and RMA are listed in Table 2. The grading curves obtained from coarse and fine NA and RMA are presented in Figure 4.

Figure 3. Fine RMA after crushing.

Table 2. Physical properties of fine NA and fine RMA.

Physical properties	Abbreviations	Standard used	Fine NA	Fine RMA
			0/5 mm	0/5 mm
Apparent Density (g/cm^3)	D	NF P 18-555 [32]	1.61	1.6
Absolute Density (g/cm^3)			2.30	2.70
Water Absorption (%)	WA		1.9	2.00
Sand Equivalent (%)	SE	NF P 18-598 [33]	78.5	90.0
Finesse Modulus	FM	NF P 18-560 [34]	2.60	2.63

It can be observed, from Tables 1 and 2, that the LA of coarse RMA is 10% less compared to coarse NA. Also, coarse RMA used presents slightly higher WA and slightly higher P compared to coarse NA. However, coarse RMA present a higher D compared to coarse NA. In the case of fine aggregates, the fine RMA has a higher D and WA than that of calcareous sand. Moreover, fine RMA has a FM comparable to calcareous sand. However, fine RMA has a higher SE value when compared to calcareous sand.

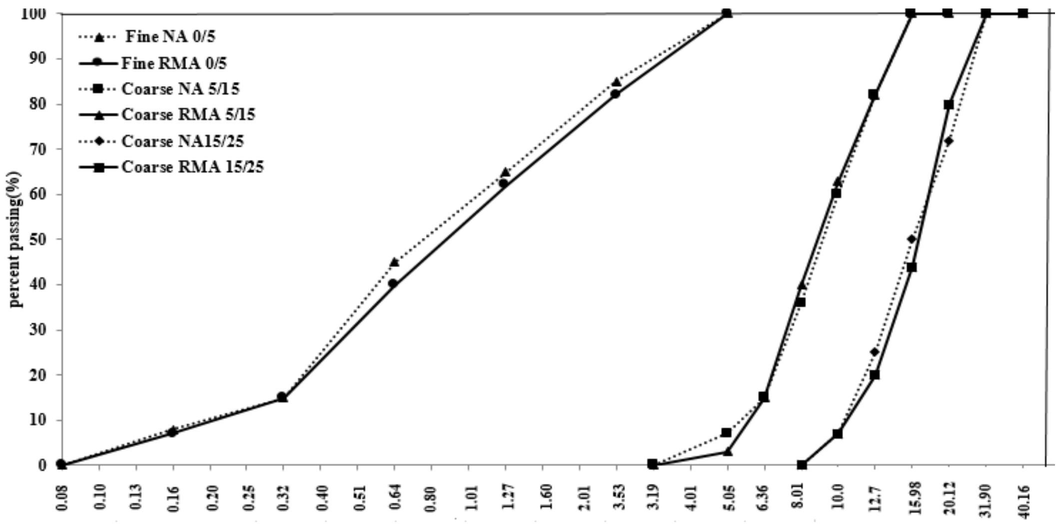

Figure 4. Sieving curves for NA and RMA.

4.2. Mix proportion

4.2.1. Details of concrete

Four concrete mixtures were developed as a part of this research programme in two separate families: For the first family, conventional concrete (which considered as reference concrete RC), the one control mixture with cement dosage of 370 kg/m^3 (w/c=0.5) was made only of 100% coarse and fine NA. RC formulation was determined according to Dreux and Festa method [35]. For the second family, three concrete mixtures (CRMA, FRMA and CFRMA), with the same cement dosage and w/c of RC were prepared by replacing 100% (by weight) of NA (coarse, fine or both) with marble wastes. A summary of these mixtures are summarized below:

_ CRMA concrete mixture was prepared by replacing 100% by weight of coarse NA by coarse RMA.
_ FRMA concrete mixture was prepared by replacing 100% by weight of fine NA by fine RMA.
_ CFRMA concrete mixture was prepared by replacing 100% by weight of coarse and fine NA by coarse and fine RMA.

The mixture proportions of conventional concrete and concrete containing marble wastes are given in Table 3. It should be noted that no kind of chemical admixtures was added in the fabrication of these concretes. Notation: the symbol "C" Coarse, "F" Fine, "CF" Coarse and Fine, "RMA" Recycled Marble Aggregates

4.2.2. Specimens preparation

In this work, six concrete mixtures were poured into cubic steel molds with a size of 100 mm × 100 mm × 100 mm. The concrete samples were kept under water for 14 and 28 days at room temperature (20±2°C).

Table 3. Mix proportions and nomenclature of mixes (kg/m^3).

<table>
<tr><th>Mixtures</th><th>Cement</th><th>Water</th><th>w/c</th><th>Fine NA</th><th>Coarse NA</th><th>Fine RMA</th><th>Coarse RMA</th></tr>
<tr><td>RC</td><td>370</td><td rowspan="4">185</td><td rowspan="4">0.5</td><td>663.12</td><td>960.12</td><td>-</td><td>-</td></tr>
<tr><td>CRMA</td><td>370</td><td>663.12</td><td>-</td><td>-</td><td>960.12</td></tr>
<tr><td>FRMA</td><td>370</td><td>-</td><td>960.12</td><td>663.12</td><td>-</td></tr>
<tr><td>CFRMA</td><td>370</td><td>-</td><td>-</td><td>663.12</td><td>960.12</td></tr>
</table>

4.2.3. Testing procedure

In order to assess the physical and mechanical properties of the concrete produced, the following tests were examined on samples: (a) Density(D); (b) Ultrasonic Pulse Velocity (UPV); (c) Dynamic Elastic Modulus (E_{dy}); (d) Compressive Strength (f_S).

The concrete density was determined through the water saturation method. The concrete density was evaluated on three specimens for each type of concrete mixture according to the NF EN 12390-7 [36]. The concrete density was measured according to the below equation (1):

$$D = \frac{Ms}{Mw - Mw`} \quad (1)$$

Where D is the concrete density, Ms is the dried mass, Mw is the saturated mass Mw' is the immersed mass.

To study the effect of coarse, fine or both RMA on the quality of concrete, the UPV was performed according to AFNOR P18-418 [37]. Moreover, the UPV value was used to measure the Dynamic Elastic Modulus (E_{dy}) according to the ASTM C 597-16 [38]. The E_{dy} was calculated using the below formula (2):

$$Edy = \frac{\rho c^2 \ (1+\upsilon)x(1-2\upsilon)}{(1-\upsilon)} \quad (2)$$

Where E_{dy} is the dynamic elastic modulus of concrete; **ρ** is the dry density; c is the UPV value; υ is the Poisson ratio (taken as υ = 0.2 for concrete [39]; [40]).

To study the effect of coarse, fine or both RMA on the f_S of concrete mixtures, three cubic samples were tested for each type of concrete mixture according to the NF EN 12390-3 [41]. About 24 samples were tested after the 7 and 28-days curing period.

To assess the sustainability of the concretes prepared with RMA in this study, the environmental impact associated with the production of 1 m^3 of concrete was evaluated. Cement and aggregates are the main components for the emission of carbon dioxide in concrete production Devi et al. [42]. For the environmental study, four environmental impact categories were selected in this study, namely global warming (GWP), acidification (AP), eutrophication (EP) and photochemical oxidant formation (POCP). The values of GWP, AP, EP and POCP for each raw material of concrete (cement, natural aggregates and water) were taken from the previous literature [42,43] and mentioned in Table 4. These values are used to calculate the value of environmental impact of concrete by using equation (3).

$$\text{GWP/ AP/ EP/ POCP} = \sum gi \times mi \quad (3)$$

Where g_i is the characterization values of the impact category, m_i is the mass of the concrete ingredients.

It should be noted that the environmental impact categories for RMA were considered null because it is a by-product and does not need any further processing.

Table 4. Characterization value of raw materials for concrete [42,43]

Concrete ingredients	GWP	AP	EP	POCP
	kg CO_2eq	kg SO_2eq	kg PO_4^{-3}	kg C_2H4eq
C	0.898	1.48×10^{-3}	2.211×10^{-4}	1.42×10^{-4}
NA	0.0052	0.011	0.00192	0.000107
W	0.01258	0.000194	0.0006557	0.000209

The symbol "C" Cement, "NA" Natural Aggregates "W" Water

5. Results and discussion

5.1. Density (D)

The effect of recycled marble aggregates on the D of concrete is presented in Figure 5. It can be seen from the figure that the D of all concretes tested at 14 and 28 days decreased when the NA were replaced with RMA. For concrete produced with 100% coarse RMA, the D of CRMA concrete mixture was reduced by about 5% at 14 days and about 6% at 28days compared to reference concrete (RC). However, the inclusion of 100% of fine RMA in concrete results in a higher D compared to concrete prepared with 100% of coarse RMA, which can be explained by the high density of fine RMA (see Table 2). For example, the concrete density is decreased by 3% at 14 and 28 days for FRMA concrete mixture. As seen in Figure 5, the decrease in D of concrete produced with 100% of coarse and fine RMA is negligible. The reduction reached 1% and 2% at 14 and 28 days, respectively. In other words, the combined use of coarse and fine RMA improved concrete density more than the other concrete mixtures (CRMA and FRMA), which could be due to the good consistency between coarse and fine RMA.

5.2. Ultrasonic Pulse Velocity test (UPV)

The UPV test is an important parameter used to know the quality of concrete after incorporating the RMA. Figure 6 shows the UPV of the various mixtures tested at the age of 14 and 28 days. It clearly appears that concretes prepared with RMA (coarse, fine or both) present a lower UPV value then the RC. Generally, this property is more affected by the incorporation of RMA than the density of the concrete, since it may depend more on the quality of aggregates used.

As seen in Figure 6, the decrease in UPV was approximately 19 % and 14% after 7 and 28 days of curing for the CRMA concrete mixture, respectively. Concrete containing 100% of fine RMA had a UPV reduction of about 15% at 14 days and about 11% at 28 days. In the case of CFRMA concrete mixture, a moderate decrease in UPV was observed, it reaches 11% at 14 days and 5% at 28 days. Kore and Vyas [27] found that the interconnectivity of pores in concrete containing RMA is more as compared to that of conventional concrete. Therefore, this interconnectivity of pores increased the time travel in pulse velocity testing.

In spite of the convergence of UPV results, it can be seen in Figure 6 that the CRMA concrete mixture presents the greatest decrease in UPV. This could be due to the high porosity of coarse RMA, which was 4% higher than that of the coarse NA. The results obtained indicate that the quality of concrete produced with RMA (CRMA, FRMA and CFRMA concrete mixtures) can be classified as good (3500 m/s < UPV < 4500 m/s) at the age of 14 and 28 days.

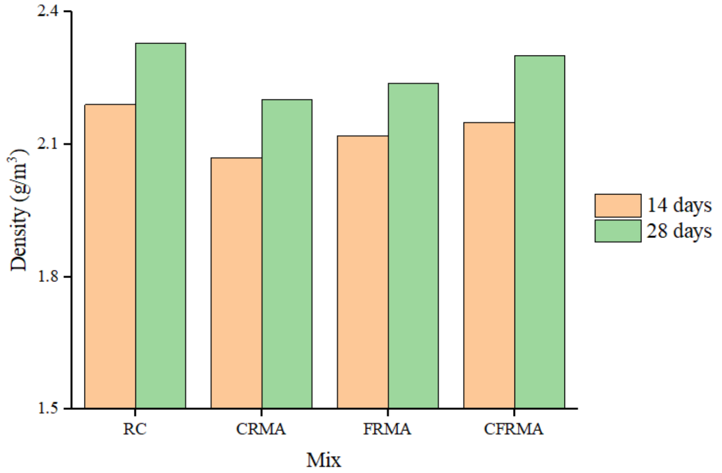

Figure 5. Effects of marble aggregates (coarse, fine or both) on the concrete density.

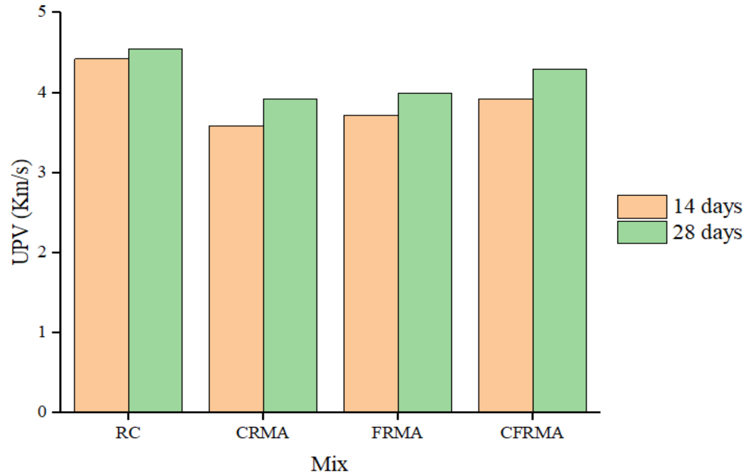

Figure 6. Effects of marble aggregates (coarse, fine or both) on the UPV of concrete.

5.3. Dynamic elastic modulus (E_{dy})

Experimental results of the E_{dy} of the various mixtures tested at the age of 14 and 28 days are presented in Figure 7.

It can be seen from Figure 7 that, regardless of the size fraction of the aggregates replaced, the E_{dy} of concrete produced with RMA (coarse, fine or both) is affected. In addition, Figure 7 shows that the E_{dy} of all specimens is lower than the control specimen (RC). The inclusion of 100% of coarse RMA in concrete leads to a greater decrease in E_{dy} than that of the control specimen (RC), this decrease was about 37% and 29% after 7 and 28 days of curing, respectively.

According to Alves et al. [44], the E_{dy} of concrete is strongly linked to the rigidity of coarse granular. However, the utilization of 100% of fine RMA causes a reduction in E_{dy} of concrete slightly less than that when 100% of coarse RMA was employed. As seen in Figure 7, a drop in E_{dy} of about 29% and 23% was observed for FRMA concrete mixture at the age of 14 and 28 days, respectively, compared to the RC.

On the other hand, in a combination of coarse and fine RMAs, the E_{dy} was enhanced compared to CRMA and FRMA concrete mixtures. Moreover, a slight decrease in E_{dy} is observed for CFRMA concrete mixture compared to RC. A reduction in E_{dy} of about 20% and 10% was registered after 7 and 28 days of curing for the CFRMA concrete mixture, respectively. This improvement in the E_{dy} can be explained by the increase in density and the UPV which were observed in Figure 5 and Figure 6, respectively. The roughness of the surface structure and the shape of RMA in concrete play a significant role in the aggregate-cement interfacial zone [45]. In fact, it was found that coarse and fine RMA had a further angular shape than the coarse and fine NA. Therefore, the improvement of the E_{dy} of concrete mixture made with 100% of coarse and fine RMA may be attributed to the greater adherence between these aggregates and the hydrated cement.

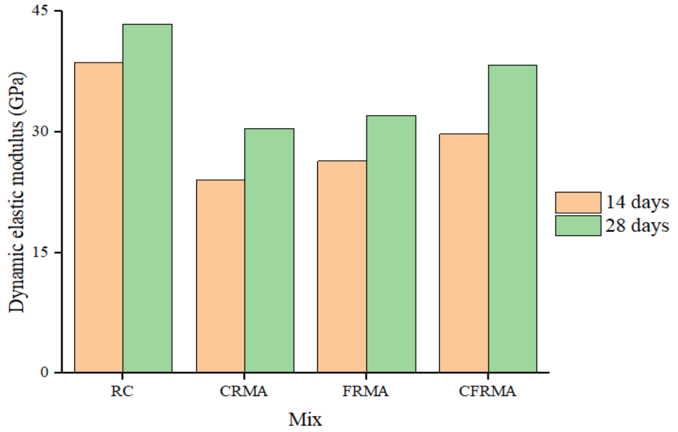

Figure 7. Effects of marble aggregates (coarse, fine or both) on the dynamic elasticity modulus of concrete.

5.4. Compressive strength (f_S)

Figure 8 presents the f_S of the cubic samples tested at 14 and 28 days. It can be seen from the figure that concretes containing RMA (CRMA, FRMA and CFRMA) had a lower f_S value in comparison with RC. The f_S of CRMA, FRMA and CFRMA concretes is affected by the type of RMA used (coarse, fine or both). The lowest f_S strength was measured in the case of CRMA and FRMA concrete mixtures at the age of 14 and 28 days. As seen in Figure 8, the f_S of CRMA concrete mixture, due to the replacement of 100% coarse RMA, declined by 22% and 17% at the age of 14 and 28 days compared to RC, respectively. Moreover, the replacement of 100% of fine RMA in FRMA concrete mixtures has reduced compressive strength by 19% and 13% at the age of 14 and 28 days, respectively. Authors such as Kore and Vyas, [27] and Uygunoğlu et al. [45] found that the main reasons for the reduction in f_S were attributed to the RMA having a flakier shape than natural aggregates, resulting in higher fraction in marble aggregates during mixing. In contrast, the highest f_S of recycled concrete was obtained for the CFRMA concrete mixture (see Figure 8). The results declared that the f_S of the CFRMA concrete mixture, which simultaneously contained coarse and fine RMA, was reduced by about 11% and 9% at the age of 14 and 28 days, respectively.

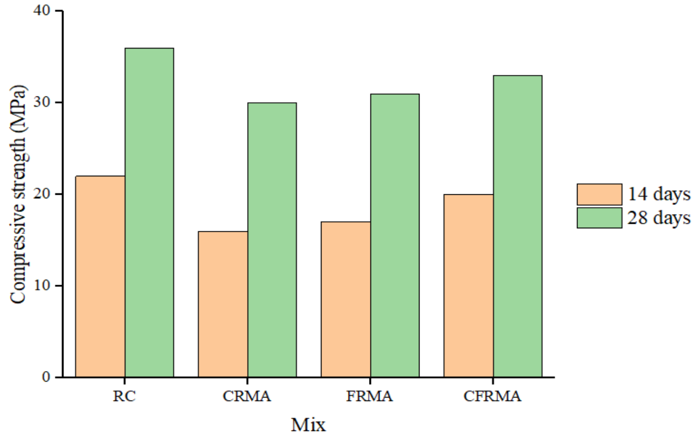

Figure 8. Effects of marble aggregates (coarse, fine or both) on the compressive strength of concrete.

5.5. Environmental Impact Assessment

Table 5 shows the results of the evaluation of the four environmental impacts. As can be seen in Table 5, GWP had the highest contribution to the environmental impact. In other words, the GWP evaluation results for RC was 343.02 (kg CO_2eq). However, a comparison between the mixes with RMA (CRMA, FRMA and CFRMA) and RC showed that the replacement of NA (coarse, fine or both) by 100% of RMA had a lower effect on the GWP. For instance, the GWP of recycled concrete was 338.04 (kg CO_2eq) for CRMA, 339.60 (kg CO_2eq) for FRMA and 334.60 (kg CO_2eq) for

CFRMA. It is clear according to Table 5 that the inclusion of RMA reduced the GWP due to a reduction in aggregate content.

In particular, the AP, EP and POCP of the control mixture were evaluated to be 18.44 (kg SO_2eq), 3.32 (kg $PO4^{-3}$) and 0.26 (kgC_2H_4eq), respectively. However, the AP, EP and POCP evaluation results for CRMA, FRMA and CFRMA concrete mixtures were lower than that of the RC. The AP, EP and POCP evaluation results for CRMA concrete mixture were 7.88 (kg SO_2eq), 1.42 (kg $PO4^{-3}$) and 0.16 (kgC_2H_4eq), respectively. However, in the case of FRMA concrete mixture in which the total of the fine NA was replaced with RMA, the AP, EP and POCP evaluation results were higher than that of the CRMA concrete mixture (see Table 5). On the other hand, a comparison between the mixture of CFRMA and RC showed that the replacement of coarse and fine NA by 100% of RMA had a significant influence on the AP, EP and POCP. For instance, the AP, EP and POCP of mix CFRMA were 0.58 (kg SO_2eq), 0.20 (kg $PO4^{-3}$) and 0.09 (kgC_2H_4eq), respectively.

As a conclusion, the results showed that the replacement of NA (coarse, fine or both) by RMA exerted the greatest impact on AP, EP, and POCP evaluation results. In contrast, the replacement of NA by RMA did not seem to have a significant influence on GWP. Alzard et al., [46] reported similar results in the literature.

Table 5. Environmental impact assessment of different concrete mixes.

	RC	CRMA	FRMA	CFRMA
GWP (KgCO_2eq)	343.02	338.04	340.02	334.60
AP(kg SO_2eq)	18.44	7.88	11.14	0.58
EP(kg $PO4^{-3}$)	3.32	1.48	2.05	0.20
POCP(kgC_2H_4eq)	0.26	0.16	0.19	0.09

6. Conclusions

According to the research carried out in this study, the following results are presented as research achievements:

- The inclusion of RMA as a total replacement for NA in concrete negatively affects its compressive strength. A decrease was from 17% to 22% for the CRMA concrete mixture and from 13% to 19% for the FRMA concrete mixture. Interestingly, the use of 100% of coarse and fine RMA results in decrease in compressive strength of approximately 9% after 28 days of curing.
- The use of RMA as a complete substitute for NA (coarse, fine or both) in concrete mixtures has no significant impact on the concrete density. Here, the decline of concrete density is below 10%, it reaches 6% for concretes containing 100% coarse RMA, 3% for concretes containing 100% fine RMA and 2% for concretes containing 100% coarse and fine RMA after 28 day of curing.
- The E_{dy} of concrete containing RMA is the most affected property. Owing to lower abrasion resistance of RMA, the E_{dy} decrease. Mixes prepared with 100% of coarse RMA has a lower E_{dy} (about 37% and 29% after 14 and 28 days of curing, respectively).
- Concrete containing RMA exhibit adequate quality as structural concrete (3.5 km/s < UPV < 4.5 km/s). The lowest loss of UPV was observed when the coarse and fine NA were replaced with 100% of RMA.
- It can be concluded that concrete made with 100% coarse and fine RMA shows a satisfactory performance compared to conventional concrete.
- The GWP, AP, EP and POCP evaluation results for all the recycled concrete mixtures proportions investigated in this study were lower to those of the reference mixture.
- The substitution of NA (coarse, fine or both) by RMA leads to contributes more intensely to reducing the AP, EP, and POCP.

Finally, it can be concluded that the combined use of RMA may lead to the fact that recycled aggregate is an environmentally friendly material.

Authors Contribution

M. Khattab: Writing – original draft, Investigation, Validation, Methodology, Writing – review & editing. **S. Hachemi:** Conceptualization, Supervision, Validation, Investigation**. O. JARADAT:** Resources, Validation, Investigation. **H. Suleiman:** Writing—review and editing, Data curation, Validation. **Hicham Benzetta:** Resources, Validation

Conflict of Interest

The authors declare no conflict of interest

Abbreviations:

RMA: Recycled Marble Aggregates
NA: Natural Aggregates
CRMA: Concrete made with Coarse Recycled Marble Aggregates.
FRMA: Concrete made with Fine Recycled Marble Aggregates.
CFRMA: Concrete made with Coarse and Fine Recycled Marble Aggregates.
E_{dy}: Dynamic elastic modulus
UPV: Ultrasonic Pulse Velocity
D: Density
$f_{S:}$ compressive strength
GWP: Global Warming.
AP: Acidification.
EP: Eutrophication.
POCP: Photochemical Oxidant Creation.

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