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Assessment of Construction Waste Recycling as a Substitute for Fine Aggregate in the Sustainable Concrete Industry

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ABSTRACT

In Libya, the accumulation of construction waste has increased due to the war, which damaged structural buildings, as well as demolition, construction, and rehabilitation. Estimates indicate that the amount of post-conflict waste is approximately 82 million tons, which could be recycled or further processed for use in building construction and other economic sectors. At the same time, there is a continuous depletion of natural resources (fine and coarse aggregates) in the production of concrete, posing a challenge to the environment and the sustainability of natural resources. This study explored the use of construction waste recycling to create eco-friendly concrete by replacing 10% and 20% of the fine aggregate by weight with brick, marble powder, and ceramic waste. Cubic specimens of 150 × 150 × 150 mm and cylindrical specimens of 150 × 300 mm were cast to determine compressive and splitting tensile strengths, respectively. Eighty-four cubes and twenty-one cylinders were prepared and tested at ages 7, 28, and 56 days. The results indicated that the marble powder concrete mixture with 10% replacement had the lowest workability. Furthermore, at 56 days, the compressive strength of the ceramic waste concrete mixture increased by 25.41% when replacing 20% of the fine aggregate, while the highest tensile strength for the sustainable marble powder waste concrete mixture was recorded at 39.89% using the optimum 10% replacement at 28 days.

تقييم إعادة تدوير مخلفات البناء كبديل جزئي للركام الناعم في صناعة الخرسانة المستدامة

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الكلمات المفتاحية:
إعادة التدوير.
مخلفات البناء.
الركام الناعم.
مقاومة الضغط.
الاستدامة.

الملخص

في ليبيا، ازداد تراكم مخلفات البناء بسبب الحرب التي أثرت على المباني الهيكلية، بالإضافة الي الهدم والبناء وإعادة التأهيل. وتشير التقديرات إلى أن كمية مخلفات تبلغت حوالي 82 مليون طن، والتي يمكن إعادة تدويرها أو معالجتها مرة أخرى لاستخدامها في تشييد المباني والقطاعات الاقتصادية الأخرى. من ناحية أخرى، هناك استنزاف مستمر للموارد الطبيعية (الركام الناعم والخشن) في إنتاج الخرسانة، مما يشكل تحديا للبيئة واستدامة الموارد الطبيعية في المستقبل. استكشفت الدراسة استخدام إعادة تدوير نفايات البناء لإنشاء خرسانة صديقة للبيئة عن طريق استبدال الركام الناعم بالطوب ومسحوق الرخام ونفايات السيراميك بنسبة 10% و20% من وزن الرمل. تم صب العينات المكعبة بابعاد150 × 150 × 150 ملم والعينات الأسطوانية بابعاد 150 × 300 ملم لاختبارات الضغط والشد، على التوالي. تم تحضير واختبار أربعة وثمانين مكعبا وواحد وعشرين أسطوانة بعد عمر 7 و28 و56 يوما. أشارت النتائج إلى أن خليط خرسانة مسحوق الرخام، باستخدام 10 % من وزن الرمل، كان أقل قابلية للتشغيل. علاوة على ذلك، في 56 يوما، أظهرت مقاومة الانضغاط تحسنا هائلا في خليط خرسانة مخلفات السيراميك بنسبة 25.41 % عند استبدال 20% من وزن رمل، بينما تم تسجيل أعلى مقاومة الشد لخليط خرسانة مخلفات بودرة الرخام بنسبة 39.89 % باستخدام النسبة المثلى البالغة 10 % عند 28 يوما.

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1. Introduction

Concrete is an essential component of the construction industry and the most widely consumed material worldwide. Although the production of cement results in the emission of large amounts of carbon dioxide, the extraction and production of aggregates cause vegetation loss and environmental damage, such as desertification [1,2]. To mitigate the negative environmental effects of the concrete industry, it is essential to develop more sustainable concrete production methods within the context of green structures and eco-friendly cities [3].

Construction and demolition waste can be classified into steel waste, recycled concrete aggregate, recycled glass, recycled plastic, brick waste, ceramic waste, and wood, among others. However, the enormous increase in construction waste has become a major impediment to proper disposal. The definition of construction and demolition waste varies across studies; several describe it as waste generated from construction, renovation, and demolition activities. Therefore, researchers are exploring the use of construction waste as a substitute for cement, coarse aggregate, or fine aggregate to conserve natural resources and produce more sustainable concrete [4].

The use of construction materials containing recycled components provides a proactive and practical approach to addressing waste management problems, offering societal benefits such as resource and energy conservation and creating new markets for recycled materials. Recycling is an integral part of the waste management process; however, there remains a widespread misconception that it alone can resolve all environmental and economic issues [5]. On construction sites, waste can be classified as material or non-material waste. The loss, damage, irreparability, or unusability of material during construction is referred to as material waste, whereas non-material waste is associated with the loss of time and money caused by delays and inefficiencies in project execution.

Foo et al. [6] examined waste generation at building sites and estimated that the accumulated waste reached 154.31 m³, comprising materials such as bricks, concrete, steel, timber, and packaging. Hemanth Kumar et al. [7] partially replaced coarse and fine aggregates with tile waste at 10% and 20%, respectively, and evaluated workability and compressive strength at 7 and 28 days. The optimum results were obtained with 20% sand replacement and 10% coarse aggregate replacement. Merwin et al. [8] investigated ordinary-strength concrete using ceramic waste as a replacement for coarse aggregates. Ceramic waste replaced coarse aggregates at 0%, 15%, 20%, 25%, and 30%. Tests on workability, compressive strength, and indirect tensile strength at 3, 7, and 28 days showed that ceramic waste was suitable for normal concrete mixes of Grades M15 and M20.

In a related study, Peter et al. [3] examined the mechanical properties of concrete incorporating recycled ceramic waste aggregates. Natural fine and coarse aggregates were partially replaced with ceramic waste aggregates at 25%, 50%, and 75%. The results showed that the compressive strength of samples containing 50% recycled ceramic fine aggregates and 75% recycled ceramic coarse aggregates was higher than that of the control mix. Soomro et al. [9] used marble powder waste as a cement substitute (10%) and ceramic tile waste as a coarse aggregate replacement (10%, 20%, and 30%) in concrete mixes to develop sustainable and green construction materials. They observed that workability decreased as the substitution ratio increased, and compressive strength decreased accordingly.

Ekop et al. [10] investigated the workability and compressive strength of concrete when fine aggregates were replaced with glass and iron filing waste. Fine aggregates were substituted with 0%, 5%, 10%, 15%, 20%, and 25% of glass particles and iron filings, respectively, at a water-to-cement ratio of 0.55. The results showed that increasing the waste iron filing ratio reduced slump and workability, while increasing glass waste content improved both. The optimum compressive strength was achieved at a 20% substitution level of fine aggregate with waste iron and glass. Using such materials encourages the conservation of natural resources and supports sustainable waste management in the concrete industry.

Recently, Reda et al. [11] investigated the use of granite powder, iron powder, brick powder, and waste plastic particles as replacements for fine aggregates at 5%, 10%, 15%, and 20%. They found that replacing 20% with iron powder increased compressive, tensile, flexural strength, and energy by 8.4%, 12.5%, 8.5%, and 125%, respectively. The optimal levels for granite and brick powders were 10%. Using 10% granite powder increased compressive strength, tensile strength, flexural strength, and energy by 11.7%, 25%, 21.5%, and 100%, respectively, while brick powder increased them by 12.9%, 7.6%, 15.4%, and 63%, respectively. Another study examined the influence of ceramic powder on concrete's mechanical properties and found negligible effects on compressive and tensile strength; however, RC beams with 10% ceramic waste substitution exhibited greater deformation capacity than control beams [12].

Over the past decade, numerous studies have focused on minimising environmental impacts by replacing conventional materials with waste-derived alternatives in concrete [13–19]. Some local research has examined the Libyan construction sector's adoption of sustainable concrete utilising recycled building materials, particularly recycled concrete aggregate [20–23]. The results indicated that recycling construction waste, often reused as sub-base material, can promote social, economic, and environmental sustainability.

In this context, the present study aims to promote the recycling of construction waste generated from war damage, demolition, and redevelopment projects in Libya as a cost-effective means of mitigating the negative effects of these wastes. As a step towards sustainability in building construction, the study investigates the effect of partially replacing fine aggregates with brick waste, marble powder waste, and ceramic waste (at 10% and 20% by weight of fine aggregate) on the mechanical properties of fresh and hardened concrete. These replacement levels were selected based on the findings of previous research [7–12], which demonstrated that partial rather than full replacement improves mechanical properties without compromising workability or strength. Such replacement ratios offer a balance between concrete performance and the preservation of environmental and natural resources.

2. Experimental Work

This part gives the experimental tests to assess the quality and suitability of the materials used in the current work.

2.1. Materials

The sustainable concrete mix used in this study consists of cement, coarse aggregate, fine aggregate, bricks waste, marble powder waste, and ceramics waste, in addition to water. Ordinary Portland Cement (Type I-42.5 N) was used in all concrete mixtures, according to Libyan specifications, NO. 340/2009 [24]. The coarse aggregate used was stone with an angular shape and a nominal maximum size of 20mm. The specific gravity, water absorption, impact value and crushing value were 2.64 g/cm^3, 1.42%, 15.64%, and 22.11%, respectively which conforms to the specifications of BS812[25]. Fig. 1 displays the grading curve of coarse aggregate conforming to specification limits BS882 [26]. The fine aggregate was natural sand with a fineness modulus, water absorption and specific gravity of 2.97, 2.7% and 2.617 g/cm3, respectively which conforms to the specifications of BS812[25].

Brick and ceramic wastes were collected from construction and storage sites and broken into medium to small pieces, and then its grind. Using a special mill designed for this purpose, as shown in Fig. 2, the machine is fitted with a sieve that has a diameter of 5 mm, and waste material is grinded until it passes through the sieve. Following several trials, the particle size of the waste conforms to the grading specifications of sand. Marble waste powder was collected from factories and suppliers and used according to its size and grade. The specific gravity of replacement materials such as brick, marble and ceramic wastes were 2.262, 2.577, and 2.49, respectively. Fig. 3 shows the grading curve of fine aggregate, bricks, marble powder, and ceramics waste conforming to specification limits BS882 [26], additional Fig. 4 illustrates the construction materials such as Brick BW, marble powder MP and ceramic wastes CW used in the current study.

2.2. Mixing Proportion

The proportions of concrete mixture are one of the most important factors affecting the quality of concrete. In this work, the components of the mix were used [10] by conducting experiments on components before starting the experimental program. So, the proportions of the concrete mixture components by weight (kg) per cubic meter were determined as given in Table 1.

2.3. Casting and Test Procedure

Fig. 5 shows the specimens preparation steps, which include mixing, casting, and curing. The cubes and cylinders were treated in water for 7, 28 and 56 days. A slump test is conducted to determine the workability of fresh concrete produced with brick, marble powder, and ceramics waste as fine aggregate. A water absorption test was carried out to determine the moisture ratio of the sustainable concrete cubes produced. The water absorption test was realized according to (BS 1881- 122 2011) [27]. The compression and splitting tensile tests were conducted using a compression testing machine with a capacity of 3000kN. Three standard cubes measuring 150 × 150 × 150 mm for determining the compressive strength of concrete, and three standard concrete cylinders 150 × 300mm were used to calculate the spitting tensile strength.

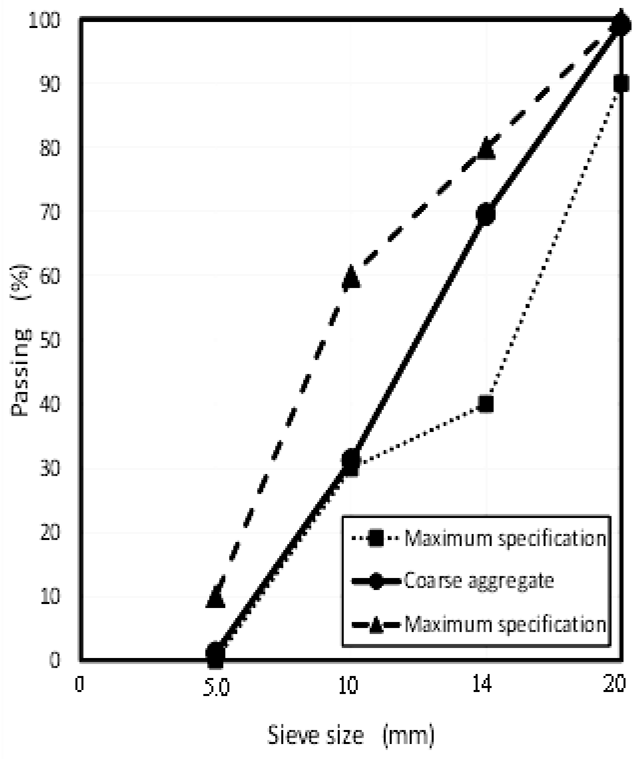

Fig. 1: Grading curves of coarse aggregates.

Fig. 2: Construction waste grinding machine used in the study.

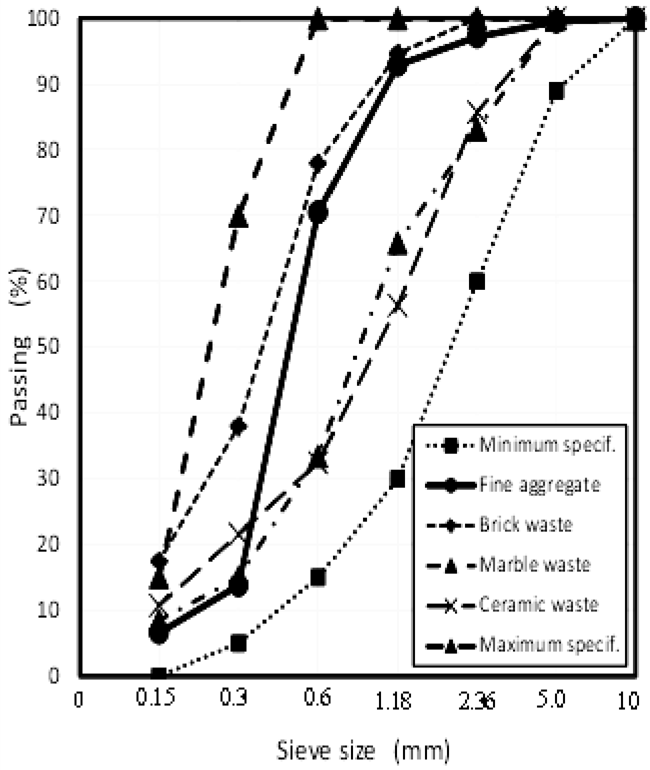

Fig. 3: Grading curves of Fine aggregate, BW, BP, and CW.

(a) (b) (c)

Fig. 4: Replacement materials: (a) Brick waste, (b) Marble powder and (c) Ceramic waste

Table 1: Mix proportion for concrete (kg/m3)

Mix	Cement (kg)	Water (Litre)	Coarse aggregate (kg)	Fine aggregate (kg)			
				Sand	Brick waste	Marble power	Ceramic waste
M-S0	420	231	1115	685	-	-	-
M-BW10	420	231	1115	616.5	68.5	-	-
M-MP10	420	231	1115	616.5	-	68.5	-
M-CW10	420	231	1115	616.5	-	-	68.5
M-BW20	420	231	1115	548	137	-	-
M-MP20	420	231	1115	548	-	137	-
M-CW20	420	231	1115	548	-	-	137

(a) (b) (c) (d)

Fig. 5: Specimens preparation stage: (a) Mixing, (b) Cast and compaction, (c) Slump test, (d) Curing

3. Results and Discussion

Table 2 gives the statistical analyses experimental results of water absorption, compressive strength, and tensile

Table 2: Statistical analysis of experimental results for all mixtures in this study

Mix	Water absorption		Compressive strength						Splitting Tensile Strength	
			7 days		28 days		56 days		28 days	
	Mean (%)	Standard Deviation (%)	Mean (MPa)	Standard Deviation (MPa)	Mean (MPa)	Standard Deviation (MPa)	Mean (MPa)	Standard Deviation (MPa)	Mean (MPa)	Standard Deviation (MPa)
M-S0	3.66	0.180	30.96	1.875	37.18	0.836	38.44	1.223	1.93	0.098
M-BW10	3.33	0.031	22.81	0.678	30.22	1.380	39.03	1.002	2.7	0.205
M-MP10	3.58	0.021	26.36	1.361	38.29	1.097	39.11	1.521	1.64	0.151
M-CW10	3.20	0.010	24.88	1.175	33.33	1.858	44.88	0.525	2.68	0.142
M-BW20	3.42	0.065	24.96	0.777	36.36	0.678	36.84	1.067	2.45	0.081
M-MP20	3.75	0.036	25.69	1.226	37.03	1.238	40.88	0.939	1.74	0.194
M-CW20	3.08	0.015	29.62	1.542	39.84	1.013	48.21	1.284	2.94	0.049

3.1. Slump and density of concrete

The workability of sustainable concrete is evaluated using a slump test. Fig. 6 illustrates the effect of the proportions of partial replacement of fine aggregate by construction waste on the slump value. Generally, the slump value decreased because of the partial replacement of sand by construction wastes; similar results were observed by [10]. It can be seen that the partial replacement of sand with 10% marble powder waste recorded a remarkable decrease in slump value compared to bricks and ceramics wastes. In contrast, ceramic waste has a lower slump at the partial replacement of sand with 20%.

The results shown in Fig. 7 revealed that the value of density is 2445.42kg/m^3 after 28 days in the case of the control M-S0 mix, while, in the case of replacing sand with brick waste for sample M-BW10 mix the decrease is from 2445.42kg/m^3 to 2412.14kg/m^3 observed. Similarly, for sample M-BW20 the decreased value to 2422.31kg/m^3. On the other hand, in the case of replacing sand with marble powder waste for specimen M-MP10, the decrease is from 2445.42kg/m^3 to 2399.41 kg/m^3. By contrast, there has been a slight increase for specimen M-MP20 increased value from 2445.42kg/m^3 to 2448.29kg/m^3. In contrast, ceramic waste has a lower density at the partial replacement of sand with 10%. It was observed that there was a reduction in density by 3.11% for sample M-CW10, this outcome is consistent with [28].

strength for mixtures partially substituted by brick, marble powder, and ceramic wastes by 10% and 20% out of the fine aggregate at curing ages of 7, 28, and 56 days.

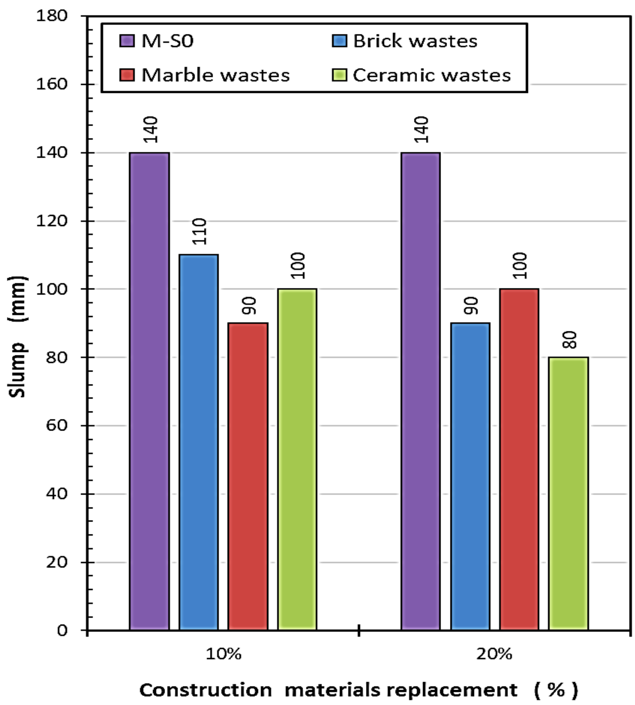

Fig.6: Influence of partially replacing sand with construction

waste on the slump value.

3.2. Water absorption of concrete

Fig. 8 demonstrates the effect of 10% and 20% partial replacement of fine aggregate with construction waste on the absorption property of concrete. The findings indicate that an absorption value of 3.66% is observed for the M-S0 mix. In contrast, with the replacement of 10% marble

powder (M-MP10), a decrease in water absorption from 3.66% to 3.58% was observed. On the other hand, a partial replacement of fine aggregate decreases water absorption with BW and CW for M-BW10 and M-CW10 mixtures to 3.33% and 3.2%, respectively compared to M-S0. Furthermore, ceramic waste has a lower water absorption at the partial replacement of sand with 20%. It was observed that there was a reduction in water absorption by 15.84% for mixture M-CW20.

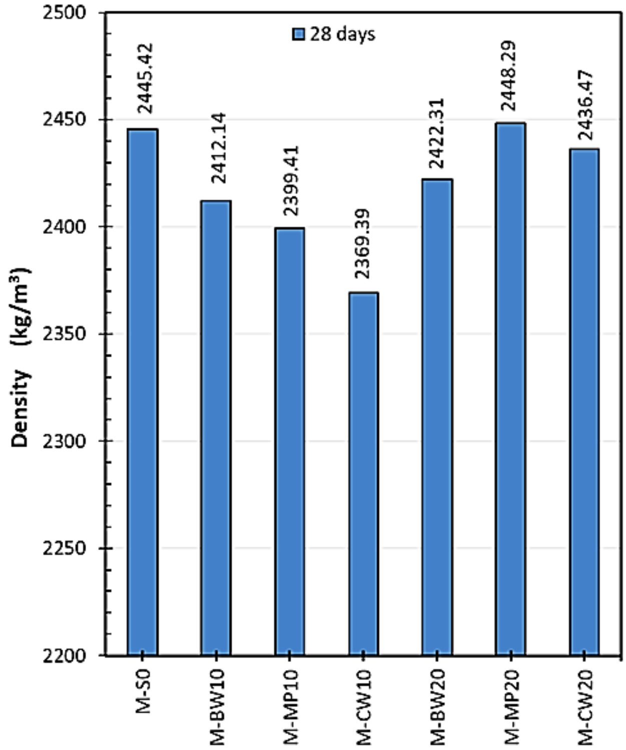

Fig. 7: Influence of partially replacing sand with construction waste on the density of sustainable concrete.

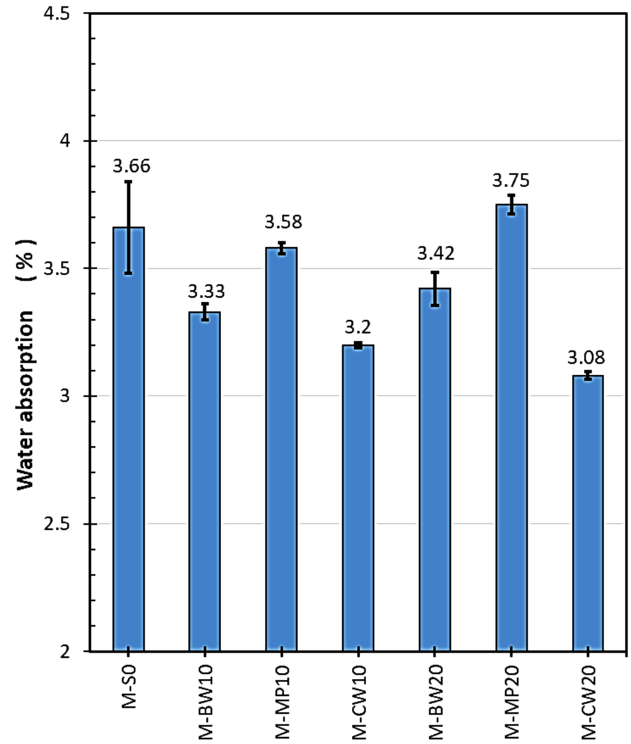

Fig. 8: Water absorption results for all mixtures.

3.3. Compressive strength

Fig. 9 presents the compressive strength behaviour after curing for 7, 28, and 56 days for mixes M-S0, M-BW10, M-MP10, and M-CW10, as a partial replacement of fine aggregate with construction waste by 10%. From the data illustrated in the figure, we can notice that the compressive strength recorded a remarkable decrease for mixtures of replacement construction materials compared to the reference mixture (M-S0) in the early days (7 days). While, the behaviour of compressive strength at the curing of 28 days for mixes M-BW 10 and M-CW 10 have notably decreased by about 18.72% and 10.35%, respectively, compared to mixes M-SO. In contrast, there was a slight increase in the compression strength at the replacement of fine aggregate with marble powder waste for M-MP10 by about 2.98% compared to M-S0. On the other hand, the results indicated that at the curing of 56 days, there was a noticeable improvement in compressive strength for mixtures M-BW10, M-MP10, and M-CW10 by about 1.53%, 1.74%, and 16.75%, respectively compared to M-S0. The highest compressive strength value of sustainable concrete by marble powder waste was recorded about 38.29MPa, at the age of 28 days, this result was reported by [29-31]. Additionally, the highest of compressive strength value of sustainable ceramic waste concrete was recorded about 44.88MPa, at

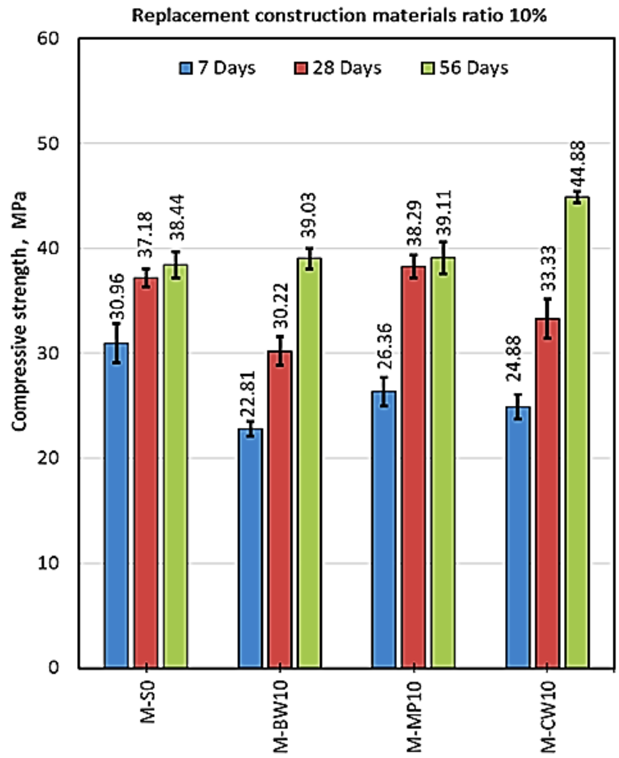

Fig. 9: Compressive strength results for concrete with construction waste by 10% at 7, 28 & 56 days.

the age of 56 days. Similar results were revealed, showing that using 10% ceramic waste leads to improvements of 34.65% in strength after 56 days of curing, compared to 28 days by [12].

Fig. 10 shows the compressive strength conduct after curing for 7, 28, and 56 days for mixes M-S0, M-BW20, M-MP20, and M-CW20, as a partial replacement of fine aggregate with construction waste by 20%. We can notice that after 7 days, no clear improvement in compressive strength was observed, for mixtures of replacement construction materials compared to the control mixture (M-S0). While, the behaviour of compressive strength at the curing of 28 days for mixes M-BW 20 and M-MP 20 have sight decreased by about 2.20% and 0.40%, respectively, compared to mixes M-S0. In contrast, there was a notable improvement in the compression strength at the replacement of fine aggregate with ceramic waste for mixture M-CW20 by about 7.15% compared to M-S0. On the other hand, the results indicated that after 56 days, there was a significant increase in compressive strength for mixtures M-MP20, and M-CW20 by about 6.34%, and 25.41%, respectively compared to M-S0. In contrast, there was a slight decrease in the compression strength at the replacement of fine aggregate with brick waste for M-BW20 by about 4.16% compared to M-S0. The highest compressive strength value of sustainable concrete by ceramic waste was recorded at the age of 28, 56 days, as reported by [32,33]. Additionally, the lowest compressive strength value of sustainable brick waste concrete was recorded at 28, and 56 days; these findings agree with the results of [11].

A relative analysis was carried out in which 28 days of compressive strength of the reference mixture is considered as a control mixture, from which various mixtures of brick waste, marble powder waste and ceramic waste recycled by 10% - 20% used in this study are compared after curing 28, and 56 days as illustrated in Fig. 11. At 28 days of curing, compressive strength was about 2.78% higher than compared to control (28 days) at 10% replacement of marble powder waste. Also, compressive strength was about 6.67% higher than compared to the control (28 days) at 20% substitution of ceramic waste, while the strength of brick waste concrete replacing 10% of sand is 17.47% lower than control concrete. At 56 days of curing, compressive strength was about 6.67% higher than the control (28 days) at 20% substitution of ceramic waste, while the strength of brick waste concrete replacing 20% of sand is 16.90% lower than control concrete.

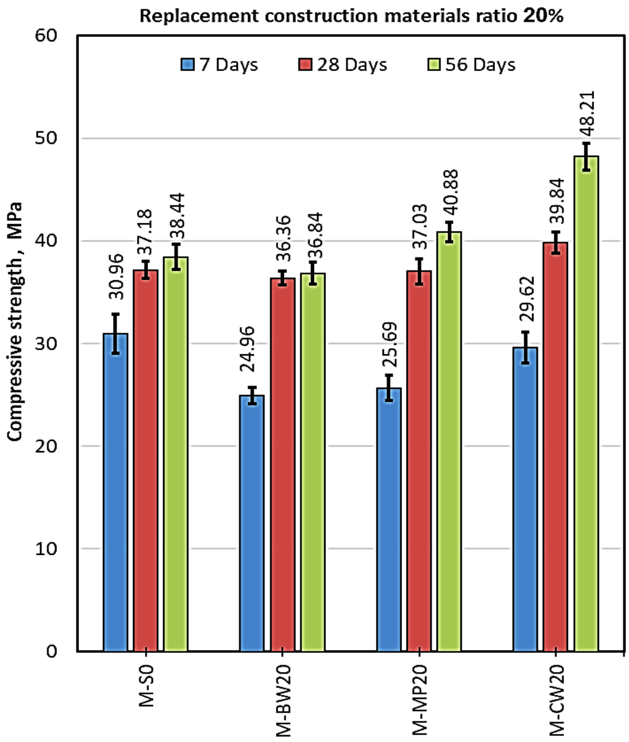

Fig. 10: Compressive strength results for sustainable concrete with construction waste by 20% at 7, 28 &56 days.

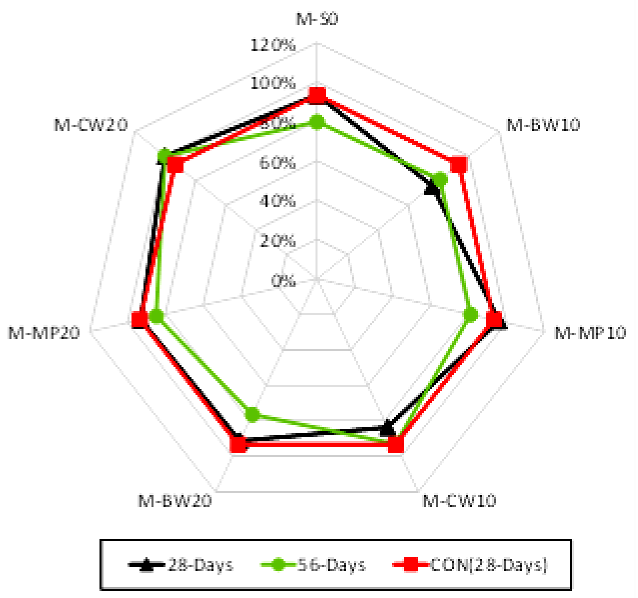

Fig. 11: Relative analysis of compressive strength of all mixtures.

3.4. Splitting Tensile Strength

Fig. 12 presents the split tensile strength behaviour after curing for 28 days for all mixtures as a partial replacement of fine aggregate with construction waste by 10%, and 20%. We can note at the partial replacement of fine aggregate by 10% that tensile strength recorded a remarkable increase for mixtures M-BW10 and M-CW10 by about 39.89%, and 38.86%, respectively, compared to the control mixture (M-S0). In contrast, there was a slight decrease in the split tensile strength using marble powder waste for M-MP10 by about 15.02% compared to M-S0. Notably, the optimum percentage of brick waste achieved maximum improvement in tensile strength was 10% compared to other mixtures. This result is confirmed by [11]. On the other hand, with the partial replacement of sand by 20% that spilt tensile strength showed a notable increase for mix M-BM 20, and M-CW20 by about 26.94%, and 52.33%, respectively, compared to mixes of M-S0. Furthermore, the behaviour of the tensile strength value of the marble powder concrete for the mixture (M-MP20) was lower than a control mixture by about 9.84%. However, significant improvement in tensile strength was observed at 20% ceramic waste as replacement of fine aggregate.

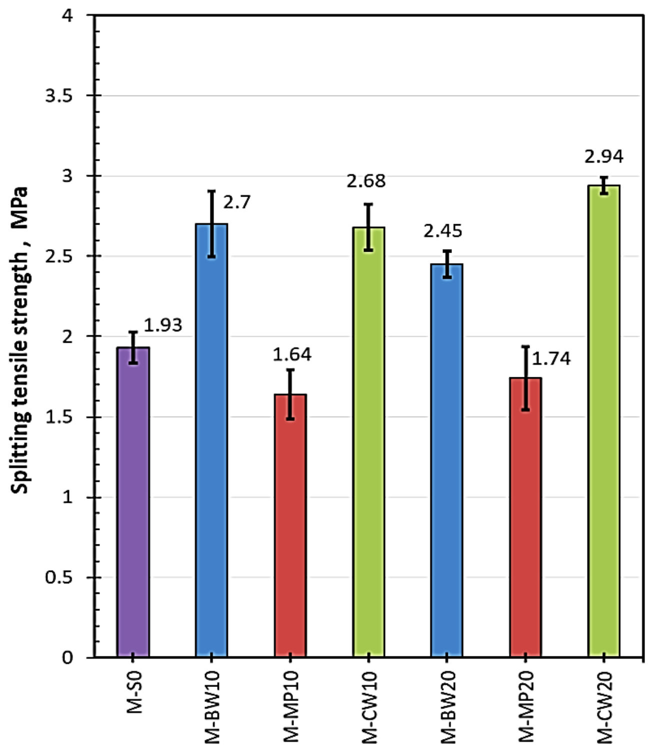

Fig. 12: Spitting tensile strength results for sustainable concrete with construction waste by10%, and 20% at 28 days.

4. Conclusions

The present work provides the following findings:

- Replacing 10% and 20% of fine aggregate with construction waste reduced workability. The marble powder concrete mixture with 10% replacement showed the lowest workability, decreasing by approximately 35.7% compared to the control mixture. In contrast, with 20% ceramic waste replacement, workability decreased by 42.8%.
- The lowest density was observed in the ceramic waste concrete mixture with 10% substitution for fine aggregate, showing a reduction of 3.10%.
- Partial replacement of fine aggregate with ceramic waste at 10% and 20% reduced water absorption by 12.5% and 15.8%, respectively, compared to the control, brick waste, and marble powder waste mixtures.
- The compressive strength of the sustainable marble powder concrete mixture increased by approximately 2.98% when using the optimum 10% replacement of fine aggregate at 28 days. In contrast, at 56 days, the compressive strength of the ceramic waste concrete mixture improved significantly by about 25.41% when 20% ceramic waste was used as a partial replacement.

- The lowest compressive strength for brick waste concrete was observed at 28 and 56 days.
- The highest tensile strength for the sustainable marble powder concrete mixture was recorded at 39.89% with the optimum 10% replacement at 28 days.
- A 20% substitution with ceramic waste resulted in the greatest improvement in split tensile strength.

Based on the results of this research, the following recommendations for future studies are proposed:

- Investigate the effect of varying the water-to-cement ratio for mixtures using construction waste replacements greater than 20%.
- Study the impact of replacing coarse or fine aggregates with various construction wastes, such as recycled concrete aggregates, plastic, and glass, among others.
- Investigate the long-term performance of sustainable concrete using construction waste, including durability tests.

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