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Use of waste marble aggregates in concrete

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ABSTRACT

Today we are faced with an important consumption and a growing need for aggregates because of the growth in industrial production, this situation has led to a fast decrease of available resources. On the other hand, a high volume of marble production has generated a considerable amount of waste materials; almost 70% of this mineral gets wasted in the mining, processing and polishing stages which have a serious impact on the environment. The processing waste is dumped and threatening the aquifer. Therefore, it has become necessary to reuse these wastes particularly in the manufacture of concrete products for construction purposes. The main goal of this study is to demonstrate the possibility of using marble wastes as a substitute rather than natural aggregates in concrete production. The paper presents the study methodology, the characterization of waste marble aggregates and various practical formulations of concrete. This experimental investigation was carried out on three series of concrete mixtures: sand substitution mixture, gravel substitution mixture and a mixture of both aggregates (sand and gravel). The concrete formulations were produced with a constant water/cement ratio. The results obtained show that the mechanical properties of concrete specimens produced using the marble wastes were found to conform with the concrete production standards and the substitution of natural aggregates by waste marble aggregates up to 75% of any formulation is beneficial for the concrete resistance.

1. Introduction

Because of continual depletion of quarries aggregates, construction materials are more and more judged by their ecological characteristics. The lack of technology and unscientific methods of quarrying marble in Algeria has generated a huge quantity of waste of this valuable mineral; leaving the waste materials to the nature directly can cause serious environmental problems. In addition, the marble cutting industry generates a high volume of wastes. Recent studies showed that marble waste can be used as aggregates for assorted construction materials.

Binici et al. [1] have studied some mechanical properties of concrete containing marble and limestone dusts; mixes were modified to 5%, 10% and 15% marble and limestone dusts instead of fine sand aggregates and their compressive strengths were compared. Binici et al. [2] investigated in another study the durability and the fresh properties of concrete made with granite and marble as recycled aggregates. In the specimens containing marble and granite there is a much better bonding among the additives, cement and aggregates. Furthermore, it may be said that marble and granite replacement rendered a good condensed matrix. The increased durability of concrete can be attributed to the glass content and chemical composition of the granite. The results of this study showed that the marble and granite waste aggregates can be used to improve the mechanical properties, workability and chemical resistance of the conventional concrete mixtures.

Corinaldesi et al. [3] showed that 10% substitution of sand by the marble powder has provided maximum compressive strength at about the same workability; mixtures were evaluated based upon cement or sand substitution by the marble powder.

The marble wastes are not only substitutes or additives to concrete; they can also be used for other kinds of building materials. Experiments carried out by Saboya et al. [4] have shown that the use of 15–20% of powder marble content in red ceramic raw material could be considered the best proportion to enhance the properties of brick ceramic. Akbulut and Gürer [5] demonstrated that the physical properties of the marble waste aggregates are within specified limits and these materials can potentially used as aggregates in light to medium trafficked asphalt pavement binder layers.

A very limited number of studies has been conducted to understand the rheological and mechanical properties of marble waste aggregates concrete. In addition, it is difficult to make comparisons between concrete results because the few existing studies have not

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always the same concerns. We have undertaken this experimental campaign to review and develop the results of studies already carried out [6,7] by our team.

In this paper, we study the marble waste of Fil-Fila quarry (wilaya of Skikda in the north-east of Algeria); the marble waste recycling is processed before use. The natural and recycled aggregates were characterized. Concrete mix designs with 25%, 50%, 75% and 100% of aggregates substitution were formulated. The performances of the "recycled aggregates" concrete were measured through tests of density, air content, workability and compressive and tensile strength.

2. Experimental program

2.1. Materials characterization

Natural aggregates are crushed gravel (limestone) from Ain-Smara quarry (Canstantine, north-east of Algeria) and rounded sand from Chatt quarry (El-Tarf, north-east of Algeria). The recycled aggregates are gravel and sand from wastes of the white marble quarry of Fil-Fila. Table 1 presents the physical and chemical characteristics of Fil-Fila marble. The main characteristics of the aggregates [8] are resumed in Table 2.

In fact, characterization results (Table 2) show that the obtained values of flakiness index and sand equivalent of recycled aggregates are consistent with the European standard [9]. The value of finess modulus of natural sand is 1.95 according to European standard [10]. It indicates that the sand is fine and may improve workability of concrete at the expense of the strength. The finess modulus of recycled sand is 3.12, it is a coarse sand which would help to have good resistance values but probably not a good workable mix. The Los Angeles coefficient of the natural and recycled aggregates are 26.14 and 38.09 respectively, these values are consistent with the standard norm [11]. The results show that natural aggregates are harder than the recycled ones according to Micro-Deval test [12]. The recycled aggregates have a higher carbonate content than the natural ones which improves the aggregate-cement paste bond.

Table 1
Physical and chemical characteristics of the marble.

Physico-mechanical properties	White Fil-Fila marble
True density (g/cm^3)	2.736
Bulk density (kg/cm^3)	2.684
Porosity (%)	1.96
Absorption (by weight) (%)	0.39
Saturation (%)	0.87
Compressive strength (dry state) (MPa)	94.3
Compressive strength (after cooling and reheating) (MPa)	94.8
Wear resistance (mm)	1.82
Impact resistance (cm)	40
Chemical characteristics	
$CaCO_3$	99.05
MgO	1.03
CaO	54.86
Fe_2O_3	0.04
Al_2O_3	0.08
SiO_2	0.15
P.C	44.26

2.2. Concrete mix design

The experimental program was applied to three types of concrete mixes formulated by Dreux–Gorisse method [13] according to the percentage of substitution of natural aggregates with recycled aggregates and is summarised as follows:

- The natural sand (NS) is substituted by the recycled sand (RS) at 25%, 50%, 75% and 100%. The concrete formulation is noted (S).
- The natural gravel (NG) is substituted by the recycled gravel (RG) at 25%, 50%, 75% and 100%. The concrete formulation is noted (G).
- The natural sand and gravel (NS, NG) are substituted by the recycled sand and gravel (RS, RG) at 25%, 50%, 75% and 100%. The concrete formulation is noted (M).
- Natural aggregates mixtures are noted (NA).

The used cement is CPA-CEMI42,5 and it was kept constant at 350 kg/m^3. The water/cement ratio was of 0.5 and constant for all tested mixtures in this experimental campaign.

Tests for density were carried out to supplement the air content test on fresh concrete, the two parameters are determined according to EN parts 6 and 7 [14]. The verification of the workability of a fresh concrete is completed with the slump test apparatus [14] part 2. The compressive and tensile strengths tests were performed at the ages of 2, 14, 28 and 90 days; the compressive tests were conducted on the concrete standardised cylinders of 16 × 32 cm and the tensile–flexural tests on prisms (10 × 10 × 40 cm) according to EN parts 2, 3, and 5 [15].

3. Results and discussion

The obtained experimental results reveal the influence of the studied parameters on the behaviour of fresh and hardened concrete. Density and air content tests are carried out on fresh concrete to provide the importance of these properties on the hardened concrete.

The density of the concrete mixtures (Fig. 1) does not change much over the change of the mixture or the substitution rate. Therefore, the variation of density values is relatively low and generally acceptable. The density of concrete is a function of the initial materials densities, mix proportions, initial and final water content and hydration degree. It can be expected that the recycled aggregates may have an influence on the density of concrete. The density values of different mixtures vary due to the different percentage of substitution content. The values obtained for the density of (M) mixture at 50% of substitution are fairly comparable to the natural aggregates concrete ones. The minimum density values were obtained for (G) formulation.

Fig. 2 illustrates the variation of air content according to the substitution rate of the recycled aggregates of the three mixtures. The air content values are acceptable and the maximum value is obtained for the mixture (S) at 100% of recycled aggregates. It is known that the air content is dependent on mix design proportions and is usually determined to ensure the presence of air entrainment for freeze–thaw durability. It is important to understand the air content from the non-air-entrained in the concrete; this parameter is very significant due to the negative impact on the properties of hardened concrete. Therefore, checking air content for these concrete mixtures is a required safety measure because of the nature of the recycled aggregates. Air content can differ for

Table 2
Aggregates characterization.

Specimen		Apparent density (g/cm^3)	True density (g/cm^3)	Flakiness index (%)	Sand equivalent (%)	Methylene blue	Los Angeles test (%)	Micro-Deval test	$CaCO_3$ (%)	Cl^- (%)
NS-0/5	Natural aggregates	1.723	2.591	–	81	0.33	–	–	25.56	0.25
NG1-5/15		1.575	2.666	12	–	–	–	–	–	–
NG2-15/25		1.551	2.666	15	–	–	26.14	21.50	88	0.12
RS-0/5	Recycled aggregates	1.667	2.666	–	75	0.33	–	–	99.25	0.12
RG1-5/10		1.578	2.666	24	–	–	–	–	–	–
RG2-10/20		1.672	2.666	9	–	–	38.9	24.66	–	–

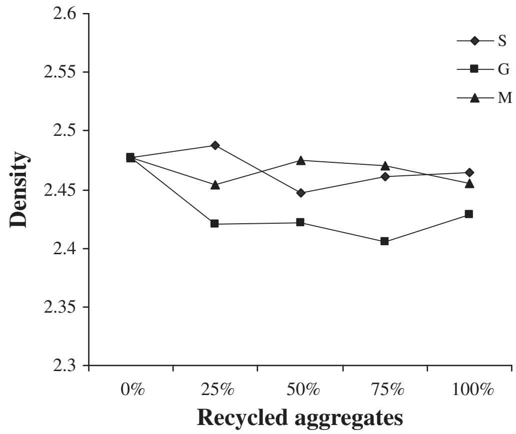

Fig. 1. Concrete density versus recycled aggregates substitution rate.

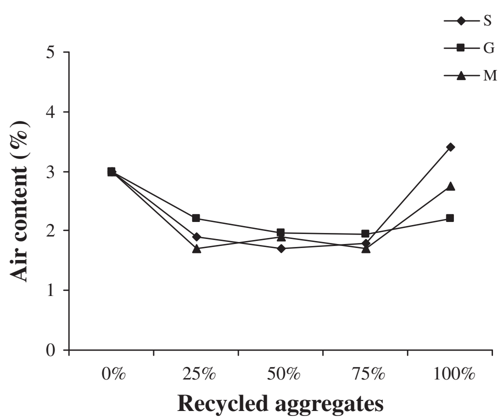

Fig. 2. Air content of concrete with recycled aggregates substitution rate.

a large number of reasons such as fine aggregates grading, aggregates substitution percentage and the influence of these recycled aggregates on the fresh and hardened concrete. Therefore, the substitution caused the diminution of air content at 25%, 50% and 75%.

The slump test is a convenient mean of measuring the workability of the concrete mix. It is therefore useful in controlling the quality of the concrete produced. The curves (Fig. 3) explain how levels of workability were achieved by these concrete formulations. They provide knowledge on the effects of the properties and proportions of mixture aggregates. They indicate that concrete workability decreases with the increase of the substitution rate. The workability has decreased for all mixtures with marble waste aggregates. However, some of the factors that may affect the workability of these concretes are grading and shape of fine aggregates, proportion of fine to coarse aggregates and characteristics of the materials. The main critical parameter in the workability is that natural aggregates absorb more water than waste marble aggregates. Therefore, the correct quantity of water required for the mixes needs correction and depends on the mix proportions [2,6,7,16].

Compressive and tensile strength are the most important investigated properties of the concrete. The concrete cylinders were cured and tested in accordance with EU standards. The specimens were tested at 2, 14, 28 and 90 days of curing in order to assess the strength development according to sand, gravel and sand–gravel substitution at different percentages. The recycled aggregates affected the compressive and tensile strengths (Figs. 4 and 5) at a certain rate of substitution. The (S) formulation showed a significant strength gain, the compressive and tensile strength with the

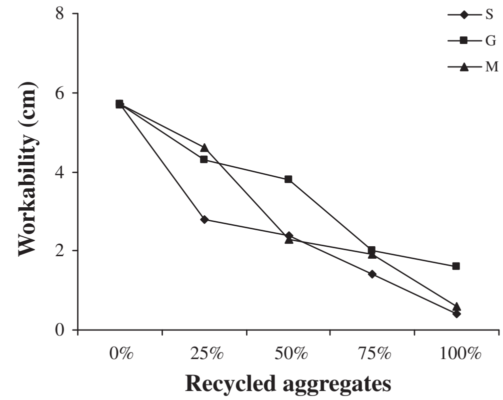

Fig. 3. Workability of concrete according to recycled aggregates substitution rate.

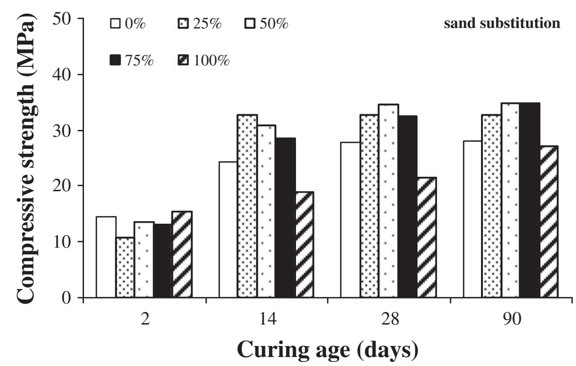

Fig. 4. The compressive strength versus the curing age, formulation (S).

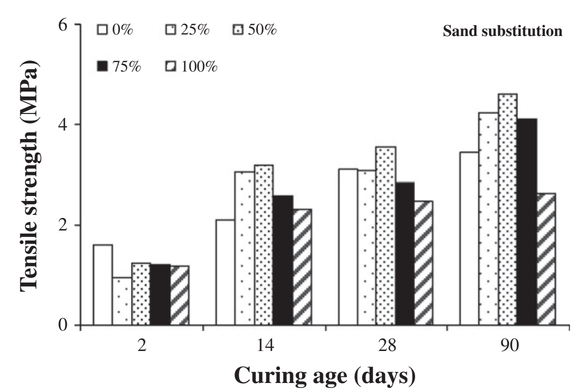

Fig. 5. The tensile strength versus the curing age, formulation (S).

substitution rate of 25%, 50% and 75% are fairly greater than values obtained with natural aggregates. The curves clearly show that the concrete with 100% substitution rate provided poor results in strength.

Figs. 6–9 show that the (G) and (M) formulations gave very good results for compressive and tensile strength at different substitution rate. The bars of 100% rate of substitution are relatively close to the ones of natural aggregates which points out that the concrete mixtures at 25%, 50% and 75% of substitution rate improve the concrete strength. We noticed a good correlation between compressive and tensile strength behaviour for the three formulations. Furthermore, the tensile strength rises after 28 days of curing; this increase is not visible for the compressive strength bars.

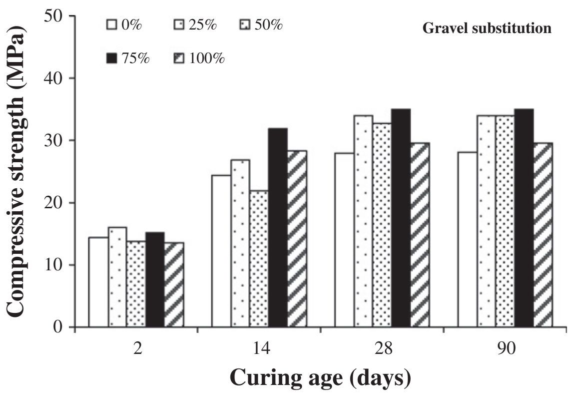

Fig. 6. The compressive strength versus the curing age, formulation (G).

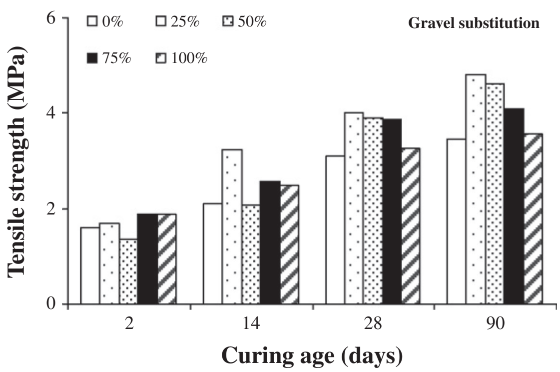

Fig. 7. The tensile strength versus the curing age, formulation (G).

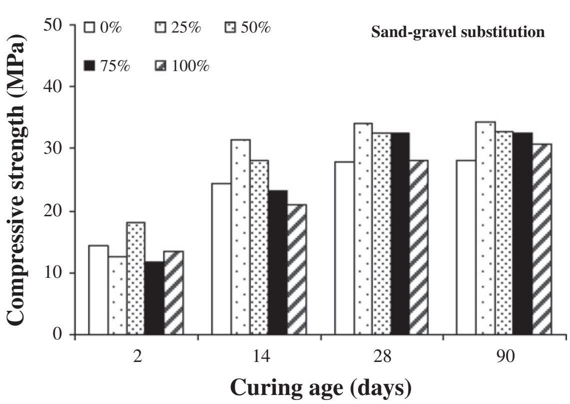

Fig. 8. The compressive strength versus the curing age, formulation (M).

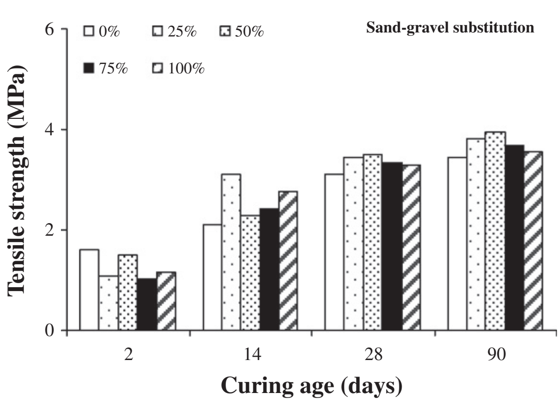

Fig. 9. The tensile strength versus the curing age, formulation (M).

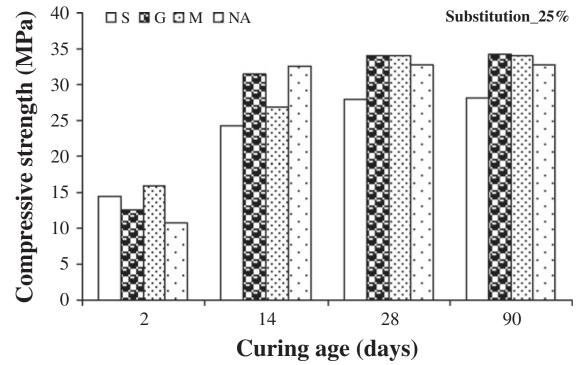

Fig. 10. The compressive strength versus the curing age, 25% of substitution.

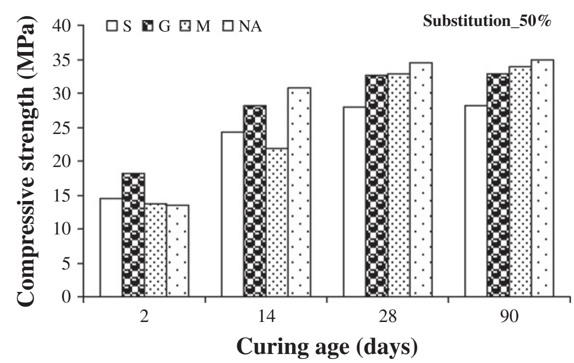

Fig. 11. The compressive strength versus the curing age, 50% of substitution.

The simple tensile test does not measure the bond strength at the aggregate interface but it is possible to compare the effect of the aggregates substitution.

The values of compressive strength of the substitution at 25% (Fig. 10) and 50% (Fig. 11) of formulations (S), (G) and (M) are relatively close but it should be noted that there is a difference for the early age of concrete (2 and 14 days). The values of the compressive strength at 75% of substitution (Fig. 12) of (S), (G) and (M) formulations are much greater when compared to those of the natural aggregates concrete. The formulations (G) and (M) with a substitution rate of 100% (Fig. 13) provided values close to those of the natural aggregates concrete. The formulation (S) of sand substitution provided low compressive strength. That being said, the substitution of natural aggregates with waste marble aggregates at a certain percentage of any formulation appears beneficial for the resistance except for the 100% substitution rate which reduces the resistance.

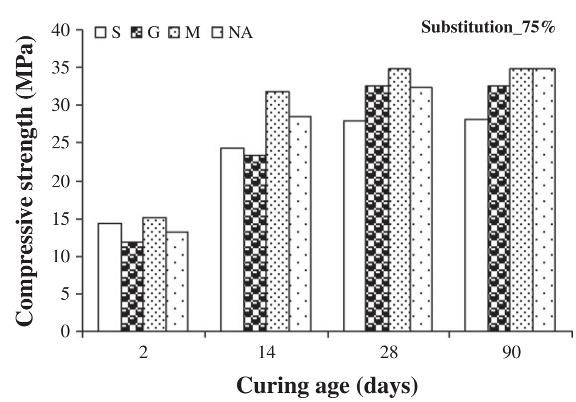

Fig. 12. The compressive strength versus the curing age, 75% of substitution.

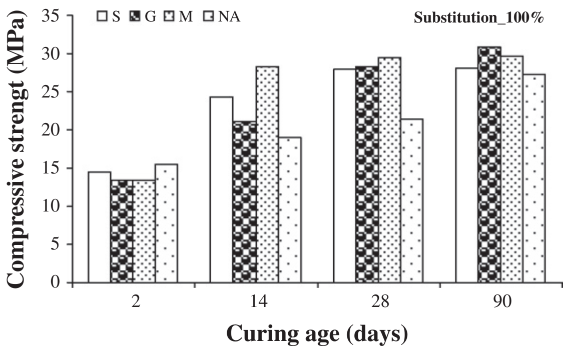

Fig. 13. The compressive strength versus the curing age, 100% of substitution.

Table 3
Compressive strength gain at 28 days.

Sand substitution_formulation (S)				
Substitution rate	25%	50%	75%	100%
Compressive strength gain at 28 days (%)	17.2	<u>23.65</u>	16.1	−23.29
Gravel substitution_formulation (G)				
Substitution rate	25%	50%	75%	100%
Compressive strength gain at 28 days (%)	21.86	17.56	<u>25.08</u>	5.7
Sand–gravel substitution_formulation (M)				
Substitution rate	25%	50%	75%	100%
Compressive strength gain at 28 days (%)	<u>22.2</u>	16.84	16.84	1.07

Table 3 recapitulates the gain in strength of concrete at 28 days of curing of the three formulations at different substitution percentages. The compressive strength gain is calculated according to the compressive strength of recycled aggregates concrete and the compressive strength of natural aggregates concrete. It is clear that all the concrete formulations showed a significant gain in strength and each of them provides the maximum gain of strength. Furthermore, we note that the substitution of 100% of sand or gravel or both aggregates together may lead to a considerable loss of concrete strength.

4. Conclusion

This research is an experimental approach to substitute natural aggregates by the waste marble aggregates; the concern is more scientific than economical and environmental. The results obtained demonstrated the performance of various concrete mixtures which may help to understand the behaviour of these recycled aggregates. Therefore, the orientation of this research has shown that setting certain parameters has identified the best percentage of substitution for each type of aggregate. Analysis of these results has revealed that the appropriate incorporation of marble waste aggregates can lead to interesting characteristics in terms of strength, indeed the use of marble aggregates resulted in a considerable increase in the compressive and tensile strength. The enhancement in resistance is very significant for 25%, 50% and 75% of substitution. The concrete workability can be improved by the correct quantity of water and the correct proportioning and grading of the "recycled sand" and the "recycled gravel" which can provide practical formulations. This research needs to be supplemented by durability studies such as freeze–thaw resistance, permeation properties, and carbonation resistance and some of these tests are in progress. The marble waste can be used as alternative aggregates for concrete and for many other purposes such as bricks manufacturing, road construction and landfills.

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