# Sustainable self-compacting concrete: effect of combined marble waste as fine and coarse aggregates

*Belgacem* Mohamed El Ghazali[a], *Ouldkhaoua* Younes[b], *Herihiri* Ouided[c], *Sadoudi* Lyacia[d], *Arroudj* Karima[e]
[a] University of Sciences and Technology Houari Boumediene
e-mail: ghazali2017@gmail.com, **corresponding author**
ORCID iD: https://orcid.org/0000-0001-8515-8568
[b] University of Sciences and Technology Houari Boumediene
e-mail: younes.ouldkhaoua@usthb.edu.dz
ORCID iD: https://orcid.org/0009-0001-8334-812X
[c] University Yahia Fares of Medea
e-mail: heri.widalg@gmail.com
ORCID iD: https://orcid.org/0000-0002-8787-029X
[d] University of Sciences and Technology Houari Boumediene
e-mail: sadoudi29@yahoo.com
ORCID iD: https://orcid.org/0000-0002-5071-7267
[e] University of Sciences and Technology Houari Boumediene
e-mail: karroudj@gmail.com
ORCID iD: https://orcid.org/0000-0003-2852-0836

doi https://doi.org/10.5937/vojtehg73-58717

FIELD: construction materials in civil engineering
ARTICLE TYPE: original scientific paper

*Abstract:*

*Introduction/purpose: Environmental protection through waste recycling is one of the major challenges of our time. Inert waste, mainly generated by industry, makes up a significant portion that harms the environment due to its accumulation in nature.*

*Methods: The primary objective of this study is to examine the influence of marble waste valorization as sand and gravel on the rheological and mechanical properties of self-compacting concrete (SCC). For this study, marble was used as fine aggregate sand (MAS) at rates of 10%, 20%, and 30%, and as coarse aggregate gravel (MAG) at a rate of 100%.*

*Results: The results of this study demonstrate that the introduction of marble waste (MW) as aggregate positively influenced the rheological characteristics, notably reducing the need for superplasticizer dosage.*

ACKNOWLEDGMENT: The authors gratefully acknowledge the Directorate-General of Scientific Research and Technological Development of Algeria (DGRSDT) for its valuable support.

*Conclusions: Additionally, in terms of mechanical outcomes, the use of MAG led to improved mechanical strengths.*

*Key words: self-compacting concrete, marble waste, rheological behavior, superplasticizer dosage, mechanical strength, environment*

## Introduction

In the construction industry, technological advancements in concrete aim not only to enhance its performance but also to reduce its environmental impact. Concrete, an essential material in most modern infrastructures, has a significant environmental impact, particularly due to the extraction of its components, such as aggregates. Natural aggregates represent about 80% of the total volume of concrete (Yu *et al.*, 2024), and their extraction from natural areas such as rivers and mountains causes numerous ecological issues. The excessive exploitation of these resources can lead to the degradation of local ecosystems, loss of biodiversity, and disruption of natural cycles (Mathodi *et al.*, 2022). Therefore, it is crucial to seek ecological alternatives to traditional aggregates in order to minimize the negative effects of their extraction and promote more sustainable construction practices (Makul, Fediuk, Amran, Zeyad, Azevedo, *et al.*, 2021).

One of the most promising solutions lies in the use of recycled materials, such as marble, to replace natural aggregates in concrete (Kore and Vyas, 2016). Marble is an abundant material, and when recycled, it can offer significant environmental benefits. It helps reduce the amount of waste produced by the construction industry, while alleviating the pressure on natural resources (Thakur, Pappu and Thakur, 2018). However, recycling marble is not without its challenges. Although the recycling process offers ecological advantages, it also requires energy consumption for crushing and transforming the material into reusable aggregates. This energy consumption must be taken into account to fully evaluate the environmental benefits of recycled marble. If this energy can be minimized or offset by the reduction in carbon footprint generated by the extraction of natural aggregates, then recycling marble could represent an environmentally and economically viable solution (Gazi, Skevis and Founti, 2012).

Recent studies have highlighted the positive effects of recycled marble on concrete properties. For example, the incorporation of marble as coarse or fine aggregates can improve the workability of concrete due to its low water absorption and the smooth surface of its aggregates (Kore and Vyas, 2016). Furthermore, research has shown that partially replacing natural sand with marble sand can increase the compressive strength of concrete, although this effect is limited to certain replacement rates (Demirel, 2010; Alyamaç and Aydin, 2015; Houria *et al.*, 2020). This opens up new possibilities for optimizing concrete formulations, taking into account not only mechanical performance but also the environmental benefits of recycling materials.

In this context, self-compacting concrete (SCC) emerges as a particularly valuable innovation due to its exceptional fluidity and its ability to flow effortlessly into complex formworks, even when dense reinforcement is present. The rheological behavior of SCC plays a critical role in its performance, especially when incorporating recycled aggregates (Ouldkhaoua *et al.*, 2019). However, the use of recycled materials poses specific challenges, as their variable characteristics such as water absorption and surface roughness can negatively affect the mix's flowability and stability (Silva, Brito and Dhir, 2018).

Despite these challenges, recent advancements in mix design techniques and the application of chemical admixtures, such as superplasticizers and stabilizers, have made it possible to overcome these limitations. These innovations allow for improved workability and consistency, even when recycled aggregates are used (Makul, Fediuk, Amran, Zeyad, Murali, *et al.*, 2021).

As a result, SCC incorporating recycled materials proves highly advantageous for placement in heavily reinforced or difficult-to-access areas, ensuring uniform filling without defects. Moreover, this approach contributes to environmental sustainability by reducing construction waste and the reliance on natural resources, all while maintaining the structural performance and durability of concrete (Rich, 2014). Ultimately, the development of SCC with recycled aggregates offers a promising solution to current environmental and technical challenges in the construction industry (Khairi *et al.*, 2020).

This study aims to investigate the enhancement of the properties of self-compacting concrete (SCC) through the incorporation of recycled marble aggregates, both fine and coarse. Specifically, the goal is to assess how the addition of recycled marble aggregates affects the workability, stability, and long-term durability of SCC. Furthermore, the study will explore the potential of recycled marble to offer an environmentally sustainable solution in concrete production by reducing dependence on natural resources. The ultimate objective is to contribute to a circular economy in the construction industry, where recycled materials not only improve performance but also help mitigate the environmental impact of traditional construction practices.

# Materials and methods

## *Materials*

The cement utilized in this study is CEM II/B, a type of ordinary Portland cement produced by GICA. This cement has a minimum compressive strength of 42.5 MPa at 28 days, making it suitable for various applications in construction.

For this study, the sand utilized is sourced from the Oued Souf region, located approximately 500 km south of Algiers.

Two types of aggregates, G 3/8 and G 8/15, derived from the crushing of limestone rocks, were used in this study. These aggregates were selected for their specific size gradation and mechanical properties, which are essential for achieving the desired performance characteristics in the concrete mixtures.

Marble waste was obtained through a crushing process using a jaw crusher, which produced a material with particle sizes ranging from 0 to 5 mm for the sand fraction, and two granular classes for the aggregates. This processed marble waste serves as a supplementary material in the concrete mixtures, contributing to their overall properties and performance.

In this research, a third-generation superplasticizer (SP) with high water-reducing capabilities was employed. This superplasticizer, supplied by Granitex-NP and marketed under the name Medaflow 30, is a yellowish liquid with a pH of 6 and a density of 1.07.

## *Formulation*

The formulation of self-compacting concrete (SCC) is a delicate process that requires finding a balance among various seemingly contradictory characteristics. An SCC mixture must possess high fluidity, allowing it to flow solely under the influence of gravity, while minimizing the risks of segregation (both static and dynamic) and instability, without compromising mechanical strength. Therefore, SCC must meet three essential criteria: fluidity, homogeneity, and robustness. In this study, we selected three relevant tests to quantify the following properties:

- Confined flowability,
- Stability and homogeneity, and
- Resistance to segregation and bleeding.

The different components of the SCM studied are presented in Table 1.

*Table1 – Different components of the SCC studied (source author)*

| Mixture | Cement (kg/m$^3$) | Sand (kg/m$^3$) | SM (kg/m$^3$) | Gravel (kg/m$^3$) | GM (Kg/m$^3$) | W/C | SP (%) |
|---|---|---|---|---|---|---|---|
| Control SCC | 469.59 | 906.22 | 0 | 536.04+ 266.10 | 0 | 0,4 | 0.8 |
| SCCG M | 469.59 | 906.22 | 0 | 0 | 536.04+ 266.10 | 0,4 | 0.7 |
| SCCG M10%S M | 469.59 | 815.52 | 90.7 | 0 | 536.04+ 266.10 | 0,4 | 0.7 |
| SCCG M10%S M | 469.59 | 724.92 | 181.3 | 0 | 536.04+ 266.10 | 0,4 | 0.7 |
| SCCG M30%S M | 469.59 | 634.32 | 271.9 | 0 | 536.04+ 266.10 | 0,4 | 0.6 |

# Testing

## *Fresh properties*

To evaluate and characterize fresh self-compacting concrete (SCC), the following tests were conducted:

- Slump flow diameter test,
- V-funnel test,
- L-Box test, and
- Sieve stability test for segregation.

## *Hardened properties*

The compressive strengthwas measured at 7, 14, and 28 days using square specimens 15x15x15 (cm). In our case, the compression test was performed on six pieces from three specimens. Each specimen was subjected to a progressively increasing load until failure, using a hydraulic press with a capacity of 2000 kN.

The measurement of wave propagation velocity was conducted using a sonic monitoring device (ultrasonic tester). The device generates electrical pulses that travel through the concrete sample from a transmitting transducer applied to a flat surface. The pulse is captured by a receiving transducer, which is also applied to a flat surface, positioned opposite and parallel to the first. When the pulse is detected by the receiver, the instrument displays the propagation time. Knowing the distance ‘d’ between the two transducers, the velocity of sound in the concrete (VAS) is calculated using the following formula:

$$VAS = \frac{\mathrm{d}}{\mathrm{t}}$$

where **d** is the distance between the transducers and **t** is the time taken for the pulse to travel through the concrete.

The test was conducted in accordance with ASTM C642-97 Standard. The method involves drying prismatic specimens in an oven at 105 ± 5°C for 72 hours. After drying, the specimens are removed from the oven, allowed to cool, and then weighed (M1). They are subsequently fully immersed in water at 21°C for 72 hours. After this period, the specimens are removed, wiped with a towel to remove excess surface water, and then weighed again (M2). The absorption rate is calculated using the following formula:

$$Ab\ (\%) = \frac{\mathrm{M1} - \mathrm{M2}}{\mathrm{M1}} * 100$$

where **M1** is the initial weight of the specimen and **M2** is the weight after immersion.

The dynamic modulus of elasticity was determined using non-destructive testing methods. A sonic testing device was employed to measure the velocity of ultrasonic waves propagating through the concrete specimens. The dynamic modulus of elasticity (Ed) can be calculated using the following formula:

$$Ed = \rho \cdot V^2$$

where **ρ** is the density of the concrete and **V** is the velocity of the ultrasonic waves measured in the specimens.

## Results and discussion

### *Optimization of G/S and SP/L ratios*

For the selection of SCC, we utilized the AFGC method. The superplasticizer/binder (SP/L) and sand/mortar (G/S) ratios were adjusted to achieve highly fluid concrete with a slump flow between 750 and 850 mm (SF3) and a suitable viscosity, with a flow time of less than 5 seconds, as well as high resistance to segregation and no visual signs of bleeding. Optimizing the SP percentage aims to develop the best fresh-state characteristics of the concrete, ensuring optimal hardened performance.

In this study, we tested four compositions with varying SP percentages, from 0.6% to 0.8%. We fixed G/S ratios at 0.9 and 1% and maintained a water/cement (W/C) ratio of 0.40. Table 2 illustrates the spread test results and flow times for selecting the optimal SP percentage and the S/M ratio.

*Table 2 – Different components of the SCC studied (source author)*

| Composition of SCC | | | | | |
|---|---|---|---|---|---|
| MIXTURES | | SCC1 | SCC2 | SCC3 | SCC4 |
| SP % | | 0,6 | 0.7 | 0,75 | 0.8 |
| G/S | | 0.9 | 0.9 | 0.9 | 0.9 |
| | | 0.95 | 0.95 | 0.95 | 0.95 |
| | | 1 | 1 | 1 | 1 |
| Slump Flow | G/S=0.90 | 500 | 570 | 650 | 700 |
| | G/S=0.95 | 520 | 595 | 692 | 730 |
| | G/S=1 | 580 | 620 | 725 | 780 |
| Flow Time | G/S=0.90 | 8 | 6.25 | 5.19 | 4.49 |
| | G/S=0.95 | 7.5 | 5.36 | 4.20 | 4 |
| | G/S=1 | 7 | 5 | 4.05 | 3.5 |
| Visual Observation | G/S=0.90 | Mixture outside recommendation | Mixture within recommendation SF1 Less fluid | Fluid mixture SF1 | Fluid mixture, no signs of bleeding or segregation (SF2) |
| | G/S=0.95 | Mixture outside recommendation | Mixture within recommendation limit SF1 | Fluid mixture SF2 | Fluid mixture, no signs of bleeding or segregation (SF2) |
| | G/S=1 | Mixture within recommendation limit SF1 | Mixture within recommendation limit SF2 | Fluid mixture SF3 | Very Fluid mixture, no signs of bleeding or segregation (SF3) |

Table 2 shows that increasing the percentage of SP improves the flowability of concrete. With a dosage of 0.6%, the slump flow was 500 mm. An increase of 0.1% in the SP dosage leads to an increase of 700 mm in the diameter of concrete.

At a dosage of 0.8%, the concrete exhibited good flowability with a slump flow of 700-780 mm. A G/S ratio of 1 with an SP dosage of 1% is adequate for achieving very fluid (SF3) and homogeneous concretes that can flow through the most congested areas. Numerous studies have shown that a G/S ratio of 1 is the optimal ratio for obtaining very fluid self-compacting concrete.

*Effect of marble aggregate on fresh self-compacting concrete*

To better understand the effect of recycled marble aggregates, the dosage of SP is fixed in the reference mixture.

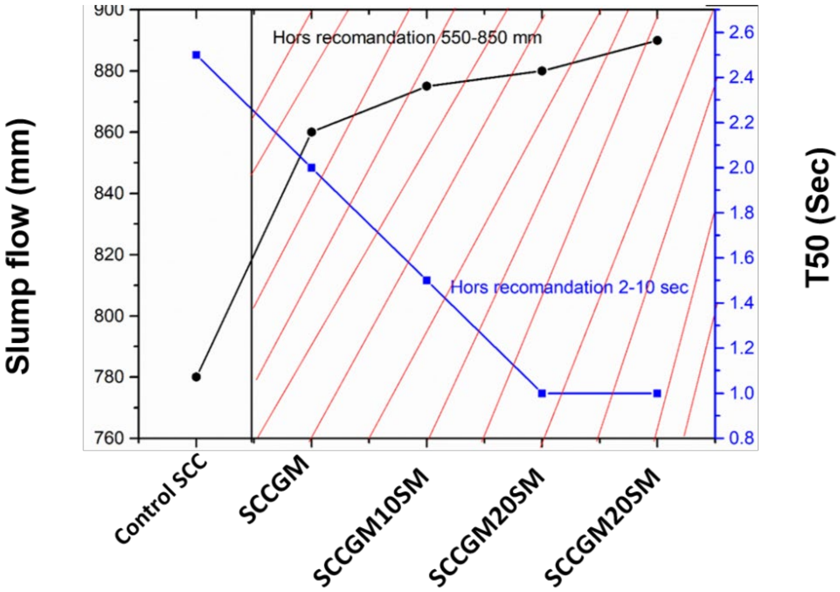


*Figure 1 – Slump flow and T50 as a function of RMA for the SCC mix (source author)*

The effect of substituting recycled marble aggregates (RMA) on the slump properties and the flow time of SCC is illustrated in Figure 1. From the figure, it is observed that the use and increase in the substitution rates of RMA enhance the slump diameter of SCC while decreasing the flow time, with values exceeding the recommended limits by (EFNARC, 2005) and showing significant signs of segregation and bleeding (Figure 2).

(Uygunoğlu, Topçu and Celik, 2014) studied the properties of SCC with marble aggregate and noted that flowability increased as the quantity of marble aggregate increased, particularly with a higher substitution rate SP. (Vaidevi, Kala and Kalaiyarrasi, 2019) investigated the effect of incorporating marble aggregate as fine aggregate on the properties of SCC.

The results indicate that flowability and filling ability are improved when natural sand is partially replaced with marble aggregate.

In summary, the introduction of marble aggregate into SCC mixtures at significant levels enhances fluidity, necessitating a reduction in SP to achieve values according to the required standards. This reduction in SP has minimized the negative impact of SCC on the total cost of 1 m³ of concrete.

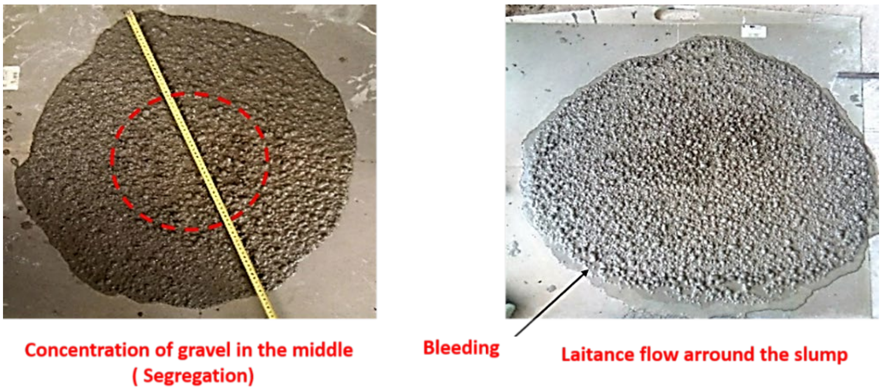


*Figure 2 – Visual control of SCC with 30% RM as sand and 100% RM as gravel (source author)*

## *Effect of marble aggregate on the dosage of superplasticizer in SCC*

Figure 3 illustrates the variation of SP dosage based on the content of recycled marble aggregates (RMA) used in SCC mixtures. The data presented in this figure indicates a clear proportional relationship between the dosage of SP and the percentage of RMA incorporated into the mixtures. As the amount of RMA increases, it becomes necessary to reduce the SP dosage to achieve the desired fluidity and viscosity in accordance with the specified recommendations. This adjustment is crucial for maintaining the workability and performance of concrete, especially in applications where flowability is essential for effective placement and consolidation.

Specifically, the incorporation of 10%, 20%, and 30% of marble aggregate as a fine aggregate, while fully substituting 100% of natural gravel with marble gravel, results in significant reductions in the SP dosage. The reductions are approximately 14%, 31%, and 50%, respectively, for each level of marble aggregate substitution. This trend suggests that higher proportions of RMA not only enhance the fluidity of SCC but also reduce the reliance on chemical admixtures to achieve the necessary performance characteristics.

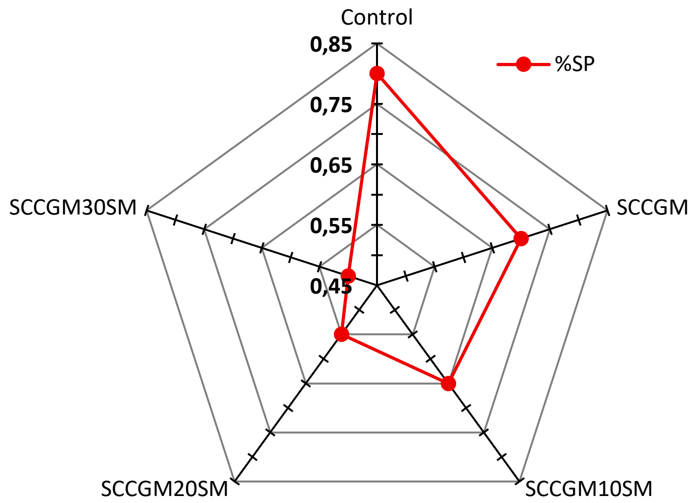


*Figure 3 – Effect of marble aggregate on the dosage of superplasticizer in SCC (source author)*

These findings underscore the importance of optimizing the mix design when utilizing recycled materials in concrete production. By effectively managing the dosage of SP in relation to the amount of RMA, it is possible to maintain high performance in terms of flowability while also minimizing the overall costs associated with the use of chemical additives in the concrete mix.

### *Slump flow with desired superplasticizer*

The results for the slump of various SCC mixtures utilizing recycled marble aggregates (RMA) are illustrated in Figure 4. The figure indicates that the slump diameters for all SCC mixtures fall within the range of 760 mm to 810 mm. This range signifies a notable level of deformability in SCC, which is essential for ensuring effective flow and filling in complex forms without the need for mechanical vibration. These slump flow values are in compliance with the guidelines set forth by EFNARC (EFNARC, 2005), placing them within the category of (SF3). This classification denotes a high level of fluidity and workability, indicating that concrete can effectively fill molds and reach tight spaces, a crucial characteristic for modern construction practices.

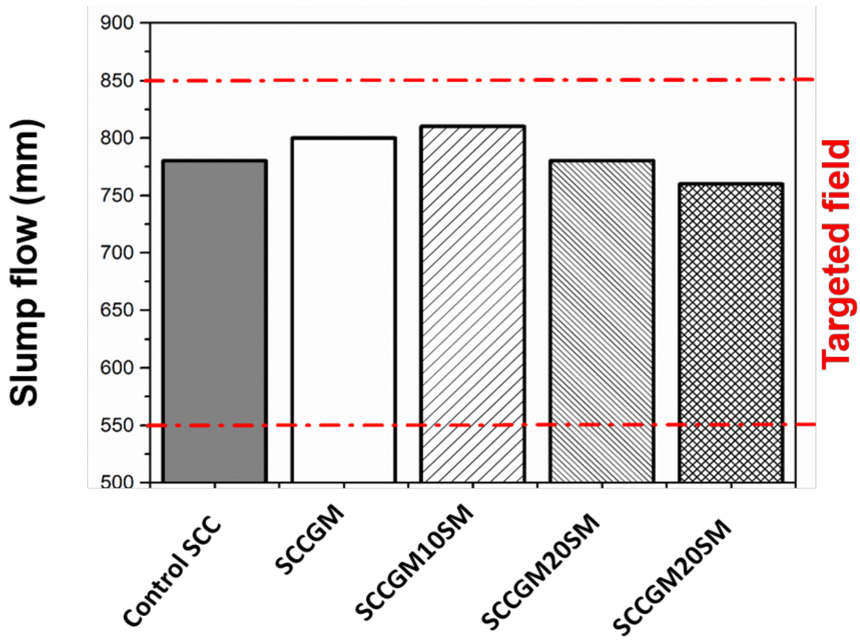


*Figure 4 – Slump flow as a function of RMA with a desired superplasticizer (source author)*

The observed improvement in diameter can be primarily attributed to the unique texture and properties of marble aggregate. Specifically, the low water absorption capacity of marble aggregates contributes to enhanced fluidity in the mixture, allowing for a more uniform distribution of the components and reducing the risk of segregation during placement.

Additionally, a study conducted by (Belaidi et al., 2012) explored how substituting natural aggregates with marble aggregates affects the properties of SCC. Their research highlighted that the inclusion of RMA not only enhances workability but also positively influences other mechanical properties of concrete. The improvements in workability facilitate easier handling and placement, making the construction process more efficient and reducing labor costs.

### *Flow time using the V-funnel test*

Figure 5 illustrates the variation in flow time for the different SCC mixtures studied. According to the results obtained from the V-funnel test, all SCC mixtures exhibited high stability, as their flow times were below the values recommended by EFNARC (EFNARC, 2005). This indicates favorable viscosity characteristics and resistance to segregation within the mixtures.

From Figure 5, it can be observed that the addition of recycled marble aggregates (RMA) increases the flow time of SCC compared to the reference mixture without RMA.

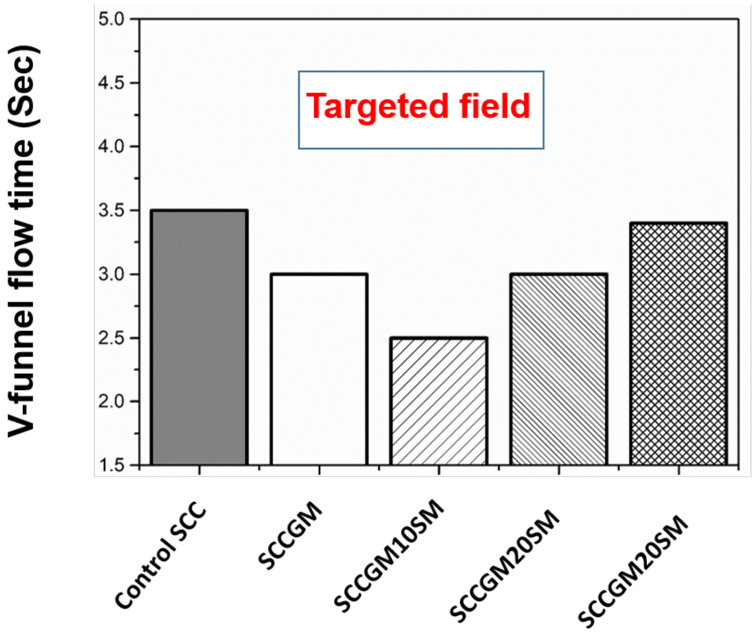


*Figure 5 – V-funnel flow time as a function of RMA with a desired superplasticizer (source author)*

However, the recorded flow times remain within acceptable limits, demonstrating that the properties of SCC can still be maintained despite a reduction in SP dosage. Even with moderate dosages of RMA, the measured flow times indicate that the incorporation of RMA contributes to reducing the SCC viscosity.

In research conducted by (Ofuyatan *et al.*, 2021), the fresh properties of SCC incorporating marble waste were examined. The study found that the flow time decreased as the quantity of marble aggregate increased, particularly with a lower dosage of SP. Optimal flow times were achieved when 30% marble aggregate was added to the mixture, which resulted in reduced viscosity and improved pumpability of concrete in confined areas. This suggests that the inclusion of RMA not only enhances the flow characteristics but also facilitates easier placement in challenging construction scenarios.

## *L-box Test*

The variation of the H2/H1 ratio as a function of the percentage of marble aggregates used as sand and gravel is depicted in Figure 6. Regarding the filling capacity estimated by the H2/H1 ratio measured through the L-box test, all groups of self-compacting concrete (SCC) exhibited excellent filling capacity, mobility, and the ability to pass through highly confined areas.

It is observed that substituting sand with marble and introducing marble as 100% gravel positively influences both the passing ability and filling capacity of the mixtures. Consequently, the H2/H1 ratio varies between 90% and 100%. This variation indicates a significant advantage in achieving rapid flow through the reinforcement bars in the L-box test, which converges more quickly toward the upper threshold. As a result, the values of the H2/H1 ratios increase, reaching up to 100%.

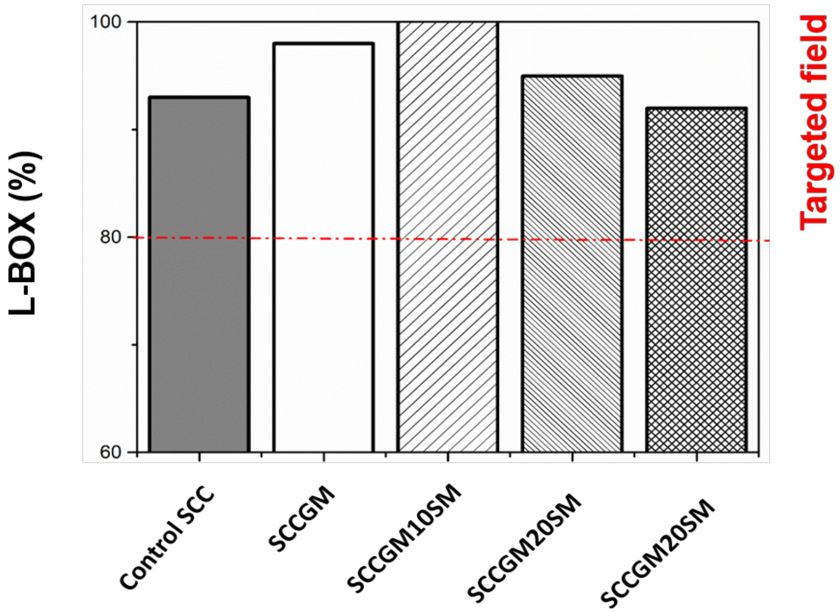


*Figure 6 – L-BOX as a function of RMA with a desired superplasticizer (source author)*

The high H2/H1 ratios demonstrate that SCC mixtures containing marble aggregates can effectively fill complex geometries and pass-through tight spaces, which is crucial for ensuring uniformity and performance in concrete applications. These enhanced flowability and filling capacity are essential for optimizing the placement of concrete in intricate designs, thereby contributing to overall structural integrity and durability.

### *Results of the sieve stability analysis*

The stability of the mixtures was evaluated using a sieve stability test, and the results are illustrated in the histogram form in Figure 7. The percentages of laitance passing through the sieve were observed to range from 5% to 15%. This variation indicates a relatively low amount of laitance, suggesting that all the powder-based SCC produced exhibit commendable resistance to both segregation and bleeding.

Visual inspections of the SCC samples further corroborate these findings, revealing that the mixtures maintain a consistent and homogeneous appearance throughout, as shown in Figure 8. This homogeneity is critical, as it implies a well-dispersed particle distribution, which contributes to the overall stability and performance of concrete in practical applications.

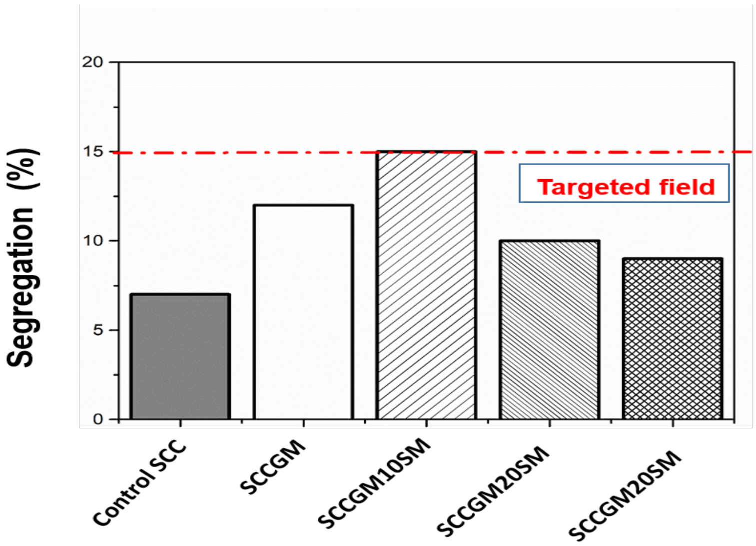


*Figure 7– Segregation as a function of RMA with a desired superplasticizer (source author)*

(Safawi, Iwaki and Miura, 2005) have established that the flow time measured in the V-funnel is an effective tool for assessing the potential for segregation in concrete mixtures. Specifically, they observed that flow times below 2 seconds are indicative of a high susceptibility to segregation, highlighting that lower viscosity mixtures are more prone to separation of components. Our results align with these observations, reinforcing the notion that the measured flow times in our study correspond directly with the sieve stability results.

**SCCGM** **SCCGM20SM** **SCCGM30SM**

*Figure.8 – Visual control of segregation and bleeding of RMA of different SCC mixtures (source author)*

Furthermore, a direct correlation between concrete viscosity and stability were investigated, indicating that reductions in viscosity are associated with decreased stability. This relationship is critical for understanding the behavior of self-compacting concrete mixtures. Our findings, which will be further supported by the data collected on flow times, suggest that maintaining an optimal viscosity is essential for achieving the desired performance characteristics in SCC.

In conclusion, the results of our study indicate that the SCC mixtures tested demonstrate robust resistance to segregation, confirmed by both sieve stability tests and visual assessments. The flow time data further support these findings, suggesting that careful control of viscosity is key to optimizing the performance of self-compacting concrete.

### *Effect of marble aggregate on the compressive strength*

Figure 9 presents the compressive strength development of different SCC mixtures at 7, 14, and 28 days. The results indicate a noticeable increase in compressive strength with the replacement of natural gravel by marble aggregate. For instance, the reference SCC exhibits a compressive strength of 32 MPa at 28 days. With a full 100% substitution of natural gravel by marble aggregate, the strength improves significantly to 43 MPa. This enhancement is attributed to the superior hardness of marble waste compared to natural gravel, which contributes to a denser, stronger concrete matrix.

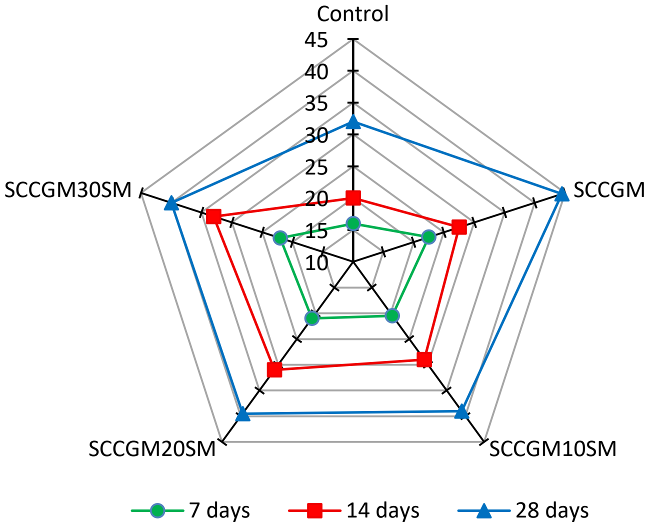


*Figure 9 – Compressive strength of RMA of different SCC mixtures (source author)*

Additionally, the compressive strength of SCC incorporating marble as a fine aggregate (denoted as SCC-MA) reaches 43 MPa at 28 days. However, when 30% of fine natural sand is replaced by marble sand, the compressive strength decreases slightly to 40 MPa. Despite this reduction, the SCC containing marble aggregate still demonstrates higher strength than conventional SCC without any recycled or alternative aggregates.

This observation aligns with findings from (Choudhary et al., 2021), who investigated the impact of marble aggregate on the mechanical properties of self-compacting concrete. Their study reported that adding marble aggregate at substitution levels of 20% and 30% reduced the compressive strength compared to the reference concrete without marble, suggesting that the optimal marble content for enhancing strength may vary depending on its role as coarse or fine aggregate in the concrete mix.

### *Effect of marble aggregate on the sonic pulse velocity*

Figure 10 shows the effect of using 100% GMR as coarse aggregate on the sonic pulse velocity (SPV) test results after a 28-day curing period. The data indicate a steady decrease in SPV values with an increasing proportion of GMR, both as coarse aggregate and in cases where 20% to 30% of natural sand is substituted with marble-based sand.

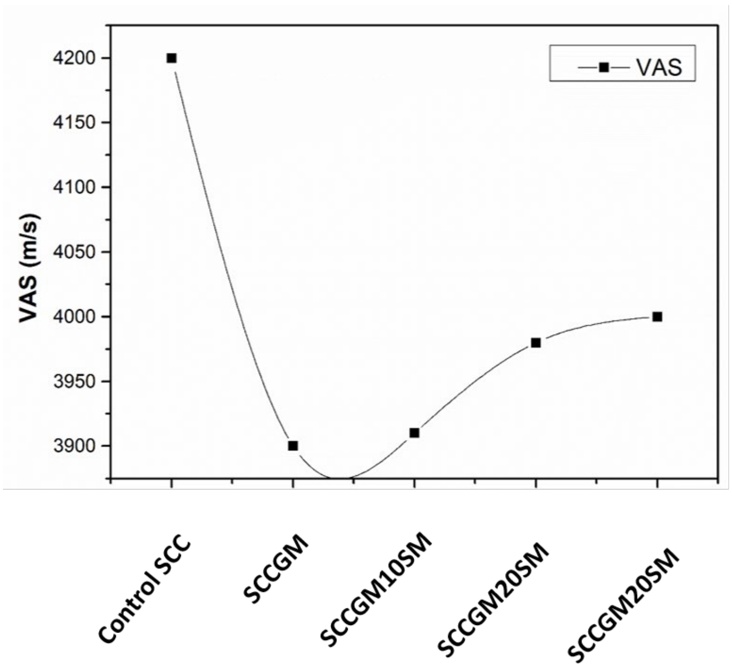


*Figure 10 – VAS as  a function of SCC with RMA ( (source author)*

SPV, or the velocity of sound waves through concrete, is an indicator of the material's quality and integrity. Higher SPV values generally correspond to denser, more homogeneous concrete with fewer pores, voids, or microcracks that might impede the wave path. When concrete contains recycled marble aggregate, however, several factors come into play that impact SPV:

1 **Density**: The presence of GMR tends to reduce the overall density of the concrete matrix. This is because GMR particles often have a mortar coating from previous use, which is less dense than natural aggregates. This lower density material slows down ultrasonic waves, contributing to lower SPV readings.
2 **Porosity and voids**: The residual mortar on GMR particles introduces additional pore space within concrete, creating more voids. This porous structure increases the distance ultrasonic waves need to travel through non-solid areas, thus reducing the overall pulse velocity.
3 **Homogeneity**: In standard SCC, natural aggregates contribute to a uniform, compact matrix that allows sound waves to travel quickly. However, the variability introduced by the GMR's residual mortar can

disrupt this uniformity, causing inconsistencies that further delay wave transmission.

4 **Wave path length**: With higher porosity and greater discontinuity due to residual mortar, the sonic wave encounters more obstacles, which effectively lengthens the path it has to travel. As a result, the wave takes longer to pass through concrete, resulting in lower SPV values.

### *Effect of RMA on capillary water absorption*

The impact of RMA on capillary water absorption in hardened concrete is shown in Figure 11, where a clear trend of reduced water absorption is observed with increasing RMA content.

The reference concrete mix, which contains only natural aggregates, shows the highest absorption coefficient, suggesting a greater porosity and capillary network that can absorb more water. By contrast, as GMR content increases, the absorption coefficient decreases significantly.

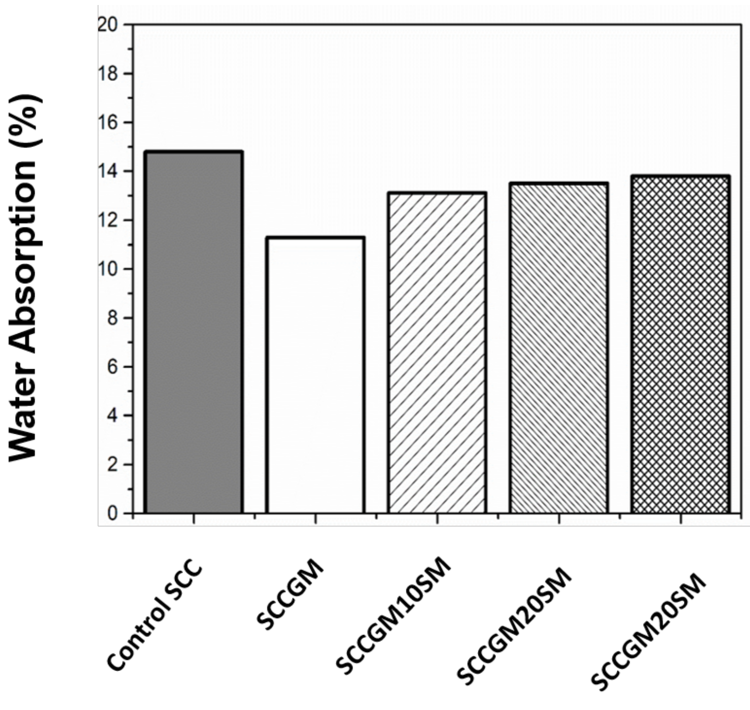


*Figure 11 – Water absorption as a function of SCC with RMA (source author)*

This reduction can be attributed to several key factors:

Low Water Absorption of GMR Particles: Marble-based aggregates are less porous than natural aggregates, meaning they absorb less water.

This characteristic inherently reduces the overall capillary action in the concrete, limiting how much water the material can absorb.

Reduced Connectivity of Capillary Pores: GMR’s coarse particles (typically in the 0-5 mm range) help disrupt the capillary network within the concrete matrix. Larger particles reduce the overall connectivity between pores, effectively blocking some pathways that water would normally travel through, leading to a lower capillary absorption rate.

Dense Microstructure: GMR’s low porosity leads to a denser concrete microstructure, minimizing the spaces through which water can penetrate. As a result, concrete with GMR exhibits improved resistance to water infiltration and, consequently, greater durability under exposure to moisture cycles.

Enhanced Durability against Cyclic Moisture Exposure: With a reduced absorption rate, concrete is better able to resist the expansion and contraction stresses associated with cyclic wetting and drying. This stability under moisture fluctuations helps prevent internal micro-cracking, which can otherwise weaken concrete over time.

When GMR content reaches around 30%, these benefits become particularly pronounced. The combination of GMR’s low water absorption coefficient and its larger particle size means that concrete is less susceptible to capillary water absorption. This makes GMR an effective material for enhancing the durability and lifespan of concrete structures exposed to environments with frequent moisture variation, as the lower capillary absorption limits water-related damage mechanisms.

### *Dynamic elastic modulus of SCC with RMA*

According to Figure 12, the dynamic elastic modulus of self-compacting concrete (SCC) with recycled marble aggregates follows a similar trend to the sonic pulse velocity (SPV) results. Additionally, SCC containing marble aggregates as both sand and gravel shows high elastic modulus values, likely due to the high compressive strength of these mixtures. The dynamic elastic modulus is highly influenced by the type of aggregate, as well as the material's compressive strength and density.

Replacing natural gravel with 100% marble gravel reduces the elastic modulus by approximately 30% compared to the reference concrete. Similarly, substituting natural sand with marble sand at 10%, 20%, and 30% decreases the elastic modulus by 21%, 11%, and 5%, respectively, relative to the reference SCC.

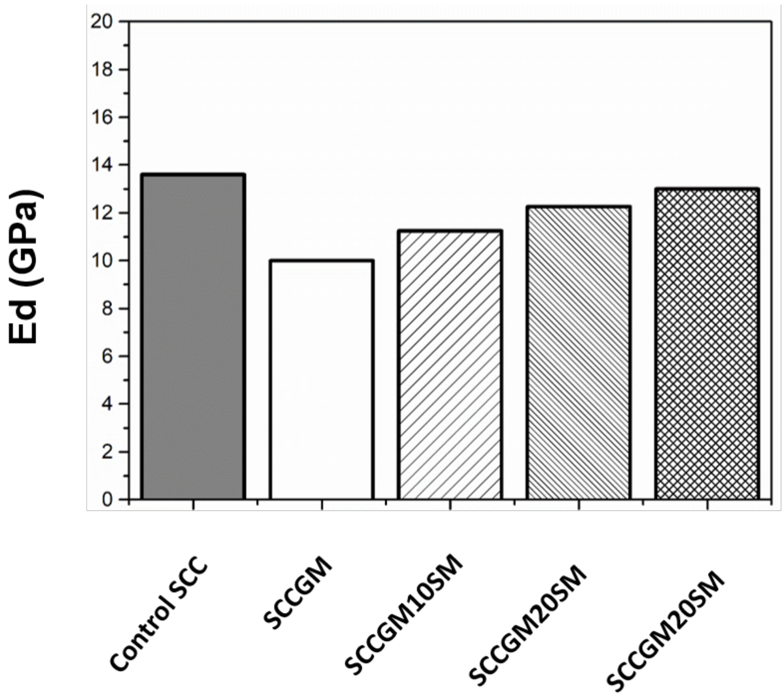


*Figure.12 – Dynamic elastic modulus as a function of SCC with RMA (source author)*

The reduction in the elastic modulus can be attributed to increased porosity, which influences how ultrasonic waves travel through the material. Higher porosity results in more wave absorption and a lower elastic modulus. Consequently, while recycled marble aggregates contribute to a high initial compressive strength, their influence on porosity and the dynamic elastic modulus must be considered in applications requiring high material stiffness.

## Conclusion

The primary objective of this study was to evaluate the impact of recycled marble waste (RMW), utilized at various percentages as both sand and gravel, on the performance of self-compacting concrete (SCC). Based on the comprehensive analysis of the results, the following conclusions can be drawn.

The investigation revealed that for the effective formulation of SCC using local materials, an optimal water-to-cement (W/C) ratio of 0.4 and a gravel-to-sand (G/S) ratio of 1 were necessary. Additionally, incorporating 0.8% superplasticizer (SP) was essential to achieve the desired workability and mechanical properties. These parameters are crucial for ensuring that SCC meets the required performance standards while maintaining cost efficiency.

The introduction of RMW as both fine and coarse aggregates led to a significant reduction in the demand for SP, approximately by 60%. This reduction not only highlights the effectiveness of RMW in enhancing the flow characteristics of concrete but also contributes to lower overall material costs, making SCC more economically viable.

The presence of RMW demonstrated a marked improvement in the flowability and filling ability of SCC. This characteristic is vital for ensuring that concrete can adequately fill complex forms and achieve a high level of homogeneity, which is essential for structural integrity.

An increase in the percentage of marble used as coarse aggregate resulted in a substantial enhancement of compressive strength, with an increase of approximately 26% compared to traditional self-compacting concrete (TSCC). This improvement indicates that RMW can effectively contribute to the structural performance of concrete, potentially leading to more durable and resilient construction materials.

Notably, a decrease in compressive strength was observed when marble was used as sand, compared to its application as gravel. However, it is important to highlight that the compressive strength of SCC with marble as sand remained superior to that of TSCC. This finding suggests that while the choice of aggregate type influences strength characteristics, RMW continues to offer viable performance.

The total immersion water absorption of SCC decreased with an increasing proportion of marble, whether used as sand or gravel. This reduction in water absorption is indicative of improved impermeability and durability, which are critical factors for the longevity of concrete structures.

The addition of RMW also led to a significant enhancement in the elastic modulus of the SCC studied. A higher elastic modulus is associated with improved stiffness and stability, contributing positively to the overall performance of the concrete under load.

In conclusion, this study underscores the promising potential of recycled marble waste as a sustainable alternative in the formulation of self-compacting concrete. By utilizing RMW, the construction industry can achieve enhanced performance characteristics while simultaneously addressing environmental concerns related to waste management. These findings pave the way for future research aimed at optimizing the use of recycled materials in concrete applications, ultimately contributing to more sustainable construction practices.

## References


Alyamaç, K. and Aydin, A. (2015) 'Concrete properties containing fine aggregate marble powder', *KSCE Journal of Civil Engineering*, 19. Available at: https://doi.org/10.1007/s12205-015-0327-y.

Belaidi, A.S.E. *et al.* (2012) 'Effect of natural pozzolana and marble powder on the properties of self-compacting concrete', *Construction and Building Materials*, 31, pp. 251–257. Available at: https://doi.org/10.1016/j.conbuildmat.2011.12.109.

Choudhary, R. *et al.* (2021) 'Permeation, corrosion, and drying shrinkage assessment of self-compacting high strength concrete comprising waste marble slurry and fly ash, with silica fume', *Structures*, 33, pp. 971–985. Available at: https://doi.org/10.1016/j.istruc.2021.05.008.

Demirel, B. (2010) 'The effect of the using waste marble dust as fine sand on the mechanical properties of the concrete', *International Journal of the Physical Sciences*, 5, pp. 1372–1380, ISSN 1992 - 1950.

EFNARC (2005) *EFNARC, M. The European Federation of Specialist Construction and Concrete System: The European Guidelines for Self-Compacting Concrete. Specification, Production and Use, 2005. - Recherche Google*. Available at: https://www.theconcreteinitiative.eu/images/ECP_Documents/EuropeanGuidelinesSelfCompactingConcrete.pdf.

Gazi, A., Skevis, G. and Founti, M. (2012) 'Energy efficiency and environmental assessment of a typical marble quarry and processing plant', *Journal of Cleaner Production*, 32, pp. 10–21. Available at: https://doi.org/10.1016/j.jclepro.2012.03.007.

Houria, H. *et al.* (2020) 'Introduction of Marble Waste Sand in the Composition of Mortar', in. Available at: https://doi.org/10.5772/intechopen.91254.

Khairi, W. *et al.* (2020) 'Relation between rheological and mechanical properties on behaviour of self-compacting concrete (SCC) containing recycled plastic fibres: a review', *European Journal of Environmental and Civil Engineering*, 26. Available at: https://doi.org/10.1080/19648189.2020.1868344.

Kore, S. and Vyas, A. (2016) 'Impact of Marble Waste as Coarse Aggregate on properties of lean cement concrete', *Case Studies in Construction Materials*, 4. Available at: https://doi.org/10.1016/j.cscm.2016.01.002.

Makul, N., Fediuk, R., Amran, M., Zeyad, A., Azevedo, A., *et al.* (2021) 'Capacity to Develop Recycled Aggregate Concrete in South East Asia', *Buildings*, 11, p. 234. Available at: https://doi.org/10.3390/buildings11060234.

Makul, N., Fediuk, R., Amran, M., Zeyad, A., Murali, G., *et al.* (2021) 'Use of Recycled Concrete Aggregates in Production of Green Cement-Based Concrete

Composites: A Review'. Available at: https://hdl.handle.net/10877/14139 (Accessed: 16 June 2025).

Mathodi, V. *et al.* (2022) 'Environmental impact assessment of laterite quarrying from Netravati–Gurpur river basin, South West Coast of India', *Environment, Development and Sustainability*, 26, pp. 1–22. Available at: https://doi.org/10.1007/s10668-022-02741-5.

Ofuyatan, O. *et al.* (2021) 'Marble waste and recycled concrete aggregates in self compacting concrete (SSC): an evaluation of fresh and hardened properties', *Australian Journal of Civil Engineering*, 20, pp. 1–13. Available at: https://doi.org/10.1080/14488353.2021.1921342.

Ouldkhaoua, Y. *et al.* (2019) 'Experimental study on the reuse of cathode ray tubes funnel glass as fine aggregate for developing an ecological self-compacting mortar incorporating metakaolin', *Journal of Building Engineering*, 27, p. 100951. Available at: https://doi.org/10.1016/j.jobe.2019.100951.

Rich, D. (2014) *On-site application of self-compacting concrete (SCC)*. thesis. Loughborough University. Available at: https://repository.lboro.ac.uk/articles/thesis/On-site_application_of_self-compacting_concrete_SCC_/9579296/1.

Safawi, M., Iwaki, I. and Miura, T. (2005) 'A study on the applicability of vibration in fresh high fluidity concrete', *Cement and Concrete Research*, 35, pp. 1834–1845. Available at: https://doi.org/10.1016/j.cemconres.2004.10.031.

Silva, R.V., Brito, J. and Dhir, R. (2018) 'Fresh-state performance of recycled aggregate concrete: A review', *Construction and Building Materials*, 178, pp. 19–31. Available at: https://doi.org/10.1016/j.conbuildmat.2018.05.149.

Thakur, A.K., Pappu, A. and Thakur, V.K. (2018) 'Resource efficiency impact on marble waste recycling towards sustainable green construction materials', *Reuse and Recycling / UN SGDs: How can Sustainable Chemistry Contribute? / Green Chemistry in Education*, 13, pp. 91–101. Available at: https://doi.org/10.1016/j.cogsc.2018.06.005.

Uygunoğlu, T., Topçu, İ. and Celik, A. (2014) 'Use of waste marble and recycled aggregates in self-compacting concrete for environmental sustainability', *Journal of Cleaner Production*, 84, pp. 691–700. Available at: https://doi.org/10.1016/j.jclepro.2014.06.019.

Vaidevi, C., Kala, D. and Kalaiyarrasi, A.R.R. (2019) 'Mechanical and durability properties of self-compacting concrete with marble fine aggregate', *Materials Today: Proceedings*, 22. Available at: https://doi.org/10.1016/j.matpr.2019.11.019.

Yu, Y. *et al.* (2024) 'Investigating specimen size and shape effects on compressive mechanical behaviors of recycled aggregate concrete using discrete element mesoscale modeling', *Construction and Building Materials*, 438, p. 137196. Available at: https://doi.org/10.1016/j.conbuildmat.2024.137196.

# Одрживи самозбијајући бетон: утицај комбинованог мермерног отпада у облику финог и крупног агрегата

*Белгасем* Мохамед Ел Газали, **аутор за преписку,** *Оулдкауа* Јунес, *Херихири* Оуидед, *Садуди* Љасија, *Аруџ* Карима
Универзитет наука и технологије Хуари Бумедјен

ОБЛАСТ: материјали
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

*Сажетак:*

*Увод/циљ: Заштита животне средине путем рециклирања отпада један је од највећих изазова данашњице. Инертни отпад, настао углавном у индустрији, представља знатан удео који штети животној средини јер се акумулира у природи.*

*Методе: Испитиван је утицај валоризације мермерног отпада у облику песка и шљунка на реолошка и механичка својства самозбијајућег бетона (SCC). За потребе истраживања мермер је коришћен као фини агрегатни песак (MAS) у количинама од 10%, 20%, и 30%, а као крупни агрегатни шљунак (MAG) у количини од 100%.*

*Резултати: Показано је да је увођење мермерног отпада (MW) као агрегата имало позитиван утицај на реолошке карактеристике, знатно смањујући потребу за дозирањем суперпластификатора.*

*Закључак: Имајући у виду механичке моменте, коришћење крупног агрегатног шљунка довело је до побољшања механичке чврстоће.*

*Кључне речи: самозбијајући бетон, мермерни отпад, реолошко понашање, дозирање суперпластификатора, механичка чврстоћа, животна средина*

Paper received on: 07.05.2025.
Manuscript corrections submitted on:23.05.2025.
Paper accepted for publishing on: 20.06.2025.