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Evaluating the Potential of Al-Selw Marble Waste as Coarse Aggregate in Concrete: A Case Study from Taiz, Yemen

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ABSTRACT

Marble deposits are abundant in Yemen, with economically significant quantities found in the Al-Selw district of Taiz. During marble extraction and processing, substantial waste is generated, which is often disposed of in open areas, leading to environmental degradation and public health concerns. Additionally, the accumulation of waste contributes to the depletion of natural resources. This study aims to assess the viability of utilizing Al-Selw marble waste as a coarse aggregate in concrete production. A series of tests, including X-ray diffraction (XRD), X-ray fluorescence (XRF), specific gravity, water absorption, Los Angeles abrasion, and particle size distribution, were conducted to achieve this objective. XRD analysis revealed the predominant presence of dolomite and calcite, while XRF results indicated major oxide components of CaO (27.06%) and MgO (23.89%), with other oxides at lower concentrations. The marble waste displayed a water absorption of 0.5% and a specific gravity of 2.82. With a unit weight of 1700 kg/m³, the Al-Selw marble waste aggregate (SMWA) met the standard requirements for Los Angeles abrasion values for use as coarse aggregates in concrete. Based on these findings, SMWA has been identified as a high-quality coarse aggregate material, offering a sustainable alternative to traditional sources.

1. INTRODUCTION

Figure 1. Waste of quarrying and processing of Al-Selw marble (Al-Selw and Al-Hawban)

Yemen boasts an abundance of natural resources, including marble rocks, which are widely distributed, especially in the Al-Selw area of Taiz. Al-Selw marble is primarily employed in construction and decoration, making it the most prevalent type of ornamental stone in the governorate. The process of quarrying ore generates a significant amount of waste due to inefficient exploitation, lack of experience, and the absence of modern equipment. Further waste is produced during the finishing and polishing processes. Figure 1 illustrates the considerable losses incurred during Al-Selw quarrying and the saw waste scattered in the Al-Hawban area.

As the population grows, the depletion of limited natural resources and the increase in environmental pollution become more pressing concerns. Marble is a metamorphic, crystalline rock predominantly composed of calcite, dolomite, or serpentine materials [1-3]. Dolomite, a calcium magnesium carbonate, has a chemical composition of $CaMg(CO3)2$. The formation of this carbonate compound can be expected due to the high contents of CaO and MgO in marble waste. Currently, the disposal of marble waste is a matter of concern for both environmentalists and manufacturers [4, 5]. Numerous attempts have been made to repurpose marble waste as aggregate [1, 6-14].

Moh's scale describes the resistance of minerals or rocks to abrasion or scratching. It comprises ten minerals arranged in increasing hardness, from talc to diamond. Composed of calcite, marble has a hardness of three on Moh's scale. The presence of calcite and dolomite as primary components lowers the hardness of marble. This characteristic is advantageous during abrasive and polishing operations, as it facilitates the cutting of ornamental stones into their final shape and reduces costs [15]. Gonfa et al. [16] found in their study that marble aggregate meets the standard specifications for base coarse material in road construction.

Marble rock is very important in the construction industry as it is one of the most aesthetically pleasing, durable, and long-lasting decorative and building materials. With a market share of approximately 50%, it is considered the most used natural stone worldwide [10].

Almost half of the marble produced worldwide is quarried from four countries: Italy, China, India, and Spain. India accounts for about 10% of the marble produced globally [17]. A high volume of marble production has generated considerable waste materials in the mining, processing, and polishing stages, which seriously impacts the environment [13, 18]. During the quarrying and processing of dimensional stones such as Granite, Limestone, Marble, Rhyolite, Tuff, Basalt, etc., a vast amount of non-biodegradable solid waste is produced. Because of this tremendous waste production, they have created major environmental issues and become a global annoyance over the years by affecting the environment and by more than one means. Therefore, finding a method to dispose or reuse waste quarries and finish building stone safely has good impacts on environmental protection and on the economy.

The waste from the marble sawmills, which spread in Al-Hawban area day by day, exacerbates the environmental problem because the owners of sawmills throw their waste near the sawmill or on the side of the street (Figure 1). The best solution for disposal of that waste is to get benefited from it, which best benefit is to reuse it as coarse aggregates. The amount of waste in Yemen is large because of the widespread building and ornamental stones, especially marble, limestone, and granite. Improper handling of this waste material can significantly affect the community and the environment. Currently, world cities generate about 1.3 billion tonnes of solid waste materials per year, which is expected to increase to 2.2 billion tonnes by 2025 [19].

Waste generation rates will more than double over the next twenty years in lower-income countries. Globally, solid waste management costs will increase from today's annual $205.4 billion to about $375.5 billion in 2025. Cost increases will be most acute in low-income and lower-middle-income countries [20].

2. STUDY AREA

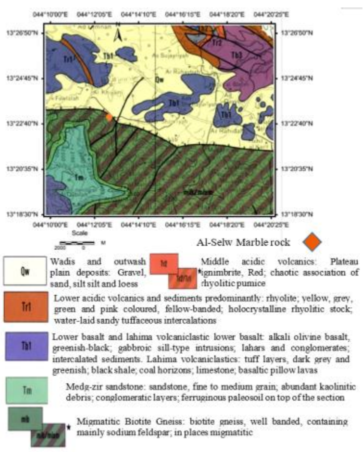

Figure 2. Geological map of Al-Selw and surrounding area

Figure 3. Dykes cutting Al-Selw marble rock

Figure 4. Dimension and finishing stone-Al-Selw marble

The selected area for the current study is Al-Hawban area and Al-Selw district. It was selected due to the abundance of marble waste available for potential recycling and reuse as aggregate. Al-Selw quarries are located in south of Taiz, approximately 30km of Al-Hawban area and 6km west of the Alrahiedah-Taiz road. Marble waste samples were collected from Al-Selw quarries at 13°23 08 N and 44°12 46 E and from marble sawmills in Al-Hwban area at 13°36 02 N and 44°04 20 E. Al-Selw marble occurs within the rocks of the basement complex (Figure 2). It is affected by the tectonic events in the region that appeared in the area as dykes, faults, and intensive metamorphism (Figures 2 and 3). Al-Selw Marble is hard and dense with white to bluish color. It's quarrying, cutting, and finishing process is easy and can be quarried as large to medium-sized blocks (Figure 4).

3. MATERIAL AND METHODOLOGY

Marble waste samples were collected from Al-Selw quarries and marble sawmills in Al-Hawban area. Visual inspection was conducted to characterize the texture, granularity, joints, cavities, and color of the samples. The samples were crushed into different sizes at Al-Saeed crusher. Laboratory tests were carried out at Al-Saeed Company for Manufacturing Concrete and Contractor to determine the grain size distribution, specific gravity, unit weight, water absorption, and Los Angeles abrasion. Unit weight, and specific gravity and water absorption were tested according to ASTM C29/C29 [21] and ASTM C127 [22], respectively (Figure 5).

The quantitative distribution of particles based on their size in an aggregate fraction is the particle size distribution of that fraction, represented graphically by a grading curve [23]. The gradation test was carried out based on the criteria provided in ASTM C33 [24] (Figure 6). The Los Angeles test is one of the most common mechanical methods measuring aggregate toughness and aggregate abrasion. This test, performed according to the standard's requirements ASTM C131/C131M-20 [25]. The materials are placed in a Los Angeles test machine along with 12 steel balls and allowed to rotate for 500 revolutions, producing an abrasive action between standard steel balls and aggregate grains when rotated in a specific drum, as presented in Figure 7.

Figure 5. Water absorption, specific gravity and unit weight tests-SMWA

Figure 6. Gradation test of coarse aggregates of Al-Selw marble waste

a. Sample before testing   b. Los Angeles machine   c. Sample after testing

Figure 7. Los Angeles abrasion resistance test of SMWA

The physicochemical properties of SMWA used in this study were determined by X-ray Diffraction (XRD), and X-Ray Fluorescence (XRF). XRD is a versatile, non-destructive technique that reveals detailed information about the crystallographic structure of natural and manufactured materials. XRD for SMWA was carried out at the Central lab of the Geological Survey and Mineral Resources Board, Sana'a (GSMBR).

Samples for XRD were prepared by grinding without treatment to very fine particles, then testing using XD-2/XD-3 Goniometer Type Vertical: 00-2 θ scan: 0-θ scan high, single-phase 508Z, 220V, max. 60kw, rated powder 3Kw. This determines the presence of dolomite, calcite, and common impurities such as quartz, feldspars, clay minerals, mica, iron oxides, etc. XRF analysis was also performed to determine the major elemental oxide composition of the Al-Selw marble waste aggregates.

4. RESULTS AND DISCUSSION

4.1 XRD and XRF

The visual study showed that the Al-Selw marble has a smooth surface, granularly grain, white to bluish, and is free of joints and cavities. The result of XRF test of SMWA is presented in Table 1. It shows that the major oxides are CaO 27.06%, MgO 23.89%, SiO_2 3.96%; the other oxides present with low concentrations. The extremely high content of MgO 23.89% indicates a strong dolomitization process. The LOI is 42.43%, reflecting the content of the marble rock's volatiles (CO_2, H_2O). This denotes high volatile and, consequently, high carbonate content since it is equivalent to the evolution of carbon dioxide following heating at 900ºC. The percentage of Fe_2O_3 is small 0.62%. Iron oxides show as leaching on the outside of the surface of marble rock, which is coming later from the magma (Figure 3).

XRD test result shows significant peaks of dolomite and calcite (Figure 8). This result confirms the chemical analysis (XRF) result, indicating that the main crystalline minerals of the tested marble are dolomite and calcite. Therefore, the rock is dolomitic marble (Figure 8).

The major oxides CaO, MgO, Fe_2O_3, SiO_2, and Al_2O_3 are also oxides of cement that contribute to accelerating the crystal growth process and building strong bonds between the aggregates and cement during the hydration process.

Table 1. Major oxides of SMWA

CaO%	27.06
MgO%	23.89
SiO_2 %	3.96
Al_2O_3%	0.71
Fe_2O_3%	0.62
Na_2O%	0.57
SO_3%	0.27
Cl%	0.25
K_2O%	0.11
P_2O_5%	0.05
TiO_2%	0.04
MnO%	0.03
SrO%	0.01
LOI%	42.43

4.2 Water absorption, unit weight and specific gravity

Water absorption gives an idea of the strength of aggregate. Aggregates with more water absorption are more porous and are generally considered unsuitable unless found to be acceptable based on strength, impact, and hardness tests [26, 27]. In addition, the measured absorption of water indicates the relative quality of the near-surface concrete property [28].

The proportion of water absorption of Al-Selw marble showed a very low 0.5% (Table 2). This result can relate to the absence or decreasing concentration of voids, cavities, and joints in SMWA. This result enhances the physical and mechanical properties of the concrete, such as workability, density, compressive, tensile strength, etc. In addition, it contributes to the suitability of using Al-Selw marble waste as coarse aggregates to produce high-quality concrete. The unit weight and specific gravity of coarse aggregates are 1700kg/m^3, and 2.82 (Table 2). The results showed little height because of the mineral composite and its surface condition.

The crushing result of marble waste showed that the aggregates produced are angular (almost cubic). In addition, the gradation result is demonstrated good based on the criteria provided in ASTM C33 [24] and compared with the standard gradation (Figure 9). The nominal maximum size is 19mm, identical to the standard of concrete production in Yemen.

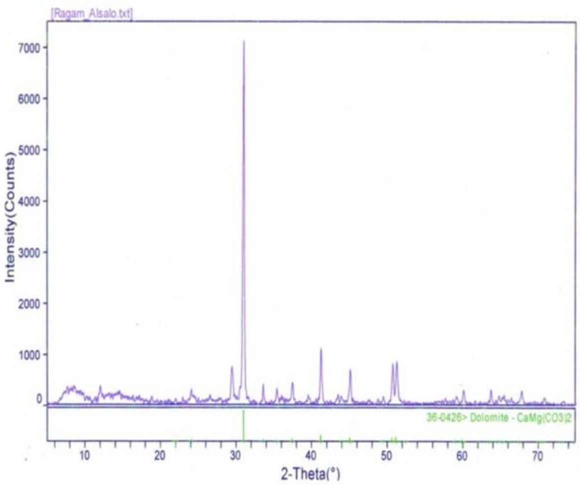

Figure 8. XRD of Al-Selw marble waste

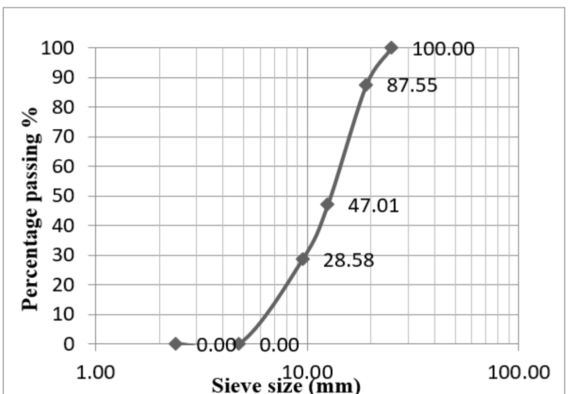

Figure 9. Gradation of coarse aggregate SMWA

Table 2. Physical and mechanical characteristics of SMWA

Properties	Result
Specific gravity	2.82
Water absorption (%)	0.5
Aggregate abrasion resistance (%)	43
Unit weight of SMWA (kg/m^3)	1700

4.3 Los Angeles

As presented in Table 2, the Los Angeles value of SMWA is equal to 43%. This value can relate to several factors influencing the fragmentation of aggregates, including the mineralogical composition of the rock, which is dolomite and calcite, as well as the grain size of aggregates, shape, angularity, and arrangement of grains. The presence of microfractures has a significant effect on aggregate quality. The value of Los Angeles is below the limit value standards specified for coarse aggregates for concretes 50% [24]. The silica content in marble waste was small (3.96%), thus negatively influencing Los Angeles. As a conclusion, SMWA has safe and acceptable abrasion to be used as a coarse aggregate for concrete production.

5. CONCLUSIONS

The following conclusions could be highlighted in light of the above results and discussions.

XRF test of SMWA indicates the major oxides are CaO 27.06% and MgO 23.89%, with low concentrations of the other oxides.

XRF and XRD results confirmed that the Al-Selw marble waste mainly comprises dolomite and calcite, and the rock is dolomitic marble.

The physical properties of Al-Selw marble waste aggregates revealed highly satisfactory results specifications for coarse aggregates.

The extent of using marble waste as a high-quality coarse aggregate depends on several factors, including the geological origin and geological characteristics, such as mineralogical composition, as well as the size, shape, and arrangement of grains and micro fractures.

The values obtained in the Los Angeles Abrasion test result are within the limits of different standards and can safely be used SMWA as coarse aggregate to produce high-quality concrete.

The gradation of the SMWA displayed good to acceptable gradations.

The Results confirm that SMWA can be used as high-quality coarse aggregates.

In Yemen, large quantities of marble waste are produced. Economically and environmentally, it is recommended to use Al-Selw marble waste as high-quality aggregates, and this will help meet the growing demand while slowing down any negative environmental impacts.

Further research should investigate the effects of Al-Selw marble waste aggregate on concrete properties through trial mixes and tests.

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