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REVIEW

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Self-Compacting Concrete with Partially Substitution of Waste Marble: A Review

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Abstract

Self-compacting concrete (SCC) is also seen as unsustainable since it uses a lot of natural resources. Recent researchers have focused on lowering construction costs and partially replacing cement with industrial waste. It is possible to effectively use various industrial wastes in concrete as cement or aggregates. Among these wastes, waste marble (WM) is a useful choice, and researchers have been interested in using WM in concrete for a couple of years. However, to pinpoint the advantages and recent advancements of research on WM as an ingredient of SCC, a comprehensive study is necessary. Therefore, the purpose of this study is to do a compressive evaluation of WM as an SCC ingredient. The review includes a general introduction to SCC and WM, the filling and passing capability of SCC, strength properties of SCC, durability, and microstructure analysis of SCC. According to the findings, WM improved the concrete strength and durability of SCC by up to 20% substitution due to micro-filling and pozzolanic reaction. Finally, the review also identifies research gaps for future investigations.

Keywords Waste marble, Chemical composition, Mechanical performance, Durability and scanning electronic microscopy

1 Introduction

Self-compacting concrete (SCC) is a modern improvement in the concrete industry that first debuted in Japan two decencies ago. Practical applications of SCC include filling in severely fortified areas and enhancing the capabilities of in-situ concrete (Ashish & Verma, 2019b). But compared to regular concrete, the cost of making SCC is greater (20–50%) (Nehdi et al., 2004). The increased expense of SCC is attributable to the need for chemical admixtures and a large proportion of Portland cement, both of which are used to achieve the appropriate fluidity (Ashish & Verma, 2019a). Numerous significant research regarding SCC has been conducted in recent years. The presence of filling material in the SCC blend is the key distinction between SCC and regular concrete. As a result, the influence of filling materials on the attributes of SCC has also been the subject of several investigations. These research findings suggest that using filler materials in SCC results in enhanced workability and lower cement percentages (Topcu et al., 2009). Low hydration heat and less shrinkage cracking may also be attained with filler materials (pozzolanic materials). According to research, utilizing fine materials with varied grain sizes and morphologies improves SCC performance over the long run by increasing compactness and lowering the danger of cracking compared to heat hydration (Boukendakdji et al., 2012). Additionally, lowering the cement concentration of concrete might be seen as an economical approach since cement is the most costly component of concrete. Additionally, the gaps between the particles are filled, allowing for the creation of impermeable concrete. Consequently, concrete's resilience is also improved (Assie et al., 2007). Actually, by enhancing the particle

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grading and wrapping, the introduction of extra cementitious ingredients results in enhanced workability and cohesiveness (Sonebi and BARTOS 1999). By employing filler resources like limestone powder as a filler, SSC is another concrete technology promoting sustainable growth. The inclusion of particles that may be divided into two categories as inert or pozzolanic can increase the SCC's fresh rheological properties, strength, and durability (Domone, 2006). The quantity and the kind of cementitious or inert powders used depend on the powders' physical and chemical characteristics, which affect how well fresh paste performs. Due to the complicated interaction of various components, there are no recognized criteria for their impact (Felekoğlu et al., 2006).

Over the last three decades, the construction industry has taken a number of steps, particularly in the United Kingdom, to limit the release of harmful chemicals associated with cement manufacturing. Alternative options involve developing a greater efficient clinker grinding process, integrating sustainable cement manufacture, substituting organic gas for coal in calcination, and utilizing chemicals to absorb carbon dioxide. Using cementitious materials, on the other hand, might be a realistic strategy for drastically reducing carbon emissions. Manufacturing wastes, such as fly ash, metakaolin, waste glass, waste marble, and silica fume, are used to substitute cement, which has the potential to dramatically decrease greenhouse gas releases.

A number of academics are currently deepening their research on renewable resource use and worldwide environmental preservation (Ahmad et al., 2022a, 2022b, 2022c, 2022d). Sustainable development is a type of assessment that aims to raise living standards while also satisfying the needs of coming generations. Its objectives include, among others, meeting basic needs, improving living conditions, and promoting the preservation and management of ecosystems (Smith et al., 2002). The reuse of diverse industrial wastes is increasing quickly on a global scale in reaction to raising community worries about ecological depreciation, the reduction of fossil fuels, and sustainable growth (Zhang et al., 2020). Overall, the development of cement, a crucial element in concrete (Siddique et al., 2018), is a substantial source of dangerous gas emissions such as carbon dioxide (Amin et al., 2020). Recent research has focused on lowering construction costs and partially replacing cement with industrial waste. Several experiments have examined the characteristics of freshly laid and cured concrete by partially replacing cement with industrial effluents (Rollakanti et al., 2020). The annual proportion of trash production is shown in Fig. 1. In the majority of developing nations, the most urgent problem is waste reduction and effective waste management (Aruntaş et al., 2010). Among these byproducts, WM provides a potential cement alternative. Recycling building and demolition debris results in energy savings since less massive rocks

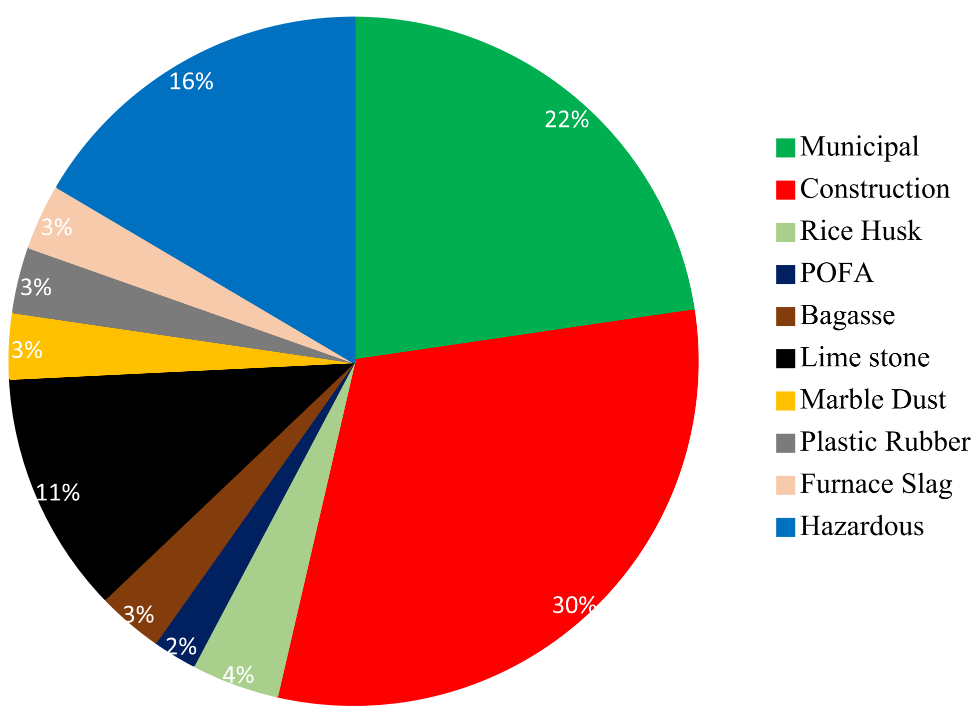

Fig. 1 Different waste production (Ofuyatan et al., 2022)

need to be processed via blasting to create the waste. Building interiors and exteriors both employ WM for decoration and esthetics. Buildings use it for 70% of their finishes, and since trash is deposited indiscriminately, it pollutes the environment.

Numerous studies favor the use of WM in cementitious products to replace cement (Elyamany et al., 2014). According to research, utilizing WM powder may significantly improve the characteristics of concrete (Ashish et al., 2016), however depending on the kind of cement used, replacing sand with WM powder results in higher performance for concrete (Aliabdo et al., 2014). According to research, concrete samples made with blast furnace slag and WM had far greater durability than control concrete. Additionally, there is a significantly improved connection between the additives and the binder in the samples that include WM, granite, and pulverized blast furnace slag (Binici et al., 2008). A study looked at how WM affected the shrinkage and compressive strength (CS) of blends. They concluded that the increase in WM replacement results in lower shrinkage. Furthermore, the carbonation depth is boosted (Abd Elmoaty 2013) due to poor matrix.

A brief review of the literature demonstrates that although SCC has a lot of advantages over conventional concrete but still not treated as conventional concrete due to a lack of knowledge. Therefore more details research is required. Furthermore, SCC is also thought to be unsustainable due greater quantity of filler requirement which also restricts its practically used. Recent researchers have concentrated on lowering construction costs and partially replacing cement with industrial waste. Although researchers suggest that WM is reliable for use as cement or aggregates in concrete. However, to pinpoint the advantages and recent advancements of research on WM as a concrete ingredient, a comprehensive study is needed. This study intends to do a compressive evaluation of WM as an SCC ingredient. The main focuses of this study are the general introduction of SCC and WM, the filling and passing capacity of SCC, the strength characteristics, durability, and microstructure analysis of SCC. According to the results, WM improved concrete strength and durability but lowered SCC capacity for filling and passing. Finally, the analysis also detects areas of unsolved research for future investigations.

2 Physical and Chemical Properties

Physical characteristics, such as specific gravity, absorption, particle size distribution, fineness, moisture, and density, are a few of the physical characteristics of WM that help define its suitability for use in concrete. WM is mostly white in color. But the color depends on the WM type. WM has a specific gravity of 2.71 (Ofuyatan et al., 2019), roughly equivalent to cement (3.0). The water absorption of WM was stated at 3.13% (Ofuyatan et al., 2022), which negatively impacts workability. The bulk density of WM is 13.75 kg/m^3 (Choudhary et al., 2021) which is slightly lower than the bulk density of cement (1440 kg/m^3). The chemical makeup of WM is comparable to cement and may be used as a binder in concrete. Fig. 2 shows the chemical makeup and XRD analysis of WM.

WM has a greater percentage of amorphous SiO_2 and microscopic particle size, making it a pozzolanic material. The sum of all the following components (magnesium, alumina, iron, lime, and lime) in WM is more than 70%. Therefore, if the total sum of silica, iron, lime, magnesium, and alumina is more than 70%, the materials may be categorized as pozzolanic materials, as per ASTM (ASTM, 2017). It should be noted that WM comprises more than 70% of the stated component. The WM has the capacity to be used in the substitution of binders in concrete. The WM's amorphous shape makes it highly reactive, allowing for a reaction between silica (found in WM) and calcium hydroxide (CH), which forms during the hydration of cement. The pozzolanic reaction leads to the formation of calcium silicate hydrates (CSH) (Ahmad et al., 2021a, 2021b, 2021c). Concrete durability and strength have increased because of the CSH binding qualities. The waste WM pictures from a scanning electron microscope (SEM) are displayed in Fig. 3.

The SEM morphology showed some bigger WM particles and tiny particles with fine clay particles in the agglomerated state. Additionally, it should be noticed that WM particles have an angular form and a rough surface. Due to increased friction, WM angular and harsh surface particles decreased the flow properties. However, the interlocking of the angular and rough surfaces may improve the concrete's strength properties.

3 Fresh Properties

3.1 Air Content

The air content of SCC decreased with the addition of WM as filler materials as shown in Fig. 4. For an SCC, the maximum allowed air content percentage is 5% (Alyousef et al., 2018a). According to research, the four SCC formulations range in air concentration from 1.2 percent to 3.2 percent. These numbers demonstrate that the four SCC are at their most compact without vibrating or clamping (air content less than 5%). The results also demonstrate that when paste volume is increased, SCC becomes more compact (Alyousef et al., 2018a). Research revealed that the air concentration of SCC was decreased when discarded glass was replaced. According to the study, concrete containing 25, 50, and 75% of fine glass aggregate had an air content of 3.0 to 3.5 regardless

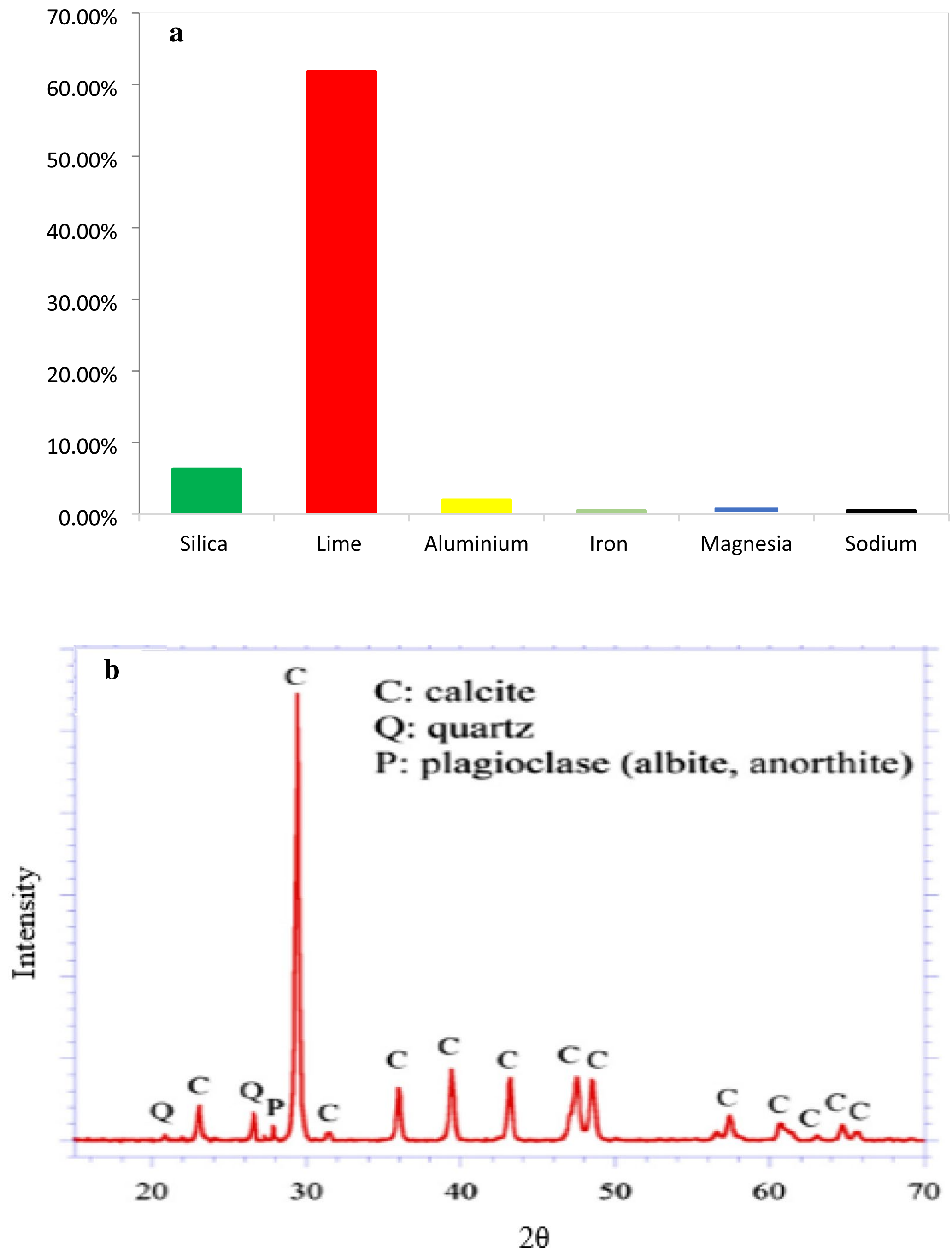

Fig. 2 (**a**) Chemical composition (Amani et al., 2021) and (**b**) XRD (Sutcu et al., 2015)

of the kind of glass utilized Tan and Hongjian (2013). Using WM in SCC has increased the amount of air in the compound. The water requirement for lubrication on filler particles has changed for the same w/c ratio as a result of the increase in filler content (Topcu et al., 2009). Reusing WM as sand in SCC decreases density and air content, assures cohesiveness, and resists segregation, according to research (Djebien et al., 2018). Research has also shown that regardless of the replacement rate, adding WM sand causes the air content to drop. When 15% WM sand is added to the mortar, the volume of occluded air somewhat drops from 7.4% for the control sample to 4.8%. The large decrease in the amount of air that is entrained in WM sand composite mortars is due to the

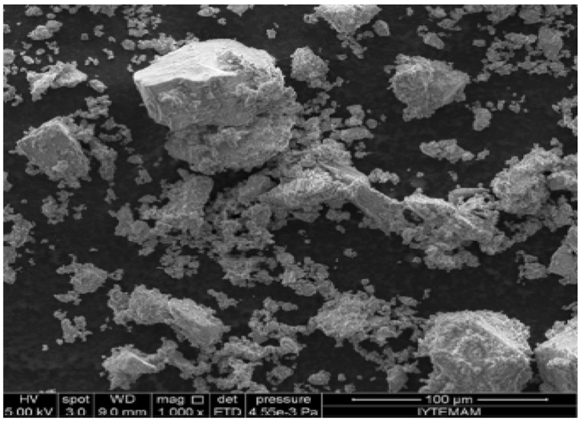

Fig. 3 SEM of marble particles (Sutcu et al., 2015)

mixes being more compact when WM sand has been used in place of natural sand (Djebien et al., 2015).

3.2 Slump Flow and Slump T50

The slump flow of SCC increased and slump T50 time decreased with the addition of WM as filler materials as shown in Fig. 5. The slump-flow test is a value-system measuring concrete's capacity to deform when subjected to its weight and surface friction without the presence of external restraints (Felekoğlu et al., 2007). Research is done on SCC as a 10–30% granite alternative manufactured from WM and recycled aggregates (RA). With increasing partial replacement with WM, slump flow may be seen to have risen (from 560 to 570 mm). Additionally, more recycled material lessens the concrete's slump flow (from 550 to 500 mm). This is because recycled aggregate has a high rate of water absorption. Results for WM were acceptable, while those for recycled aggregate (> 20 weight percent partial substitution) were not. For the T50 cm, it was noted that an increase in the percentage of recycled aggregate appears to lengthen the time it brings for the concrete to achieve the 50 cm mark on the flat board (from 7.40 to 8.00 s). This is a result of poor ability to flow. When the proportion of WM is raised, the time required for the concrete to reach the 50 cm threshold is shortened (from 5.65 to 5.36 s). In summary, although using WM enhanced the flowability of the SCC, using recycled aggregate as a partial substitute for granite decreased it (Ofuyatan et al., 2022).

A study has shown that switching from cement to WM reduces slump. However, WM has a greater specific area than Portland cement. The replacement had less flowability since there was more friction. However, it was shown that the slump increases when WM replaces the sand. It results from the WM's fine-filling action (Ashish, 2018). In research that looked at how the qualities of SCC would change when WM was substituted, improvements to concrete's workability were shown to have a detrimental impact on CS by percentages ranging from 10 to 40% (Belaidi et al., 2012). Compared to secondary cementitious materials (SCMs)

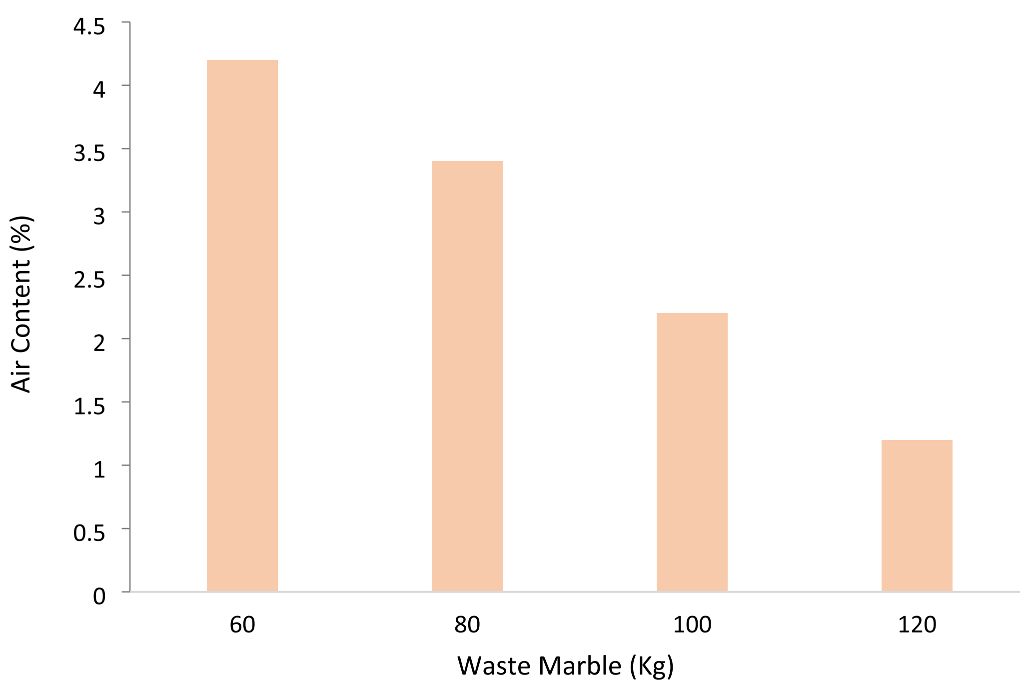

Fig. 4 Air content (Alyousef et al., 2018a)

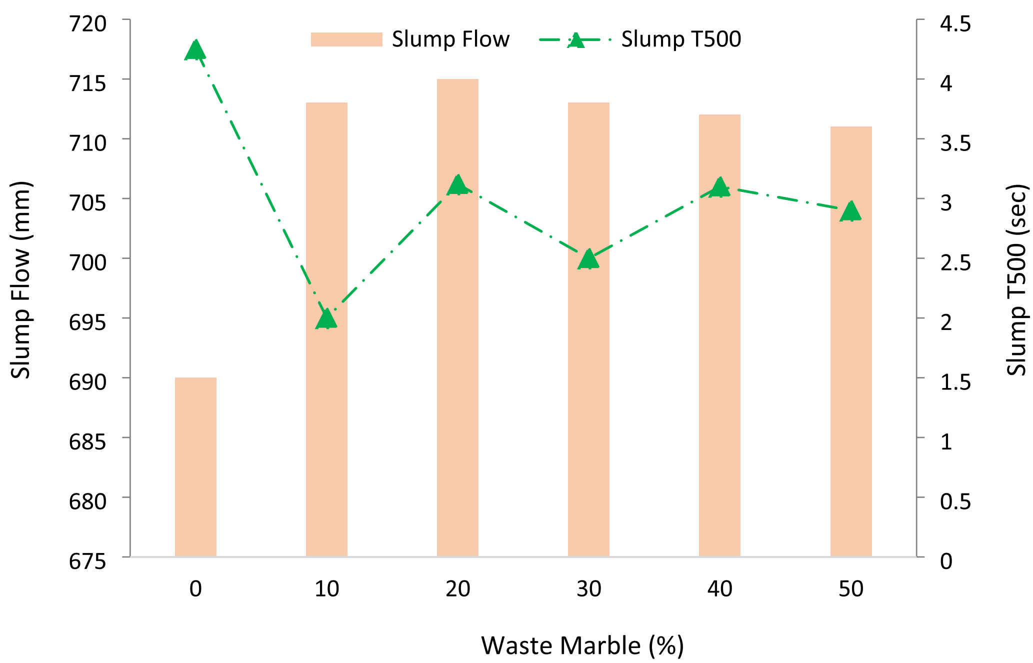

Fig. 5 Slump flow and slump T50 (Pattapu & Lal n.d.)

containing 6% silica fume, mortars made entirely of cement are much less cohesive. Because there is more interaction between the fly ash's higher cohesiveness and silica fume, the flowability of mortars containing silica fume is less good than that of mortars containing fly ash (Turk, 2012).

3.3 V Funnel and L Box Ratio

The v funnel time decreased, and the L box ratio increased with the addition of WM as filler materials as demonstrated in Fig. 6. The rheological and strength characteristics of SCC are examined with the incorporation of WM as an additional cementation material. All

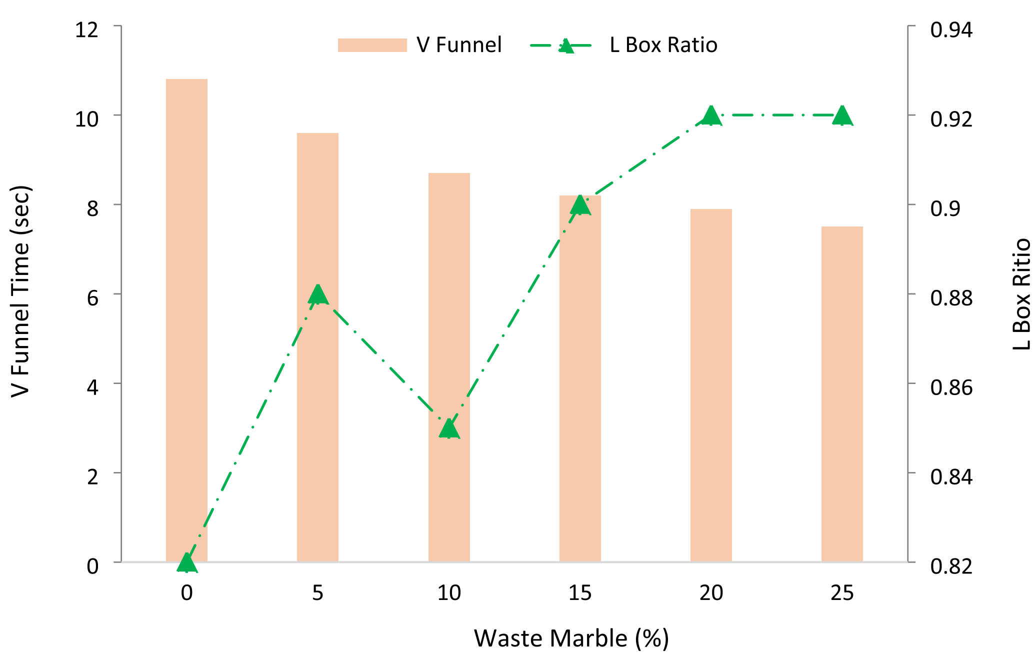

Fig. 6 V Funnel and L box ratio (Pala et al., 2015)

mixtures had a v-funnel flow time that differed from 5 to 6.6 s. It should be noted that all mixes, except the control mix, do not meet the EFNARC's minimum needs for v-funnel flow time (EFNARC & Specification, 2002).

However, several studies were able to produce a satisfactory SCC with v-funnel flow times less than 6 s, therefore these values are acceptable (Khayat & Manai, 1996). shown visually that there is no bleeding or segregation issue. Research is done on SCC as a 10–30% granite alternative manufactured from recycled aggregates (RA) and WM. It was found that the flow time rose from 8.10 to 9.32 s as the percentage of RA grew, indicating that the flowability diminished with increasing RA amounts. For WM, it was the exact reverse (from 7.45 to 7.10 s) (Ofuyatan et al., 2022). According to the study, the V funnel gradually shrinks as the silica fume proportion rises, indicating that this facilitates the vertical movement of bits by fewer air bubbles that hinder paste flow vertically (Arshad et al., 2021). But according to a study (Sharbatdar et al., 2020), 5 percent silica fume resulted in a ratio of 0.78, which is higher than the allowable limit for SCC as specified by technical standards. Although studies (Hamzah et al., 2015) showed that ratios up to 0.60 had good passage capability The technical specification declares that for the SCC to have a good passing capability, the blocking ratio value should be greater than 0.80 (Iqbal et al., 2017).

Utilizing silica fume and waste WM in substitution of cement to the extent of 30% and 5%, respectively, allowed researchers to examine the fresh qualities of SCC. As a result, the fresh characteristics are up to 20% better when WM is used to substitute cement Choudhary et al. (2019). For all the SCC combinations, the blocking ratios varied from 0.88 to 0.96, which is within the SCC limit. Due to micro-filling, WM had a beneficial effect. The research found that when the quantity of WM sludge increases, the ratio of (h_2/h_1) falls. This outcome is a result of the SCC's increased viscosity caused by the substantial quantity of WM (Alyousef et al., 2018b). A researcher asserts that because the V funnel investigation revealed that the viscosity of glass-based SCC has been lowered, the separation parameter will prevail for this kind of concrete (Sharifi et al., 2013). According to the research, improving the quantity of glass powder in the mix while maintaining the quantities of all the other mix constituents improves the concrete's flowability. The gain in flowability with more WG may be due to this improvement in compact packing (Rehman et al., 2018). WM-SCC showed greater blocking ratios than SCC using recycled aggregates, according to research. However, for recycled aggregates and WM SCC, the blocking ratios decreased by boosting the substitute from 0.84 to 0.80 and from 0.95 to 0.85, respectively (Ofuyatan et al., 2022). Table 1 depicts the summary of fresh properties of SCC with WM substitutions.

3.4 Yield Stress and Plastic Viscosity

Low yield stress is necessary to produce highly mobile concrete, while high viscosity is needed to produce concrete with great resistance to separation. Unfortunately, adding water also decreases viscosity, making it unable to reduce yield stress. Although the viscosity will only be somewhat reduced by the use of a superplasticizer, the yield stress will also be decreased. A mix's viscosity may be raised by altering its parts, adding a viscosity modifier, or adding filler components. Fig. 7 shows the yield stress and plastic viscosity with the substitution of WM. It can be noted that the yield stress and viscosity both

Table 1 Summary of filling and passing ability of concrete with WM

Ref.	Percentage Range of WM	Replacement	*W/C*	Slump Flow (600 to 850 mm)	Slump T50 (2 to 5 s)	V Funnel (6 to 12 s)	L Box Ratio (0.8 to 1.0)	Remarks
(Topcu et al., 2009)	0 to 50%	Cement	0.38	820 to 590	–	–	–	Not within the limit of SCC
(Boukhelkhal et al., 2016)	0 to 20%	Cement	0.40	705 to 740	–	6.6 to 5.0	–	Within the limit of SCC
(Ofuyatan et al., 2022)	0 to 30%	Coarse Aggregate	0.40	560 to 570	–	7.2 to 7.0	0.95 to 0.85	Not within the limit of SCC
(Choudhary et al., 2019)	0 to 30%	Cement	0.36	–	3.0 to 5.0	12 to 10	0.92 to 0.88	Within the limit of SCC
(Pala et al., 2015)	0 to 25%	Sand	0.36	–	4.5 to 3.0	10.8 to 7.5	0.82 to 0.92	Within the limit of SCC
(Rahman et al., 2019)	0 to 50%	Sand	–	670 to 740	4.3 to 2.1	10.2 to 8.4	–	Within the limit of SCC
(Pattapu and Lal n.d.)	0 to 50%	Cement	0.33	690 to 711	4.25 to 2.9	–	0.8 to 0.99	Within the limit of SCC

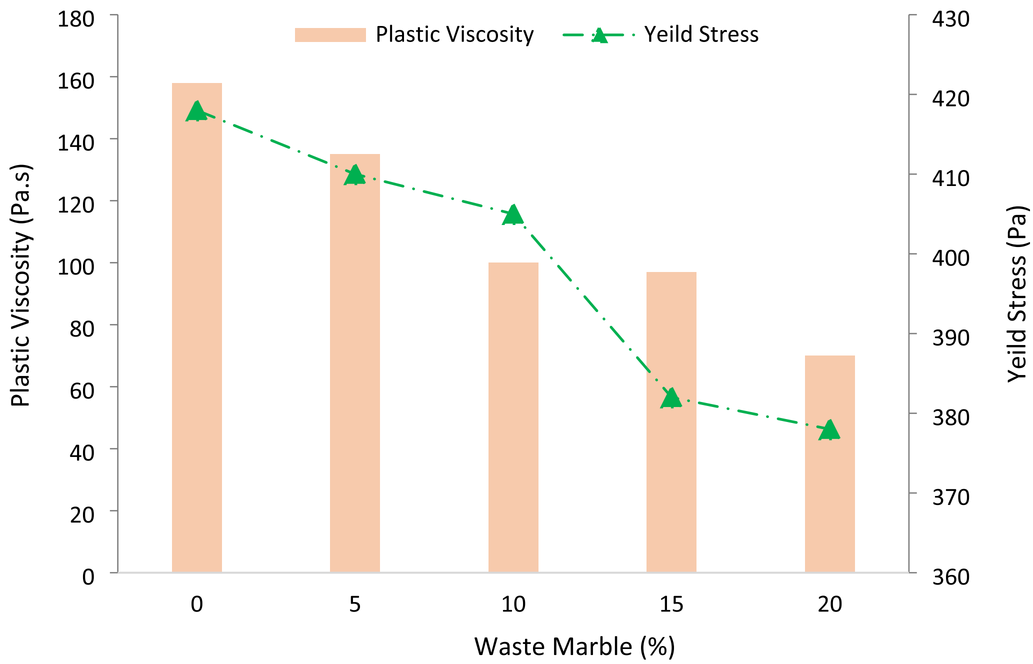

Fig. 7 Plastic viscosity and yield stress (Boukhelkhal et al., 2016)

declined with the substitution of WM. SCCs are typically constructed with low yield stresses of zero to 60 Pa and plastic viscosities of 20 to 100 Pa. (Níelsson & Wallevik, 2003). According to this Fig. 7, raising the WM concentration reduces yield stress. The yield stress is reduced by 1.8, 3.5, 8.6, and 10.3 percent for blends 5, 10, 15, and 20 respectively. The yield stress is a measure of intergranular frictions; as intergranular frictions grow, so does the yield stress. The reduction in yield stress may be ascribed to the substitution of WM for cement, which results in a higher paste compared to the reference blend, which lowers the connections among the aggregate fragments and, as a consequence, the yield stress decreased (Yahia et al., 2005). Similarly, increasing the WM quantity reduces the plastic viscosity. The plastic viscosities of the 0, 5, 10, 15, and 20% WM mixtures are 154, 135, 99, 94, and 64 Pa.s, correspondingly. This indicates that the plastic viscosity of the mixes 5, 10, 15, and 20 WM decreases by 12, 35, 39, and 58 percent, correspondingly. These findings might be described by a decline in resistance at the interface aggregate, which reduces SCC flow opposition (Topcu et al., 2009). The plastic viscosity of concrete is often connected to the permeability processes. In reality, lowering the plastic viscosity makes the concrete easier to pump and the casting time much shorter Khayat et al., 1999). Higher concrete viscosity levels are often associated with stiffer concrete, which may make pumping more difficult. The lower viscosity values of glass blends allow for improved concrete component cohesion and easy pumping ability. Pozzolanic materials mixed with concrete have higher homogeneity due to improved physical action of particle gradation and particle packing. Because of the rough surface of the glass particles, the plastic viscosity increased with particle size (Cyr et al., 2000).

4 Strength Properties

4.1 Compressive Strength

Generally, compressive strength (CS) decreased with substitution WM in SCC as shown in Fig. 8 and Table 2. According to one research (Choudhary et al., 2021), the incorporation of WM into SCC blends at a 10% replacement level resulted in higher CS than empty blends. This increase in CS was mostly due to the filling impact. Furthermore, the minerals present in WM (dolomite and calcite) may be responsible for heterogeneous nucleation, which aids in the synthesis of CH (Uysal & Sumer, 2011). However, increased WM incorporation (i.e., 20% and 30%) in SCC blends resulted in lower CS (Choudhary et al., 2021). The dilution of C_3S and C_2S molecules caused the strength decline. The research had similar findings (Uysal & Sumer, 2011). The pozzolanic interaction of SiO_2 in cementitious materials with CH results in the formation of additional binding chemicals, such as CSH, which is accountable for the beneficial effect on CS. Concrete may continue to build strength over time with the addition of the additional binder created by the slag reaction with available lime. However, at higher doses, strength diminishes due to the dilution effect, which

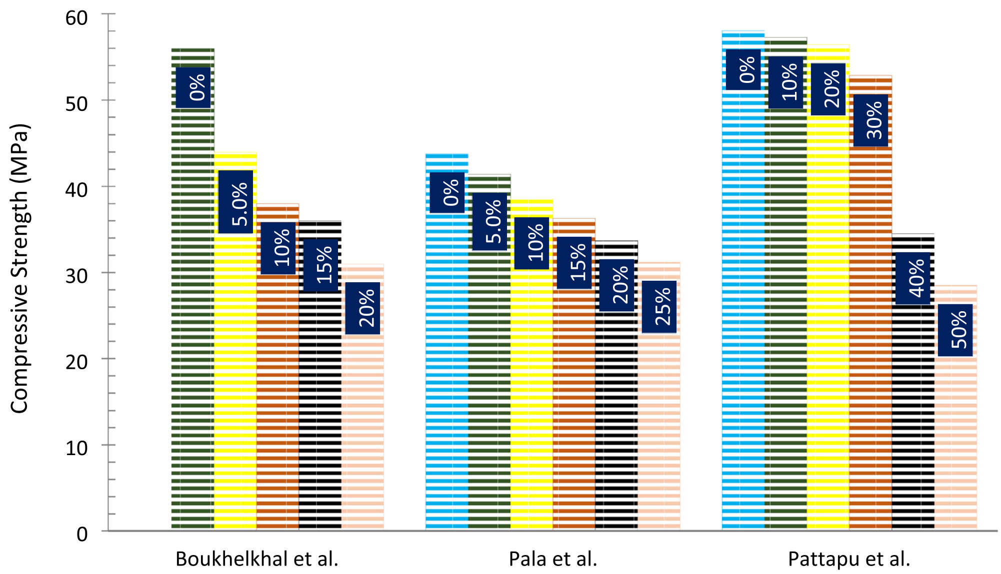

Fig. 8 Compressive strength (Boukhelkhal et al., 2017; Pala et al., 2015; Pattapu & Lal n.d.)

causes the alkali–silica reaction due to a larger quantity of unreactive silica being available due to the enhanced proportion of slag used in concrete. Research also suggested that the pozzolanic activity, which happens at a slower pace than the rate of cement hydration and is paired with the filling cavities in concrete elements of pozzolanic materials, results in better strength (Ahmad et al., 2021a, 2021b, 2021c).

According to one research, the drop in CS was caused by a decrease in binder content, since WM is an inert and non-pozzolanic substance (Choudhary et al., 2019). The CS rises with concrete age and falls with rising WM concentration (Boukhelkhal et al., 2016). The lowering of CS is related to the use of an inactive mineral, which, in contrast to a pozzolanic admixture, reduces the CS with time (Heikal et al., 2000). Studies explored the characteristics of concrete mixes including limestone and WM. The results showed that increasing the quantity of WM enhanced the CS and abrasion resistance (Hanifi et al., 2007). According to one research, CS rose somewhat up to 15% cement substitution of WM when associated with the blend without WM concrete. This is owing to the pore-filling action in WM (Ashish, 2018), which increases the qualities of the transition zone (TZ) around the aggregate (Shirule et al., 2012). The substitution of 5% cement by WM provides significant strength; however, this strength decreases as the replacement percentage increases over 5%. The strength produced by substituting up to 20% of the sand with WM is the same as that of a concrete mix containing 100% sand (Pathan & Pathan, 2014). The chemical makeup of WM, particularly its high SiO_2 concentration, provided favorable conditions for action not only as a filler but also partly as a binder owing to pozzolanic activity (Belaidi et al., 2012).

A researcher created SCC using limestone as a filler material and w/c of 0.30 and 0.34. The addition of limestone filler raises the CS. The filler is an inert additive that may be expected as an ultrafine which fills spaces. The CS of SCC in 0.30 w/c varied between 43 and 58 MPa (Bonavetti et al., 2003). By filling holes, stone dust, and WM boost both initial and late-age CS. If stone dust and WM are used in significant quantities in SCC, the loss in CS is caused by a growth in the requirement for binder owing to the fineness of the filler (Topcu et al., 2009).

Fig 9 depicts the strength age relationship of CS at 7, 14, and 28 days after curing with varied replacement ratios of WM. As a benchmark strength, the CS of control concrete at 28 days is used. For reference, the CS of SCC with 15% WM substitution with cement was utilized. At the 15% substitution ratio of WM, CS is 46 percent less than reference CS after 7 days of curing. With 14 and 28 days, the CS at 15% replacement of WM with cement is 35 and 18% lower than the corresponding concrete. It is possible to conclude that SCC with WM as a cement gained as curing days increased. According to one study, the significant improvement in CS at 56 and 90 days is due to the pozzolanic reaction of pozzolanic materials as it gradually gains strength as judged by the hydration of OPC (Ahmad et al., 2022a, 2022b, 2022c, 2022d). Similarly, investigations have shown that the pozzolanic response is slower than OPC hydration (Ahmad et al., 2022a, 2022b, 2022c, 2022d;

Table 2 Strength Properties of Concrete with WM

References	Percentage Range of WM	Replacement	*W/C*	Days	Max Change in Compression Strength (%)	Max Change in Tensile Strength (%)	Max Change in Flexure Strength (%)	Remarks
(Boukhelkhal et al., 2017)	0 to 20%	Cement	0.4	28	44	–	–	Decreased
				56	35			
				90	33			
				180	19			
(Topcu et al., 2009)	0 to 50%	Cement	0.38	28	48	-	36	Decreased
(Boukhelkhal et al., 2016)	0 to 20%	Cement	0.40	7	33	23	-	Decreased
				28	40	17		
(Ofuyatan et al., 2022)	0 to 30%	Coarse Aggregate	0.40	7	38	68	15	Decreased
				14	33	72		
				28	28	44	40	
(Choudhary et al., 2019)	0 to 30%	Cement	0.36	7	13	–	–	Decreased
				28	14			
(Latha et al., 2015)	0 to 20%	Sand	0.4 to 0.5	7	12.5	–	–	Increased
				28	12.5	12.6	12.3	
(Abid & Singh, 2019)	0 to 15%	Sand	0.45	7	30	67	146	Increased
				14	26	79	31	
				28	28	65	32	
(Pala et al., 2015)	0 to 25%	Sand	0.36	7	28	–	–	Decreased
				14	28			
				28	28			
(Rahman et al., 2019)	0 to 50%	Sand	–	7	17.1	9.0	8.0	Increased
				28	10.5			
(Tomar & Kumar, 2018)	0 to 50%	Sand	–	7	4.5	–	–	Increased
				28	7.9			
(Pattapu & Lal n.d.)	0 to 50%	Cement	0.33	28	50	–	33	Decreased
(Choudhary et al., 2021)	0 to 30%	Cement	0.33	7	11	–	–	Increased
				28	8.0			
				56	7.0			
				90	13			
(Ofuyatan et al., 2019)	0 to 35%	Sand	0.50	7	30	10	–	Increased
				28	22	41		
				56	5.0	16		
				90	6.0	8		

Ahmad et al., 2022a, 2022b, 2022c, 2022d). Similarly, research indicates that the loss in early age strength (3 and 7 days) with the replacement of quarry dust is attributable to the fact that the pozzolanic reaction occurs slowly in comparison to cement hydration. Similar research found that the pozzolanic process is slower than cement hydration (Ahmad et al., 2022a, 2022b, 2022c, 2022d). As a result, the early age strength (3 and 7 days) dropped when quarry dust was substituted. However, at a later age, there was an improvement in strength (28 days). However, with larger WM doses, there was a significant drop in CS. It is possible that the lack of flowability raised the compaction affords, resulting in larger voids in hardened concrete. Furthermore, greater doses (25%) generate an alkali-silica response owing to dilution effects, resulting in a drop in CS. According to one research, WM is an inert ingredient that does not significantly alter the phase composition of the resulting mix. Indeed, using WM as a filler in the SCC composition enhances intruded pore volume, decreases the fraction of tiny pores, and raises the SCC CS (Alyousef et al., 2018a).

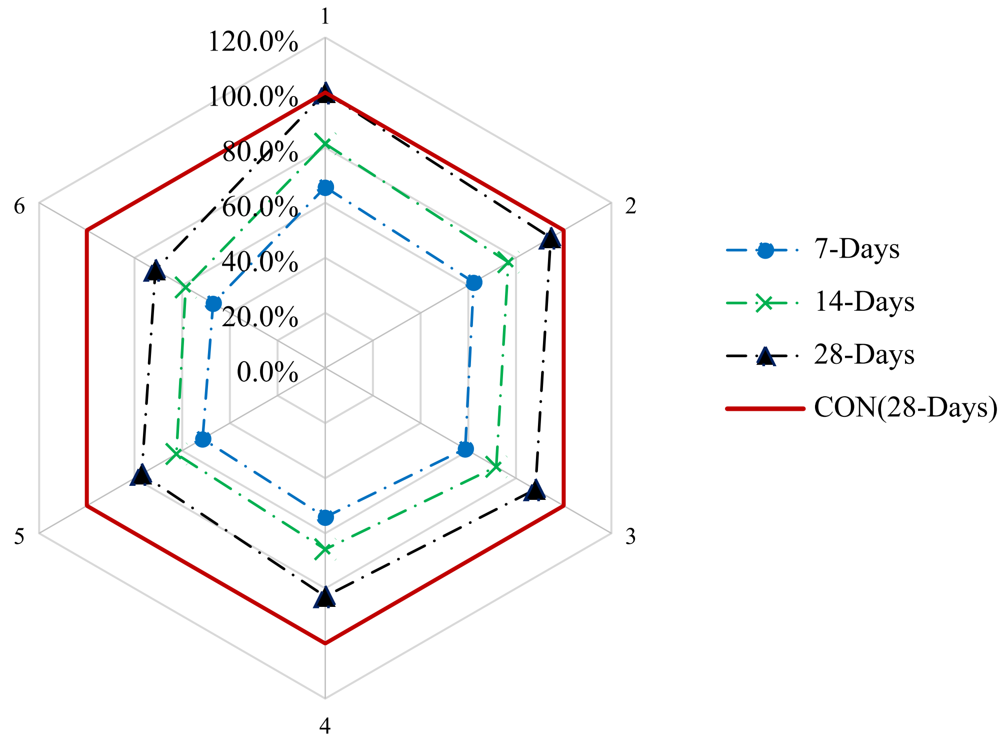

Fig. 9 Relative compressive strength (Pala et al., 2015)

4.2 Split Tensile Strength (STS)

Similar to the compressive strength (CS), split tensile strength (STS) also decreased with substitution WM in SCC as shown in Fig. 10 and Table. 2. However, some studies claimed that the STS of SCC improved with WM. The STS of concrete having 0%, 10%, and 15% WM as partial replacement of sand was measured after 7-, 28-, 56-, and 90-day curing periods. The outcome

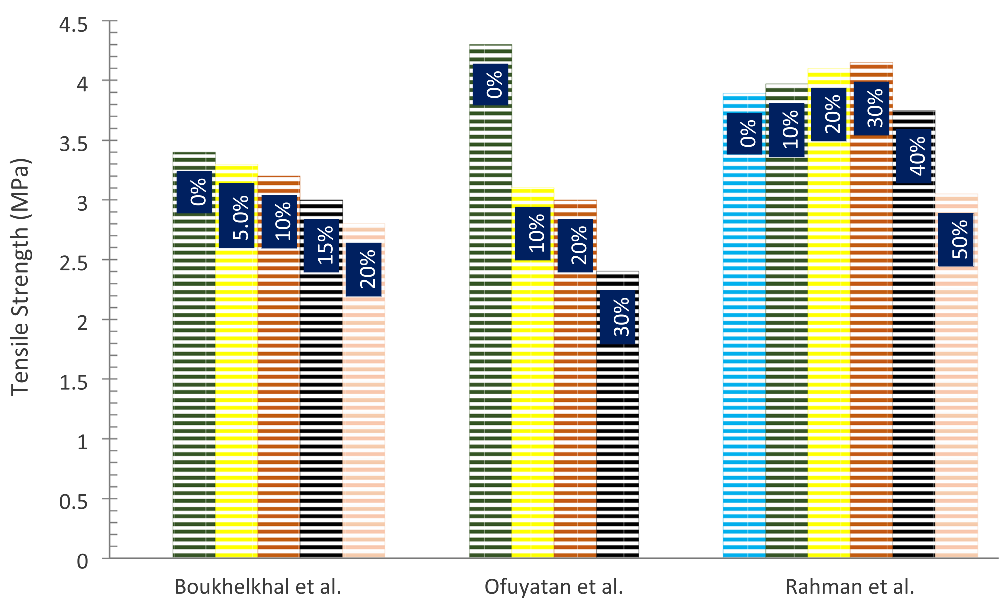

Fig. 10 Tensile strength (Boukhelkhal et al., 2017; Ofuyatan et al., 2022; Rahman et al., 2019)

demonstrates the effect of replacing sand with WM. It can be shown that the maximum STS can be obtained with 10% WM as a sand substitute, while somewhat lower results were obtained with 15% WM as compared to 10% WM at all curing ages. A study also concludes that 50% of foundry sand can be a substitute for concrete without decreasing its performance(Ashish & Verma, 2021). Low permeability is often accountable for this development in STS when WM is used as a filler. The use of WM as a sand substitute enhances the STS associated with the reference blend (Ashish, 2018). Low porosity is often responsible for this improvement in STS with the use of WM as a filler. Compared to the control mix, the use of WM as a sand substitute enhances the STS (Rahman et al., 2019). It was discovered that the STS of M15 grade concrete at 7 and 28 days rises with the proportion of WM powder by up to 35%. At 7 and 28 days, the STS of M15 grade concrete improved by 15.55 percent and 17.95 percent, respectively. This improvement in strength is caused by the WM's filling capacity and cohesive qualities inside the concrete mix (Ofuyatan et al., 2019). The concrete mixture performs extremely well in terms of strength and quality when sand is substituted with 50/50 marble sludge powder and quarry rock dust. According to the data, a 50 percent quarry dust mix generated higher CS and breaking STS. When the marble sludge powder content is raised by more than 50%, the CS and TS of concrete are impacted, but the workability improves (Hameed & Sekar, 2009).

According to one research, substituting normal sand with WM at a proportion of 15–75 percent increases compressive and tensile strength by 20 to 26 percent and 10 to 15 percent, correspondingly (Arel, 2016). According to one research (Ergün, 2011), replacing 5% of the cement with WMP in binary and ternary-blended cement resulted in compressive and flexural strengths (FS) greater than reference concrete. Furthermore, the inclusion of waste WM as fine and coarse aggregates in concrete has been shown to be beneficial in increasing both compressive and tensile strengths; however, when it comes to concrete workability, some adjustments in the amount of water, mix proportions, and grading of fine and coarse WM aggregates are needed to improve it (Hebhoub et al., 2011). A researcher created concrete mixes by substituting gravel with WM at several rates ranging from 5 to 50%. They discovered an increase in the compressive and tensile strength of samples with 50% WM (Chavhan & Bhole, 2014). It is thought that adding a particular amount of pozzolanic materials is critical to increasing the STS of concrete since adding more pozzolanic ingredients than required weakens the material. The formation of weak zones as a result of inadequate pozzolanic material distribution might provide proof for it. The quick consumption of $Ca(OH)_2$ created during hydration, particularly in later stages due to the increased reactivity of pozzolanic minerals, might be the reason of higher STS in concrete containing pozzolanic components.

Fig. 11 depicts the relationship between CS and STS at various percentages of WM. It is commonly known that CMS and STS are connected, i.e., STS of concrete is 9 to 10% of CS (Basar & Aksoy, 2012). Consequently, with an R^2 value of 80, there is a significant association between

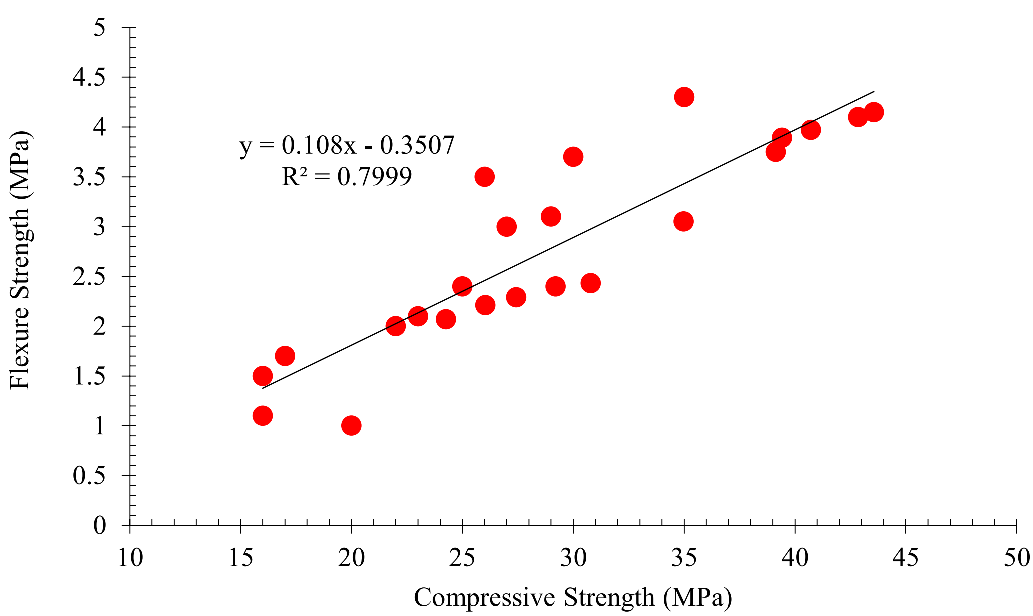

Fig. 11 Correlation between compressive strength and flexural strength (Ofuyatan et al., 2022; Rahman et al., 2019)

CPS and STS. Based on different WM percentages, the following equation has been developed.

$$F_{STS} = 0.108F_{CS} - 0.35 \quad (1)$$

where f_{STS} = STS and f_{CS} = compressive strength.

Therefore, Eq. (1) can be used to predict the tensile strength from the compressive strength of SCC with varying doses of WM.

4.3 Flexural Strength (FS)

Similar to the compressive strength (CS), flexural strength (FS) also decreased with substitution WM in SCC as shown in Fig. 12 and Table. 2. However, some studies claimed that the STS of SCC improved with WM. According to research, the amount of WM substituted for cement led to a drop in the FS of SCC (Pattapu & Lal n.d.). According to research, the key components and strength-giving agents of cement, C2S, and C3S are diluted by the WM addition, which causes a drop in strength (Türker et al., 2002). According to research, SCC that used recycled aggregates as a partial replacement had a somewhat better FS than those that used WM. Poorer FS was caused by higher partial replacement of granite. The best FS for the partial substitute specimens was 2.0 MPa and 1.86 MPa for recycled aggregates and WM SCC, correspondingly (at 10% partial substitute and 28 days of curing period) (Ofuyatan et al., 2022). When the cement was partly replaced with silica fume during curing, the FS of the SSC was reduced during the whole curing duration. When silica fumes are used to partly replace cement, strength is reduced because of a weak interfacial transition zone. The silica fume application has a poor transition zone, which adversely affects the strength properties (Ofuyatan et al., 2021). More glass powder was used, which produced a higher FS, as opposed to employing fly ash. When compared to reference concrete, the FS of 20% glass replacement is improved by 57.47%. Glass powder has a higher active silica content than fly ash (Öz et al., 2017), which causes more CSH and more FS of SCC.

However, the researcher discovered that adding 5% WMP to binary- and ternary-blended cement leads to compressive and FS values that are greater than those of control concrete (Ergün, 2011). The pozzolanic and micro-filling actions of WM are what cause the elevated FS. Research that evaluated the impact of WM as a partial substitute for natural fine aggregate on the strength and durability of low-strength concrete mixes revealed an increase in CS and FS of 84 percent and 18.6 percent, correspondingly (Chawla et al., 2020). Concrete with crushed particles that are angular in form and have a rough texture has a greater FS when compared to naturally rounded gravel (Mehta, 1986). This is because there is a stronger physical and chemical connection between the cement paste and the aggregate. Research has shown that utilizing quarry rock dust in place of sand boosted the FS and CS of concrete. This rise may have been caused by the fine aggregates' inherent strength and the cement paste's close relationship with the fine aggregate (Rao et al., 2012). Similar to

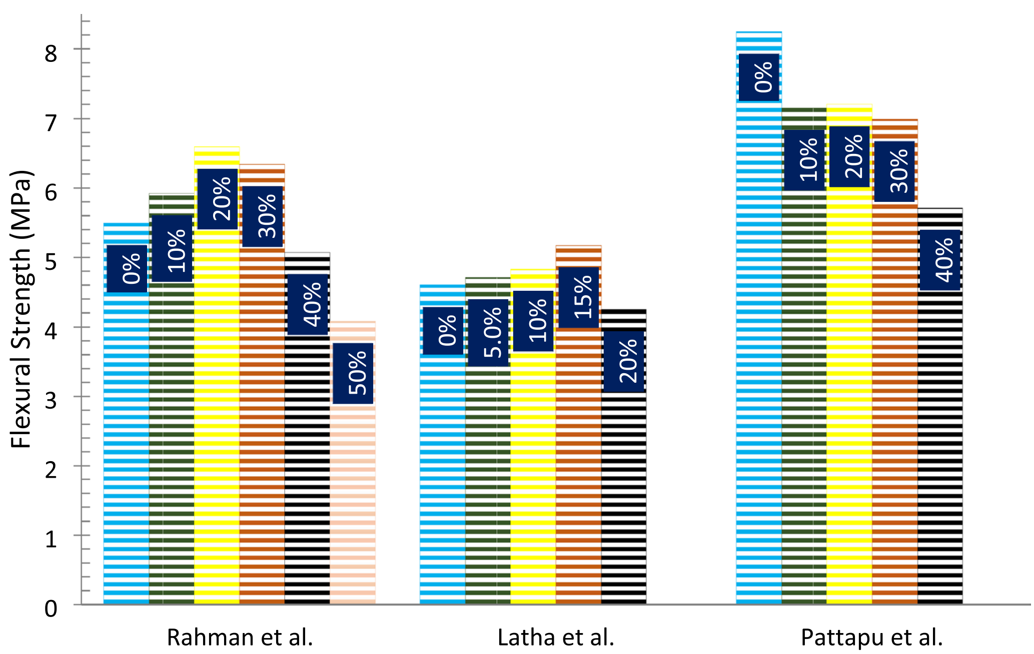

Fig. 12 Flexural strength (Latha et al., 2015; Pattapu & Lal n.d.; Rahman et al., 2019)

this, research finds that adding waste WM enhances the strength of concrete by up to 15% when replacing cement by weight and that any addition of waste WM results in a minor reduction in strength when compared to regular concrete. The nucleation of waste WM around small particles, which substitute for the big, orientated crystals of calcium hydroxide, may be the cause of the enhancement in FS (Latha et al., 2015). One research claims that adding fly ash and silica fume boosts concrete's flexural strength by 10%. The mixes with the highest replacement percentage in terms of flexural capacity were those with 5% silica fume and 10% fly ash (Yener & Hinislioğlu, 2011).

The correlation between concrete CS and FS at various curing phases and with varied amounts of WM is shown in Fig. 13. Flexural might make up between 10 and 20 percent of the CS, depending on the mix design. It should be noted that the CS ad FS trendline seems to be linear. There has been a strong correlation between CS and FS, with an R^2 value of more than 80%.

$$F_{FS} = 0.24F_{CS} - 3.27 \quad (2)$$

where F_{FS} = flexural strength and F_{CS} = compressive strength.

Therefore, Eq. (2) can be used to predict the flexural strength from the compressive strength of SCC with varying doses of WM.

5 Durability

5.1 Water Absorption

Fig. 14 depicts that water absorption of SCC increased with the WM substation. According to research, an increase in the quantity of WM replaced causes a rise in water absorption. The water absorption percentages for mixes containing 0, 5, 10, 15, and 20% WMP are, respectively, 4.67, 5.10, 5.11, 5.13, and 5.17 percent. This indicates that the water absorption rate is increased by 9.26, 9.47, 9.9, and 10.9 percent, respectively, when WMP is included at substitution levels of 5, 10, 15, and 20 percent. The usage of inert materials with a low water absorption potential may be to blame for the increased water absorption (Boukhelkhal et al., 2017). Similar research asserted that because WM is an inert and non-pozzolanic substance, the drop in strength was caused by the decrease in cement content (Choudhary et al., 2019), which enhanced water absorption since there was no binder and more voids as a consequence. The water permeability resistance was improved when 10 percent WM was added to SCC to replace cement. The 10% WM mix had an average water penetration depth of 54 mm, which was 36.47 percent less than the control mixture. Water permeability depths were raised as a consequence of the enhanced WM substitution in SCC (Choudhary et al., 2021). According to Correia et al. (Correia et al., 2006), water absorption by soaking grows as the proportion of

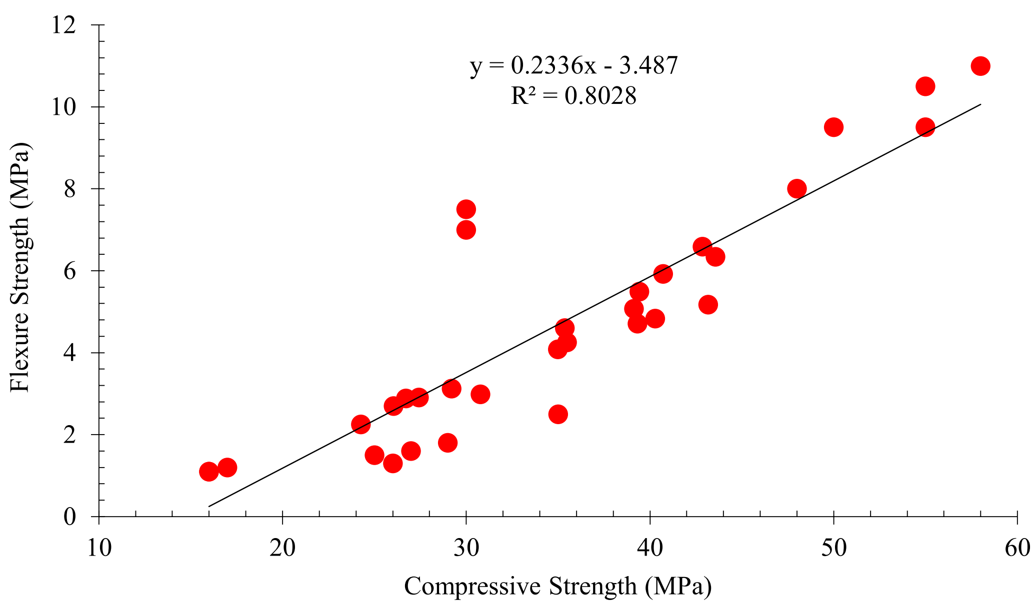

Fig. 13 Correlation between compressive strength and flexural strength (Latha et al., 2015; Ofuyatan et al., 2022; Rahman et al., 2019; Topcu et al., 2009)

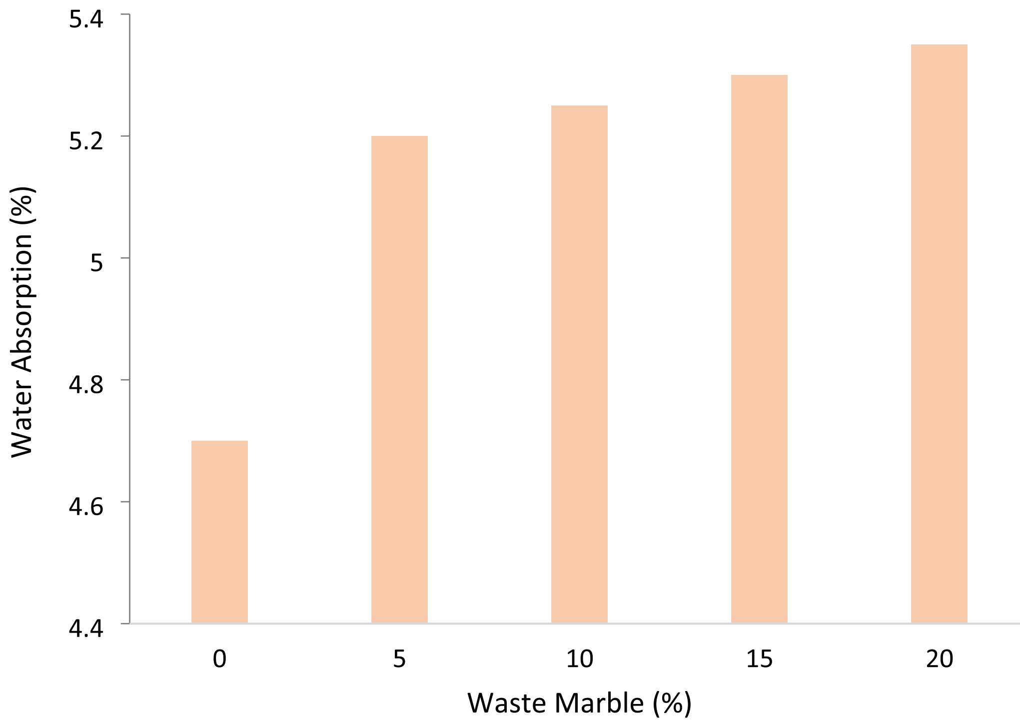

Fig. 14 Water absorption (Boukhelkhal et al., 2017)

ceramic particles in the concrete mix climbs. However, according to Neville (Neville, 1995), none of the water absorption test results above 10% by mass. According to Chan and Sun (Chan & Sun, 2006), increased water adsorption reduces the workability and durability of concrete. It can be inferred that, although WM increased water absorption owing to the inadequate matrix, the rise is less than 10%, and hence concrete is claimed to be durable. The outcome demonstrates that the introduction of additional cementitious materials improved the durability qualities of concrete when 15% of the sand was replaced with WM (Ashish, 2019). The chemical interaction between natural pozzolans and CH in hydrated paste utilizing lime and creating CSH gel increases the cementing properties, developing an additional solid mass and lower water absorption (Ahmad et al., 2022a, 2022b, 2022c, 2022d).

5.2 Chloride Penetration

The chloride diffusion values demonstrated that the substitution of WM in SCC enhances chloride penetration resistance, while greater deployment (20% and 30%) results in a decrease in chloride penetration resistance as presented in Fig. 15. The chloride infiltration depth was somewhat smaller (by 0.5 mm) than the reference mix with a 10% replacement of WM. However, the penetration depths of the blends 20% and 30% WM were 2.75 mm and 6 mm greater, correspondingly, than the control mixture (Choudhary et al., 2021). The decline in chloride diffusion of WM (10%) may be related to the pozzolanic activity of WM, which produces cementitious materials (CSH). The cementitious chemicals increased the adhesion capabilities, resulting in lesser chloride penetration. Furthermore, the micro-filling gaps of WM result in a compact matrix, resulting in decreased chloride penetration. The combination of WM's pozzolanic activity and micro-filling has a beneficial effect on chloride diffusion. However, a high dosage of WM has a negative impact on chloride permeability owing to dispersion or a lack of permeability. Furthermore, the use of fly ash in SCC demonstrated a continual increase in chloride penetration resistance as fly ash concentration in SCC mixes increased. The 35 percent fly ash mixture had the lowest chloride permeability. The chloride infiltration depth was 72.37 percent less than the control mixture (Choudhary et al., 2021). This increase in carbonation depth by fly ash absorption was caused by the creation of more portlandite ($Ca(OH)_2$) during concrete hardening (Esquinas et al., 2018). After 28 days of curing, concrete containing a 20% alternative of stone dust exhibited fewer chloride ion permeability for Nowshera and Dara than the reference specimens. Because stone dust fragments are coarser than sand particles, they fill the spaces among ingredients. Because there are fewer holes in concrete,

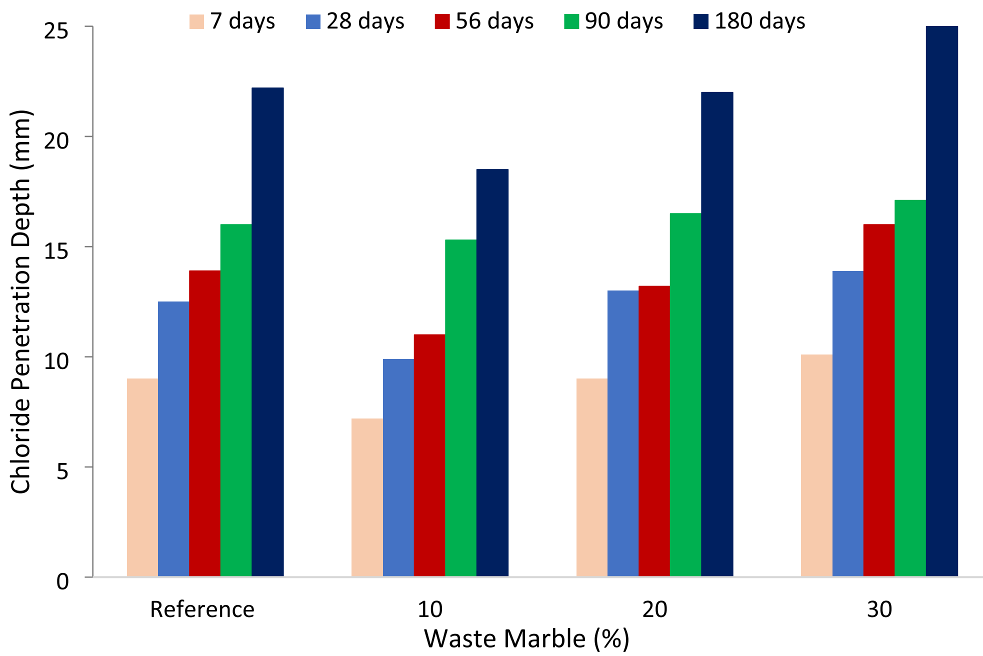

Fig. 15 Chloride ions penetration (Choudhary et al., 2021)

its density increases, and the crevices are filled with stone dust (Humayun et al., 2021). However, greater WM doses result in increased chloride permeability owing to a lack of flowability. According to one research, concrete materials exposed to severe weather decay faster owing to their intrinsic porosity. Because chloride-laden water hastens the beginning of corrosion in concrete containing steel, this test procedure is excellent for assessing the penetrability assets in adverse environmental circumstances (Sounthararajan & Sivakumar, 2013).

5.3 Ultra-Sonic Pulse Velocity (UPV)

The increase in WM content reduces the UPV for all ages as shown in Fig. 16. At 28 days of curing, the UPV rates of blends 0%, 5%, 10%, 15%, and 20% WM are 4454, 4413, 4396, 4387, and 4362 m/s, respectively. At 90 days, these values are 4870, 4830, 4800, 4780, and 4750 m/s, correspondingly (Boukhelkhal et al., 2016). According to one research, as the amount of WM added climbed, the permeability of the concrete reduced and its UPV was boosted (Bahar, 2010). The filler impact of WM on cement hydration is related to porosity reduction. Research also concluded that there is no discernible influence on the ultrasonic pulse velocity result when WM is replaced with sand (Ashish, 2018). When the proportion of pozzolanic elements in SCC mixtures increased, the UPV rates of SCC samples fell for all curing times. Conventional concrete and SCC specimens with silica fume had the highest UPV rates at 28 and 130 days, observed by SCC specimens with fly ash (Turk et al., 2010). The SCC with 0.75 percent steel fiber has the fastest rate of improving compressive strength as a consequence of replacing cement with silica fume (Mastali & Dalvand, 2016).

5.4 Carbonation Depth

According to one study, the concrete structure's pore diameter, the percentage of moisture in the concrete, and the relative humidity of the adjacent atmosphere all have a significant influence on the rate of carbonation (Song & Kwon, 2007). A scholar investigated the effect of WM on the CS and shrinkage of concrete mixtures. They claimed that improving the WM substitution reduced the drying shrinkage. Furthermore, the depth of carbonation was enhanced (Elmoaty & Mohamed, 2013). According to one research (Choudhary et al., 2021), including WM in SCC mixtures has a good impact on the corrosion assets of SCC. The corrosion resistance of the WM-mixed SCC mixtures was greater. Even after 180 days, the SCC mix with 10% WM showed a 90 percent likelihood of no corrosion. However, increasing WMS content resulted in larger negative half-cell potential values. The ternary mix (30 percent WM) exhibited the greatest negative half-cell potential value. After 180 days of exposure, the mix corroded because the half-cell values were more than

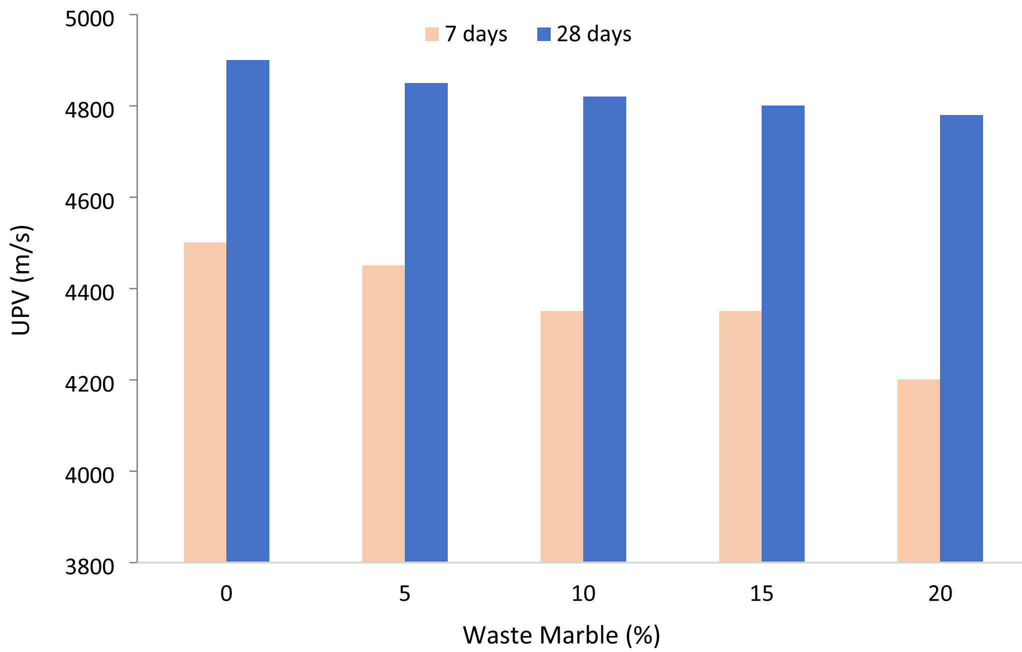

Fig. 16 Ultra-sonic pulse velocity (Boukhelkhal et al., 2016)

350 mV. The addition of WM and fly ash in quaternary SCC mixtures resulted in improved corrosion resistance. Except for the 20 percent WM + 35 percent fly ash mix, all of the quaternary SCC combinations had greater half-cell potential values than the reference mix. Fig. 17 depicts the carbonation pattern at the lowest and greatest depths. However, the quaternary mix of 35% fly ash and 20% marble progressed toward higher negative values and fell into the 90% chance of corrosion group after 180 days of exposure. The half-cell potential pattern was nearly identical to the pattern of chloride penetration depth. The quaternary combination of 15% fly ash and 10% marble also demonstrated improved corrosion resistance.

5.5 Sulfate Resistance

The samples submerged in Na2SO4 solution showed no signs of change until the seventh month. Damage to the ordinary concrete, gravel tile waste, and marble tile waste concrete samples was noticed beginning in the eighth month. The ordinary concrete samples were broken and swollen after being immersed in a Na_2SO_4 solution

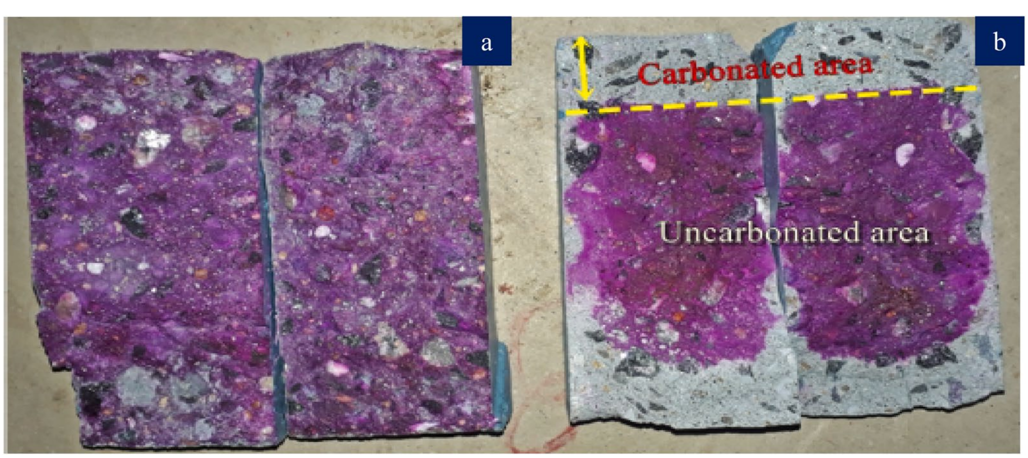

Fig. 17 Minimum and maximum carbonation depth (**a**) reference and (**b**) 35% fly ash and 20% marble (Choudhary et al., 2021)

for 20 months. The activity of sulfate on the aluminates in the paste (cement or cement with waste having additional alumina than limestone filler) might explain these findings. The sulfate reaction leads to the development of ettringite, which produces expansion and, as a consequence fracture (Tennich et al., 2017). The findings of the mass deviation of the specimen submerged in a sodium sulfate mixture are shown in Fig. 18. For the first four months, a little mass improvement was seen in all samples, ranging from 2.2 percent for the marble waste to 3 percent for the gravel tile waste, this mass improvement is attributable to water absorption and is lower than that of the specimens submerged in water. It is possible to deduce that Na_2SO_4 solution influences water absorption in various concretes even before the fourth month. Concrete mixes with a higher amount of slag (75 and 85 percent) demonstrated superior resistance to sulfate attack, regardless of w/b and wet curing duration (3, 7, and 28 days) (Wee et al., 2000). The swelling rises as the soaking time in the sulfate solution increases. It was discovered that there is an inversely proportionate relationship between increasing WMP volume and decreasing expansion (Boukhelkhal et al., 2017). According to the findings, the blend including 15% natural pozzolan and 15% silica fume provided the highest safety in sulfates solutions and sea waters. After a year of preservation in sulfate solutions and seawater, it protected greater than 65% of its strength. The higher resistance of that mix to sulfate attack may be ascribed to the pore refinement process and additional compaction of the transition region affected by the exchange of lime formed during cement hydration into additional binding material through the pozzolan response (Shannag & Shaia, 2003). According to one research, the reduced acid challenge of the empty blend, as opposed to acid assault, may be linked to the fact that it includes a large quantity of lime, which generates a substantial amount of free CH during hydration and reacts with the acid, leaving a soft and mushy substance behind. In bentonite mixtures, the CH reacts with the SiO_2 in the concrete to form CSH gel, causing a tiny amount of CH and better acid resistance. The mass loss trend was the same when the two acids were compared. Sulfuric acid was proven to degrade faster than hydrochloric acid. The higher deprivation of H_2SO_4 is caused by the formation of a substance known as calcium sufflarninate (Ettringite), which swells and causes the concrete paste to break (Rawal, 2003).

6 Microstructure

Cement–WM paste specimens were found to be compact and less porous than cement paste samples. The morphology of mixtures is made of enormous layers of amorphous calcium silicate hydrate (CSH) and calcium hydroxide (CH) crystals. Ettringite (E) needles are inserted into pores, after which the paste is entirely hydrated, and all gaps are filled. Following that, when additional WM is utilized, the resultant SCC is denser and less porous Alyousef et al. (2018a). Research also

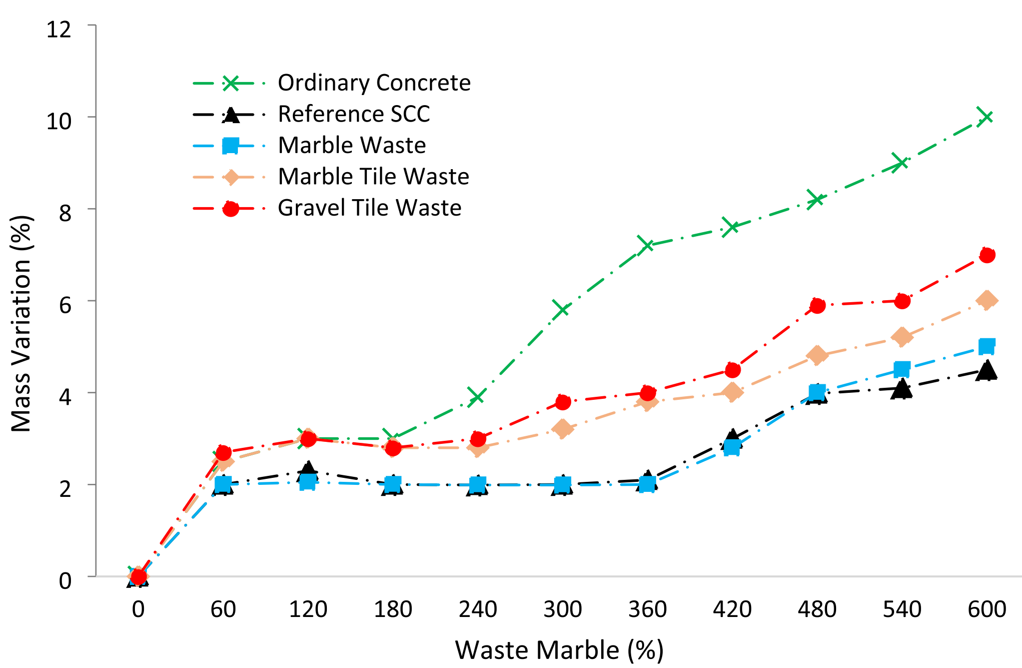

Fig. 18 Mass variation due sodium sulfate (Tennich et al., 2017)

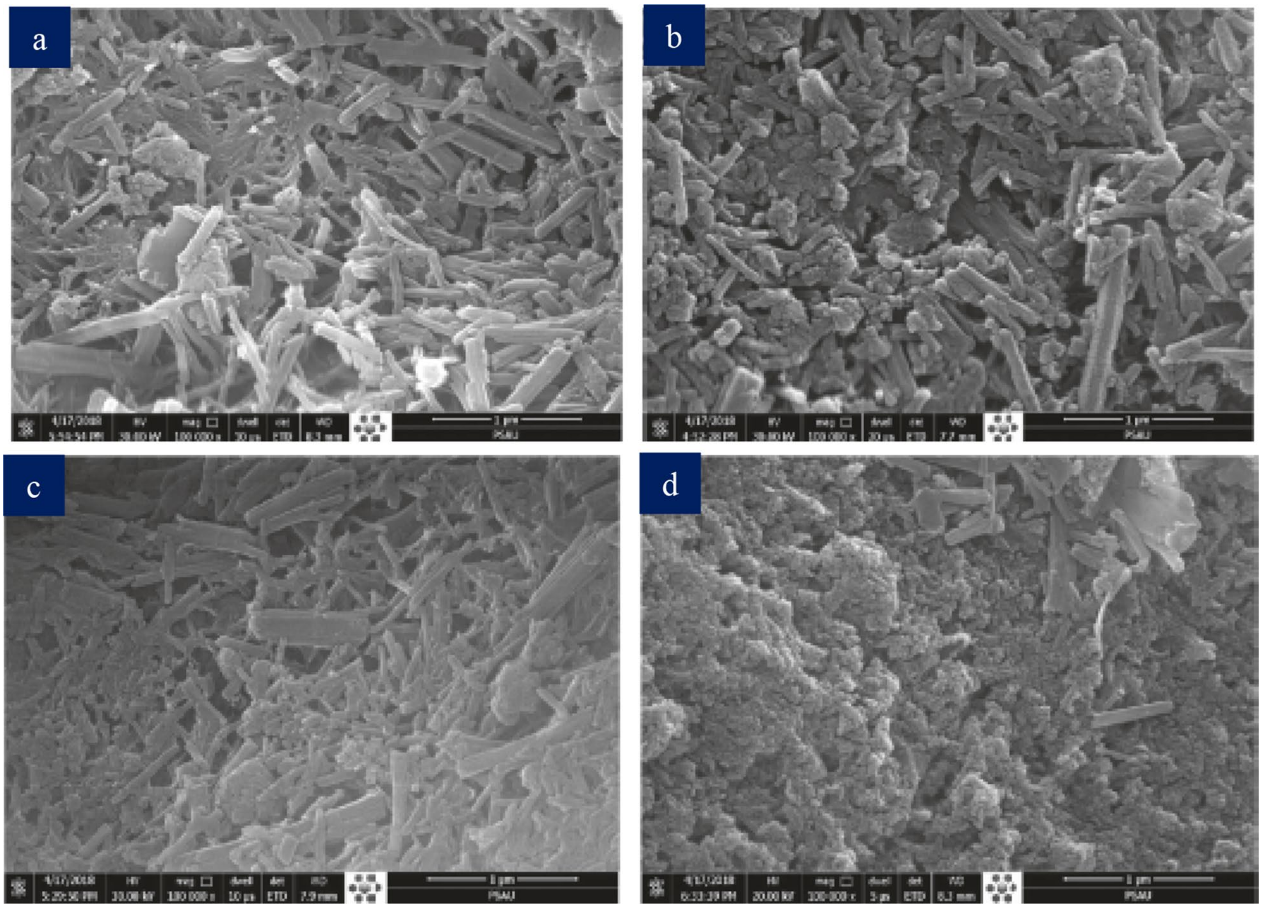

Fig. 19 SEM (**a**) 60,(**b**) 80,(**c**) 100, and (**d**) 120 kg (Marble) (Alyousef et al., 2018a)

finds that satisfactory interaction of the cement elements was accomplished in the micrographs with 10% partial substitutions with WM (Fig. 19). According to the study, SEM examination reveals weak contact between the concrete ingredients, which could explain the wide holes and deep fissures visible in the concrete's morphology. According to the microstructural investigation, the use of granite substitution increases the contact among the concrete ingredients. Nevertheless, the RA specimen outperformed the WM samples in this aspect (Ofuyatan et al., 2022). According to one investigation, adding WM into cement paste had no qualitative effect on phase composition. It demonstrates that WM is an inert ingredient that has little effect on the phase composition of the resulting blend Alyousef et al. (2018a). When a considerable quantity of WM is added, the microstructure of the resulting paste becomes less permeable, as does the number of big holes in the matrix. These findings demonstrate that the pore structure of SCC has been refined as compared to conventional concrete. SCC has a more refined pore structure than conventional concrete (Alyousef et al., 2018a).

The comparison of cement paste with varying levels of WM reveals no significant differences across specimens, particularly in terms of calcium hydroxide (CH) concentrations, as shown in Fig. 20. In addition, research (Alyousef et al., 2018a) discovered that introducing WM into cement paste had no qualitative effect on phase composition. It clearly shows that WM is an inert ingredient that has little effect on the phase configuration of the resulting blend. Indeed, using WM as a filler in the SCC enhances intruded pore volume, decreases the fraction of tiny pores, and raises the SCC CS. The source of the good impact on strength is micro-filling, which fills up the hole among SCC ingredients to generate compact SCC. However, with a greater dose of pozzolanic ingredients, there was a 30% loss in workability due to reduced flowability, which requires more compaction energy and resulted in bigger gaps in the hard pore of concrete and a lower density of concrete (Ahmad et al., 2021a, 2021b, 2021c).

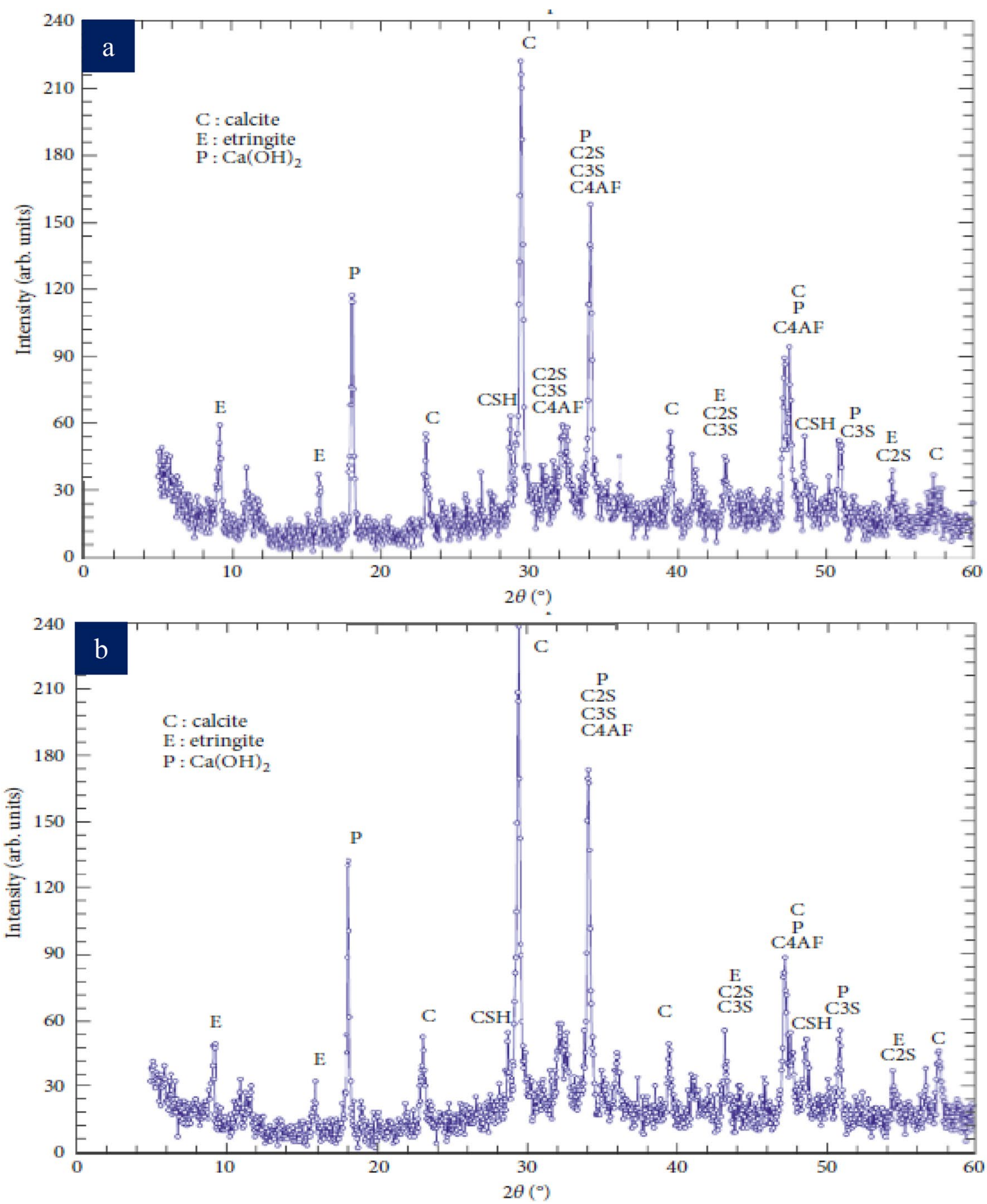

Fig. 20 XRD (**a**) 60 and 80 kg (Marble) (Alyousef et al., 2018a)

7 Conclusions

The study examines the rheological, strength, durability, and microstructure properties of SCC with WM substituted as cement or aggregate. Cement is a costly component and replacing it with sand may lead to the creation of both inexpensive and sustainable concrete. Waste dumping is also less of a financial burden with the usage of WM in SCC, which leads to improved financial performance. The conclusion is stated in detail below—

- The chemical composition of WM is similar to that of cement. The WM has the creditability to be utilized as a binder in SCC.
- Flow properties of SCC improved with the substitution of WM due to micro-filling cavities. Therefore, the additional paste is accessible to lessen the resistance among concrete ingredients.
- The strength properties of SCC decreased with the substitute of WM due to a weak interfacial transition zone. However, up to 20% substitution of WM, strength is equal to reference concrete. Furthermore, a strong correlation is developed among strength properties having R^2 is 80%.
- The durability properties of WM improved owing to micro-filling, making it appropriate as an addition or as a partial substitution in concrete. According to the review, higher substitution (greater than 20%) might be detrimental to strength and durability attributes.
- SEM pictures reveal that the considerable quantity of WM added results in a mix with porous microstructures that affects the CS of SCC. Control concrete and blended concrete specimens exhibit no noteworthy results in microstructure research, confirming that WM plays no discernible function in hydration.
- Waste marble (WM) can be utilized up 20% in concrete without any negative effect on the strength and durability of concrete. The experimental findings discover that the supplement of WM can be a good alternative for concrete, and therefore, can be successfully used in industrial applications by up to 20%. The utilization of WM in concrete provides multiple benefits in terms of waste utilization, improvement in sustainability, low cost, eco-friendly and better strength and durability of concrete. Additionally, it will address the issue of environmental health risks.

8 Recommendations

Although the previous study has focused on WM as a cement replacement in SCC and concluded that WM could be employed as a binder of fill, however several areas remain unclear, and the assessment suggests that they be investigated further before being employed.

- A decrease in the strength properties of SCC was observed due to poor internal structure. Therefore, more details study is required to improve its performance with the addition of secondary cementitious materials.
- The performance of WM is also depending on its particle size. However, no study is available on the different particle sizes of WM on the strength properties of SCC.
- Although to some extent WM can used be in SCC, however, SCC is still weak in tension. Therefore, a details study is required to improve its tensile performance with the addition of suitable fibers.
- Few data are accessible on durability attributes, mainly shrinkage and creeps' aspects. Therefore, the review suggests that dry shrinkage and creep characteristics of marble-based SCC should be further investigated.
- Details research on microstructure analysis, such as hydration phase and decomposition of chemicals.

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Author contributions
JA writing the original draft. ZZ Supervision, Conceptual, Review, and editing. AFD, Methodology, Review, and editing. All authors read and approved the final manuscript,

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Consent for publication
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References

Abid, M., & Singh, K. (2019). Effect of waste marble powder and polypropylene fiber on the properties of self-curing concrete. *Int. J. Civ. Eng. Technol, 10*, 899–911.

Ahmad, J., Aslam, F., Martinez-Garcia, R., De-Prado-Gil, J., Qaidi, S. M. A., & Brahmia, A. (2021a). Effects of waste glass and waste marble on mechanical and durability performance of concrete. *Scientific Reports, 11*(1), 21525.

Ahmad, J., Aslam, F., Martinez-Garcia, R., Ouni, M. H. E., & Khedher, K. M. (2021b). Performance of sustainable self-compacting fiber reinforced concrete with substitution of marble waste (MW) and coconut fibers (CFs). *Scientific Reports, 11*(1), 1–22.

Ahmad, J., Kontoleon, K. J., Al-Mulali, M. Z., Shaik, S., Ouni, M. H. E., & El-Shorbagy, M. A. (2022a). Partial substitution of binding material by bentonite clay (BC) in concrete: a review. *Buildings, 12*(5), 634.

Ahmad, J., Kontoleon, K. J., Majdi, A., Naqash, M. T., Deifalla, A. F., Kahla, N. B., Isleem, H. F., & Qaidi, S. M. A. (2022b). A Comprehensive review on the

ground granulated blast furnace slag (GGBS) in concrete production. *Sustainability (switzerland), 14*(14), 8783.
Ahmad, J., Majdi, A., Deifalla, A. F., Isleem, H. F., & Rahmawati, C. (2022c). Concrete made with partially substitutions of copper slag (CPS): State of the art review. *Materials, 15*(15), 5196.
Ahmad, J., Martínez-García, R., De-Prado-Gil, J., Irshad, K., El-Shorbagy, M. A., Fediuk, R., & Vatin, N. I. (2022d). Concrete with partial substitution of waste glass and recycled concrete aggregate. *Materials, 15*(2), 430.
Ahmad, J., Zaid, O., Shahzaib, M., Abdullah, M. U., Ullah, A., & Ullah, R. (2021c). Mechanical Properties of sustainable concrete modified by adding marble slurry as cement substitution. *AIMS Materials Science, 8*(3), 343–358.
Aliabdo, A. A., Abd Elmoaty, M., & Auda, E. M. (2014). Re-use of waste marble dust in the production of cement and concrete. *Construction and Building Materials, 50*, 28–41.
Alyousef, R., Benjeddou, O., Khadimallah, M. A., Mohamed, A. M., & Soussi, C. (2018a). Study of the effects of marble powder amount on the self-compacting concretes properties by microstructure analysis on cement-marble powder pastes. *Advances in Civil Engineering*. 1–13. https://doi.org/10.1155/2018/6018613
Alyousef, A., Khadimallah, M. A., Soussi, C., Benjeddou, O., & Jedidi M. (2018b). Experimental and theoretical study of a new technique for mixing self-compacting concrete with marble sludge grout. *Advances in Civil Engineering* , 1–11. https://doi.org/10.1155/2018/3283451
Amani, A., Babazadeh, A., Sabohanian, A., & Khalilianpoor, A. (2021). Mechanical properties of concrete pavements containing combinations of waste marble and granite powders. *International Journal of Pavement Engineering, 22*(12), 1531–1540.
Amin, S. K., Allam, M. E., Garas, G. L., & Ezz, H. (2020). A Study of the chemical effect of marble and granite slurry on green mortar compressive strength. *Bulletin of the National Research Centre, 44*(1), 19.
Arel, H. Ş. (2016). Recyclability of waste marble in concrete production. *Journal of Cleaner Production, 131*, 179–188.
Arshad, M. T., Ahmad, S., Khitab, A., & Hanif, A. (2021). Synergistic use of fly ash and silica fume to produce high-strength self-compacting cementitious composites. *Crystals, 11*(8), 915.
Aruntaş, H. Y., Gürü, M., Dayı, M., & Tekin, İ. (2010). Utilization of waste marble dust as an additive in cement production. *Materials & Design, 31*(8), 4039–4042.
Ashish, D. K. (2018). Feasibility of waste marble powder in concrete as partial substitution of cement and sand amalgam for sustainable growth. *Journal of Building Engineering, 15*, 236–242.
Ashish, D. K. (2019). Concrete made with waste marble powder and supplementary cementitious material for sustainable development. *Journal of Cleaner Production, 211*, 716–729.
Ashish, D. K., & Verma, S. K. (2019a). An overview on mixture design of self-compacting concrete. *Structural Concrete, 20*(1), 371–395.
Ashish, D. K., & Verma, S. K. (2019b). Determination of optimum mixture design method for self-compacting concrete: validation of method with experimental results. *Construction and Building Materials, 217*, 664–678.
Ashish, D. K., & Verma, S. K. (2021). Robustness of self-compacting concrete containing waste foundry sand and metakaolin: a sustainable approach. *Journal of Hazardous Materials, 401*, 123329.
Ashish, D. K., Verma, S. K., Kumar, R., & Sharma, N. (2016). Properties of concrete incorporating sand and cement with waste marble powder. *Advances in Concrete Construction, 4*(2), 145.
Assie, S., Escadeillas, G., & Waller, V. (2007). Estimates of self-compacting concrete 'potential'durability. *Construction and Building Materials, 21*(10), 1909–1917.
ASTM. (2017). ASTM D6868 standard specification for biodegradable plastics used as coatings on paper and other compostable substrates. *ASTM International, West Conshohocken PA* 3. Retrieved from http://www.astm.org/DATABASE.CART/HISTORICAL/D6868-03.htm
Bahar, D. (2010). The effect of the using waste marble dust as fine sand on the mechanical properties of the concrete. *International Journal of Physical Sciences, 5*(9), 1372–1380.
Basar, H. M., & Aksoy, N. D. (2012). the effect of waste foundry sand (WFS) as partial replacement of sand on the mechanical, leaching and micro-structural characteristics of ready-mixed concrete. *Construction and Building Materials, 35*, 508–515.
Belaidi, A. S. E., Azzouz, L., Kadri, E., & Kenai, S. (2012). Effect of natural pozzolana and marble powder on the properties of self-compacting concrete. *Construction and Building Materials, 31*, 251–257.
Binici, H., Shah, T., Aksogan, O., & Kaplan, H. (2008). Durability of concrete made with granite and marble as recycle aggregates. *Journal of Materials Processing Technology, 208*(1–3), 299–308.
Bonavetti, V., Donza, H., Menendez, G., Cabrera, O., & Irassar, E. F. (2003). Limestone filler cement in low w/c concrete: a rational use of energy. *Cement and Concrete Research, 33*(6), 865–871.
Boukendakdji, O., Kadri, E.-H., & Kenai, S. (2012). Effects of granulated blast furnace slag and superplasticizer type on the fresh properties and compressive strength of self-compacting concrete. *Cement and Concrete Composites, 34*(4), 583–590.
Boukhelkhal, A., Azzouz, L., Belaïdi, A. S. E., & Benabed, B. (2016). Effects of marble powder as a partial replacement of cement on some engineering properties of self-compacting concrete. *Journal of Adhesion Science and Technology, 30*(22), 2405–2419.
Boukhelkhal, A., Azzouz, L., Benchaa, B., & Belaidi, A. S. E. (2017). Strength and durability of low-impact environmental self-compacting concrete incorporating waste marble powder. *Journal of Building Materials and Structures, 4*(2), 31.
Chan, D., & Sun, P. C. (2006). Effects of fine recycled aggregate as sand replacement in concrete. *HKIE Transactions, 13*(4), 2–7.
Chavhan, P. J., & Bhole, S. D. (2014). To study the behaviour of marble powder as supplementry cementitious material in concrete. *International Journal of Engineering Research and Applications, 4*(1), 377–381.
Chawla, A., SyedAhmedKabeer, K. I., & &Vyas, A. K. (2020). Evaluation of strength and durability of lean concrete mixes containing marble waste as fine aggregate. *European Journal of Environmental and Civil Engineering, 24*(9), 1398–1413.
Choudhary, R., Gupta, R., Alomayri, T., Jain, A., & Nagar, R. (2021). *Permeation, corrosion, and drying shrinkage assessment of self-compacting high strength concrete comprising waste marble slurry and fly ash, with silica fume*. Elsevier.
Choudhary, R., Jain, A., & Gupta, R. (2019). *Utilization of waste marble powder and silica fume in self-compacting concrete*. UKIERI.
Correia, J. R., de Brito, J., & Pereira, A. S. (2006). Effects on concrete durability of using recycled ceramic aggregates. *Materials and Structures, 39*(2), 169–177.
Cyr, M., Legrand, C., & Mouret, M. (2000). Study of the shear thickening effect of superplasticizers on the rheological behaviour of cement pastes containing or not mineral additives. *Cement and Concrete Research, 30*(9), 1477–1483.
Djebien, R., Belachia, M., & Hebhoub, H. (2015). Effect of marble waste fines on rheological and hardened properties of sand concrete. *Structural Engineering and Mechanics: an International Journal, 53*(6), 1241–1251.
Djebien, R., Hebhoub, H., Belachia, M., Berdoudi, S., & Kherraf, L. (2018). Incorporation of marble waste as sand in formulation of self-compacting concrete. *Structural Engineering and Mechanics: an International Journal, 67*(1), 87–91.
Domone, P. L. (2006). Self-compacting concrete: an analysis of 11 years of case studies. *Cement and Concrete Composites, 28*(2), 197–208.
EFNARC Specification. (2002). Guidelines for self-compacting concrete. *London, UK: Association House, 32*, 34.
Elmoaty, A., & Mohamed, A. E. (2013). Mechanical properties and corrosion resistance of concrete modified with granite dust. *Construction and Building Materials, 47*, 743–752.
Elyamany, H. E., Abd Elmoaty, M., & Mohamed, B. (2014). Effect of filler types on physical, mechanical and microstructure of self compacting concrete and flow-able concrete. *Alexandria Engineering Journal, 53*(2), 295–307.
Ergün, A. (2011). Effects of the usage of diatomite and waste marble powder as partial replacement of cement on the mechanical properties of concrete. *Construction and Building Materials, 25*(2), 806–812.
Esquinas, A. R., Álvarez, J. I., Jiménez, J. R., & Fernández, J. M. (2018). Durability of self-compacting concrete made from non-conforming fly ash from coal-fired power plants. *Construction and Building Materials, 189*, 993–1006.

Felekoğlu, B., Tosun, K., Baradan, B., Altun, A., & Uyulgan, B. (2006). The effect of fly ash and limestone fillers on the viscosity and compressive strength of self-compacting repair mortars. *Cement and Concrete Research, 36*(9), 1719–1726.

Felekoğlu, B., Türkel, S., & Baradan, B. (2007). Effect of water/cement ratio on the fresh and hardened properties of self-compacting concrete. *Building and Environment, 42*(4), 1795–1802.

Hameed, M. S., & Sekar, A. S. S. (2009). Properties of green concrete containing quarry rock dust and marble sludge powder as fine aggregate. *ARPN J. Eng. Appl. Sci, 4*(4), 83–89.

Hamzah, A. F., Ibrahim, M. H. W., Jamaluddin, N., Jaya, R. P., Arshad, M. F., & Abidin, N. E. Z. (2015). Fresh characteristic and mechanical compressive strength development of self-compacting concrete integrating coal bottom ash as partial fine aggregates replacement. *Int J of Mechanical and Mechatronics Engineering, 15*(4), 61–67.

Hanifi, B., Hasan, K., & Salih, Y. (2007). Influence of marble and limestone dusts as additives on some mechanical properties of concrete. *Scientific Research and Essays, 2*(9), 372–379.

Hebhoub, H., Aoun, H., Belachia, M., Houari, H., & Ghorbel, E. (2011). Use of waste marble aggregates in concrete. *Construction and Building Materials, 25*(3), 1167–1171.

Heikal, M., El-Didamony, H., & Morsy, M. S. (2000). Limestone-filled pozzolanic cement. *Cement and Concrete Research, 30*(11), 1827–1834.

Humayun, M., Ahad, M. Z., Naveed, A., Ahmad, F., Arif, M., Afridi, S., Sadiq, M., Jan, S. U., & Asif, M. (2021). Physical and Mechanical characterization of sand replaced stone dust concrete. *Materials Research Express, 8*(8), 85507.

Iqbal, S., Ali, A., Holschemacher, K., Ribakov, Y., & Bier, T. A. (2017). Effect of fly ash on properties of self-compacting high strength lightweight concrete. *Periodica Polytechnica Civil Engineering, 61*(1), 81–87.

Khayat, K. H. & Manai, K. (1996). Self-leveling concrete—properties and applications. *Proceedings*, 1–30.

Khayat, K., Hu, C., & Monty. H. (1999). Stability of Self-consolidating concrete, advantages, and potential applications. self-compacting concrete: proceedings of the first international RILEM Symposium, 143–52.

Latha, G., Reddy, A. S., Mounika. K., & Student, P. G. (2015). Experimental investigation on strength characteristics of concrete using waste marble powder as cementitious material. *International Journal of Innovative Research in Science, Engineering and Technology (An ISO)*, 3297(2). https://doi.org/10.15680/IJIRSET.2015.0412070

Mastali, M., & Dalvand, A. (2016). Use of Silica fume and recycled steel fibers in self-compacting concrete (SCC). *Construction and Building Materials, 125*, 196–209.

Mehta, P. K. (1986). Properties and materials. CONCRETE-Structure, 26–27.

Nehdi, M., Pardhan, M., & Koshowski, S. (2004). Durability of self-consolidating concrete incorporating high-volume replacement composite cements. *Cement and Concrete Research, 34*(11), 2103–2112.

Neville, A. M. (1995). *Properties of concrete* (Vol. 4). Longman.

Níelsson, I., & Wallevik. Ó. H. (2003). Of some empirical test methods. PRO 33: 3rd *International RILEM Symposium on Self-Compacting Concrete* 33, 59. RILEM Publications

Ofuyatan, O. M., Adeniyi, A. G., & Ighalo, J. O. (2021). Evaluation of fresh and hardened properties of blended silica fume self-compacting concrete (SCC). *Research on Engineering Structures and Materials, 7*(2), 211–223.

Ofuyatan, O. M., Olowofoyeku, A. M., Obatoki, J. & Oluwafemi. J. (2019). Utilization of marble dust powder in concrete. *IOP Conference Series: Materials Science and Engineering*, 640(1), 12053. https://doi.org/10.1088/1757-899X/640/1/012053

Ofuyatan, O. M., Omole, D., Enoch, K.-T., & Ogundeji, O. (2022). Marble waste and recycled concrete aggregates in self compacting concrete (SSC): an evaluation of fresh and hardened properties. *Australian Journal of Civil Engineering, 20*(1), 67–79.

Öznur Öz, H., Erhan Yücel, H. & Güneş. M. (2017). Comparison of Glass Powder and Fly Ash Effect on the Fresh Properties of Self-Compacting Mortars. *IOP Conference Series: Materials Science and Engineering*. 245(3), 032036. https://doi.org/10.1088/1757-899X/245/3/032036

Pala, K. P., Dhandha, K. J., & Nimodiya, P. N. (2015). Use of marble powder and fly ash in self compacting concrete. *International Journal for Innovative Research in Science & Technology, 1*(12), 475–479.

Pathan, V. G., & Pathan, M. G. (2014). Feasibility and need of use of waste marble powder in concrete production. *IOSR Journal of Mechanical and Civil Engineering, 6*(1), 23–26.

Pattapu, S. S., & Lal. N. V. S. (n.d.) A Study On Mechanical Properties Of Ssc With Partial Replacement Of Cement With Lime And Marble Powder.

Rahman, S., Kumar, R. Adil Dar, M. & Raju. J. (2019). Partial Substitution of Sand and Cement with Waste Marble Powder and Limestone Dust in Self Compacting Concrete. *Lecture Notes in Civil Engineering*, 21, 170–177. https://doi.org/10.1007/978-3-030-02707-0_21

Rao, K. B., Desai, V. B., & Jagan Mohan, D. (2012). Experimental investigations on mode II fracture of concrete with crushed granite stone fine aggregate replacing sand. *Materials Research, 15*, 41–50.

Rawal, P. (2003). Development of durable concrete from pulverized fly ash and pozzolan derived from agricultural wastes. Thesis Number ST-82-1. Asian Institute Technology.

Rehman, S., Iqbal, S., & Ali, A. (2018). Combined influence of glass powder and granular steel slag on fresh and mechanical properties of self-compacting concrete. *Construction and Building Materials, 178*, 153–160.

RollakantiPrasad, C. R. C. V. S. R., & SatyanarayanaKumar, P. V. V. M. P. (2020). *Experimental investigations and cost effectiveness of preformed foam cellular concrete blocks in construction industry*. Xi'an Univ Arch Technol.

Shannag, M. J., & Shaia, H. A. (2003). Sulfate resistance of high-performance concrete. *Cement and Concrete Composites, 25*(3), 363–369.

Sharbatdar, M. K., Abbasi, M., & Fakharian, P. (2020). Improving the Properties of self-compacted concrete with using combined Silica Fume and Metakaolin. *Periodica Polytechnica Civil Engineering, 64*(2), 535–544.

Sharifi, Y., Houshiar, M., & Aghebati, B. (2013). Recycled glass replacement as fine aggregate in self-compacting concrete. *Frontiers of Structural and Civil Engineering, 7*(4), 419–428.

Shirule, P. A., Rahman, A., & Gupta, R. D. (2012). Partial replacement of cement with marble dust powder. *International Journal of Advanced Engineering Research and Studies, 1*(3), 2249.

Siddique, R., Singh, G., & Singh, M. (2018). recycle option for metallurgical by-product (spent foundry sand) in green concrete for sustainable construction. *Journal of Cleaner Production, 172*, 1111–1120.

Smith, R. A., Kersey, J. R., & Griffiths, P. J. (2002). The construction industry mass balance: resource use, wastes and emissions. *Construction, 4*(September), 680.

Sonebi, M. & Bartos, P. J. M. (1999). Hardened SCC and its bond with reinforcement.1st International RILEM Symposium on Self-Compacting Concrete, 275–289.

Song, H.-W., & Kwon, S.-J. (2007). Permeability characteristics of carbonated concrete considering capillary pore structure. *Cement and Concrete Research, 37*(6), 909–915.

Sounthararajan, V. M., & Sivakumar, A. (2013). Durability evaluation in concrete using cracked permeability and chloride permeability tests". *Advances in Materials Science and Engineering*. https://doi.org/10.1155/2013/754027

Sutcu, M., Alptekin, H., Erdogmus, E., Er, Y., & Gencel, O. (2015). Characteristics of fired clay bricks with waste marble powder addition as building materials. *Construction and Building Materials, 82*, 1–8.

Tan, K. H., & Hongjian, Du. (2013). Use of waste glass as sand in mortar: part I-fresh, mechanical and durability properties. *Cement and Concrete Composites, 35*(1), 109–117.

Tennich, M., Ouezdou, M. B., & Kallel, A. (2017). Behavior of self-compacting concrete made with marble and tile wastes exposed to external sulfate attack. *Construction and Building Materials, 135*, 335–342.

Tomar, A. K., & Kumar, A. (2018). Strength chracteristics of self-compacting concrete partially replaced with waste marble powder. *J. Environ. Nanotechnol, 7*(4), 46–50.

Topcu, I. B., Bilir, T., & Uygunoğlu, T. (2009). Effect of waste marble dust content as filler on properties of self-compacting concrete. *Construction and Building Materials, 23*(5), 1947–1953.

Turk, K., Turgut , P., Karatas, M., & Benli. A. (2010). Mechanical properties of self-compacting concrete with silica fume/Fly Ash. *9th International Congress on Advances in Civil Engineering*, 27–30.

Turk, K. (2012). Viscosity and hardened properties of self-compacting mortars with binary and ternary cementitious blends of fly ash and silica fume. *Construction and Building Materials, 37*, 326–334.

Türker, P., Erdogan, B., & Erdogdu, K. (2002). Influence of marble powder on microstructure and hydration of cements. *Cem. Concr. World J. TÇMB (turkey), 7*, 38–89.
Uysal, M., & Sumer, M. (2011). Performance of self-compacting concrete containing different mineral admixtures. *Construction and Building Materials, 25*(11), 4112–4120.
Wee, T. H., Suryavanshi, A. K., Wong, S. F., & Anisur Rahman, A. K. M. (2000). Sulfate resistance of concrete containing mineral admixtures. *Materials Journal, 97*(5), 536–549.
Yahia, A., Tanimura, M., & Shimoyama, Y. (2005). Rheological properties of highly flowable mortar containing limestone filler-effect of powder content and W/C ratio. *Cement and Concrete Research, 35*(3), 532–539.
Yener, E., & Hinislioğlu, S. (2011). The Effects of silica fume and fly ash on the scaling resistance and flexural strength of pavement concretes. *Road Materials and Pavement Design, 12*(1), 177–194.
Zhang, T., Yang, Y.-L., & Liu, S.-Y. (2020). Application of biomass by-product lignin stabilized soils as sustainable geomaterials: a Review. *Science of the Total Environment, 728*, 138830.

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