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EXPLORING THE USE OF FLY ASH AND MARBLE COARSE AGGREGATES AS ECO-FRIENDLY REPLACEMENTS IN CONCRETE PRODUCTION

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ABSTRACT

This study investigates the feasibility of utilizing fly ash and marble coarse aggregates as sustainable substitutes in concrete production, responding to the increasing demand for infrastructure and the necessity to diminish the carbon footprint of construction materials. By partially substituting cement, a material that generates substantial greenhouse gas emissions, fly ash, a by-product of coal combustion, recognizes its capacity to reduce CO2 emissions. The stone processing industry produces marble waste, which, by repurposing otherwise wasted byproducts, offers an environmentally sustainable solution, simultaneously reducing the use of natural resources in the manufacture of traditional aggregates. The research aims to assess the effects of incorporating various ratios of fly ash, ranging from 10% to 50%, and marble coarse aggregates, ranging from 10% to 90%, on the workability, compressive strength, split tensile strength, and flexural strength. The results show a moderate decrease in a slump, with an 18.66% reduction at 50% marble coarse aggregates and 30% fly ash, and a significant increase in compressive strength, with a 60.22% improvement at 56 days with 40% fly ash and 70% marble coarse aggregates. Split tensile strength also improved by 35.50% to 36.66%. Non-destructive tests confirmed the structural integrity of the concrete. This study emphasizes the potential of fly ash and marble coarse aggregates as eco-friendly substitutes in concrete production.

1. INTRODUCTION

Increasing infrastructure and urbanization are major drivers of global concrete demand, which ranks second only to water in terms of usage, with worldwide manufacturing of approximately 5.3 billion cubic meters per year (Ullah et al., 2022). This figure is expected to reach 18 billion tons by 2050 (Kumar Mehta et al., 2014). As stated by the United Nations, the global urban population is projected to reach 68% by 2050, significantly increasing the demand for construction materials. This rise in demand places immense pressure on natural resources and leads to significant environmental impacts, such as the depletion of sand and gravel quarries and increased CO2 emissions from cement production (Aruntas et al.,2010; Kemer et al.,2021). 8% of the world's carbon dioxide emissions come from the production of concrete (André., 2012; André et al., 2014), with Portland cement being a major contributor (Anouar et al.,2015; Jang et al., 2016), contributing negatively to increased environmental pollution (Belaïd.,2022). Consequently, significant environmental and economic concerns have emerged due to the widespread use of concrete (Rashad et al.,2013, Sankh et al., 2014). This necessitates the complete or partial replacement of cement and aggregates with environmentally friendly materials. To address these challenges, significant research has been conducted on alternative and sustainable materials. Various industrial and agricultural wastes, such as silica fume, granulated blast furnace slag, rice husk ash, marble waste from the stone industry, textile sludge ash, sewage sludge ash, and fly ash have been proposed as partial substitutes for concrete ingredients. These materials have shown promise in improving concrete properties. The purpose of this research is to demonstrate the effectiveness of using fly ash, and coarse marble aggregates in concrete production. By examining their combined impact, the study aims to provide insights into their potential as sustainable alternatives to traditional concrete ingredients and to address the identified research gaps. Marble waste is one of these by-products; it is produced in marble quarries during the cutting of marble. As for fly ash, it is a by-product of the combustion of pulverized coal in power plants and is generally classified as class C or class F.

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Research has increasingly focused on the use of waste marble and fly ash as sustainable alternatives in concrete production. Studies, such as that by Binici (Binici et al., 2007,2008), have shown that replacing natural aggregates with waste marble can enhance workability. Similarly, Hebhoub (2011) demonstrated that using waste marble in place of sand significantly increases compressive strength, although it may reduce workability. Other researchers, including André (2012-2014) and Martin (2014), noted improvements in compressive strength and workability at certain replacement levels, confirming the viability of using marble waste. The potential of fly ash as a partial cement replacement has also been explored, with Ghazali (2021) finding improvements in workability and compressive strength at optimal substitution levels. Moreover, Temesgen (2021) observed that up to 10% of fly ash replacement increases both compressive strength and slump, highlighting its viability as a sustainable alternative. Zaryab (2022) and Gaurav (2020) studied the combined use of fly ash and marble powder, finding optimal results in strength with specific replacement levels.

These studies indicate that waste marble and fly ash can be effectively utilized in concrete, offering environmental and economic benefits while maintaining or even enhancing key mechanical properties.

2. STUDIES RELEVANCE

The principal goals of this investigation are to minimize environmental degradation and reduce reliance on natural resources. From this angle, the main objective of this research is to investigate in detail the properties of concrete that result from replacing some Fly Ash (FA) and Marble coarse aggregates (MCA) with sand and natural coarse aggregates (NCA). The primary variables examined in this study were the amount of fly ash added in place of sand and the amount of marble coarse aggregates added to the concrete mixtures in place of natural coarse aggregates. 10%, 20%, 30%, 40%, and 50% of the total volume of sand was replaced with fly ash, and 10% to 90% of the natural coarse aggregates was replaced with marble coarse aggregate, increasing by 20% over time. The ratio of water to cement is maintained at 0.55.

The mechanical properties of mixes containing various proportions of these materials were rigorously evaluated through both destructive and non-destructive tests. This research aims to evaluate the sustainability and ecological advantages of this alternative approach by looking at parameters like workability, flexural strength, compressive strength, split tensile strength, ultrasonic pulse velocity, and Schmidt rebound hammer index.

3. EXPERIMENTAL STUDY

3.1. Characterization of materials

With a minimum clinker content of 65%, Portland cement CPJ 45 was selected as the binder for this project to formulate concrete. The remaining materials consisted of additives such as fly ash, pozzolans, and fillers provided by Holcim and complying with the Moroccan specifications NM10.1.004. The concrete was mixed using water for drinking supplied by Oujda's Autonomous Intercommunal Water and Electricity Distributing Agency (RADEEO). This water meets the physical and chemical standards of NM 10.1.353. For this project, Oujda region natural sand was used. It was almost devoid of impurities, with a specific gravity of 2.68, a 2.5% water absorption, and a 2.85 fineness modulus. Its smooth, spherical, cube-shaped construction provides good workability. To manage the water content of the concrete, the sand was dried for an entire day at room temperature. The largest sand size was 4.75 mm. The NF EN 12620 standard was followed for conducting the sand tests. In this investigation, two varieties of crushed coarse stone aggregates, G1 with Sieve Range 5-11(mm) and G2 with 11-20(mm), with a specific gravity of 2.70 and 2.72 respectively, and water absorption of 1.48% and 1.50% respectively, were used as stated by the NF P-18-560 standard. As an auxiliary material in the process of shaping and cutting, marble companies provided marble dust in the form of powder and coarse aggregate. Marble waste used was crushed into crusher in order to obtain a size ranging from 5 to 20 mm.

This study utilizes F-class fly ash from the Jerad thermal power plant in Morocco, obtained through electro-static dust collection of powdery particles from the flue gas stream of boilers fueled by pulverized coal. This type of fly ash contains low calcium (1.18 %), has a Fineness Blaine of 3360 m2/kg, and a specific gravity of 2.2, as per NM 10.1.004. The marble coarse aggregate (MCA) has a specific gravity of 2.73 and water absorption of 0.50%. Table 1, displays the initial and final setting times, consistency, the sand's specific gravity, the coarse gravel's specific gravity, the Fineness Blaine, and absorption of water results. Table 2, displays the natural aggregate's chemical constituents. Figure 1, displays the size of the particles analyses of the different materials utilized.

Property	C	FA	S	G1	G2	MCA
Specific Gravity	3.15	2.2	2.68	2.7	2.72	2.73
Water absorption %		3.01	2.50	1.48	1.50	0.5
Consistency (%)	29					
Fineness modulus		0.96	2.85	6.62	6.82	7,68
Initial setting time (min)	180					
Final setting time (min)	210					
Fineness Blaine (cm^2/gm)	3100	3360				

Table 1. Physical characteristics of Concrete Constituent Materials: Cement (C), Fly Ash (FA), Sand (S), Gravel 1 (G1), Gravel 2 (G2), and Marble Coarse Aggregates (MCA)

Constituent (%)	Cement (%) by mass	Fly Ash (%) by mass	Sand (%) by mass
CaO	60.06	1.18	5.58
SiO_2	20.90	55.2	77.40
Fe_2O_3	3.90	11.2	2.66
AL_2O_3	5.85	28.3	8.18
MgO	1.85	0.68	0.77
K_2O	2.14	1.45	0.25
TiO_2	0.32	1.5	0.005
SO_3	2.35	0.44	0.018
LOI	21.84	1.06	……..

Table 2. The chemical constitution of Cement, Sand, and Fly Ash

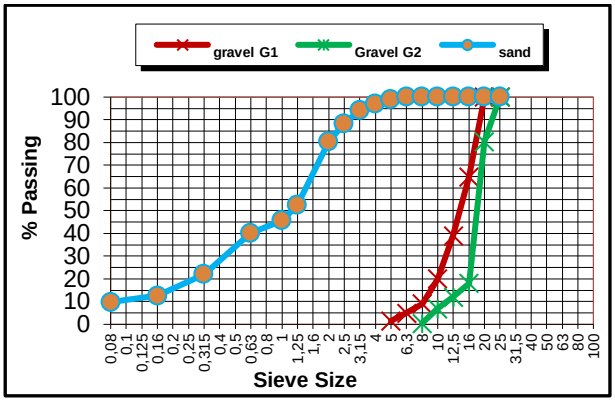

Figure 1. Distribution of sand, gravel G1, and gravel G2 particle sizes

The mixture ratios of fly ash, marble coarse aggregate, and cement are listed in Table 3. The Dreux-Gorse model was applied to carry out the concrete design. The symbol SFS indicates Fly Ash used in place of sand, and MCA indicates marble coarse aggregates instead of natural aggregates. For example, MCA30SFS10 refers to the mixture in which fly ash is employed in place of 10% of the sand, and 30% of the natural coarse aggregates are replaced with marble coarse aggregates.

Mix identification	Water (Kg/m3)	Cement (Kg/m^3)	Fine aggregates (Kg/m3)	G1 (Kg/m^3)	G2 (Kg/m3)	Fly Ash (Kg/m3)	MCA (Kg/m3)
MCA0SFS0	192	350	763	327	833	0	0
MCA10SFS10	192	350	686,7	294,3	749,7	76,3	116
MCA30SFS20	192	350	610,4	228,9	583,1	152,6	348
MCA50SFS30	192	350	534,1	163,5	416,5	228,9	580
MCA70SFS40	192	350	457,8	98,1	249,9	305,2	812
MCA90SFS50	192	350	381,5	32,7	83,3	381,5	1044

Table 3. Mixture proportions with w/c=0,55

3.2. Test Parameters

The testing laboratory for building materials at the Oujda Faculty of Science and the LABNORVIDA testing laboratory in Oujda were the two sites of the study's experimental program. Concrete mixes were meticulously formulated using a 125-liter capacity pan mixer. The fine aggregates were introduced to the mixer after the coarse aggregates had been added. A small amount of water was added, and deducted from the total amount computed. After that, a mixture of cement and marble dust was added, and finally, the remaining water. The mixer was kept going until the mixture was uniform. Consequently, to test them later, concrete samples of different sizes were first poured. After being sealed, the samples were kept for a full day at 23°C and 95 ± 5% relative humidity. After 24 hours, the concrete specimens were taken out of the molds and left to cure in water at 20 degrees Celsius for 28 days.

3.2.1. Workability: Using the slump cone test conforming to NF EN 12350-2, the impact of partially substituting fly ash for sand and marble coarse aggregate for natural coarse aggregates on the regularity of freshly mixed concrete mixes was. The dimensions of the slump cone were standard: 300 mm for height, 200 mm for bottom diameter, and 100 mm for top diameter. Slump tests were performed on all mixtures to determine their workability, and the slump values of different concrete blends were measured.

3.2.2. Compressive, split tensile, and flexural strengths: Compressive strength is crucial for assessing the structural capacity of concrete in buildings. Concrete cubes with a 150 mm side length are poured and tested after 7, 14, 28, and 56 days to measure the compressive strength., following NF EN 12390-3. Additionally, Cylinders that are 300 mm tall and 150 mm in diameter are ready to determine the concrete's split tensile strength, which is assessed at the same intervals according to NF EN 12390-6 guidelines. For flexural strength assessment, concrete prisms measuring 500 mm by 100 mm by 100 mm are cast and assessed at the same curing ages, following the guidelines of NF EN 12390-6. The compressive, tensile, and flexural strengths are measured using a universal testing machine (Figure 2).

Figure 2. Compressive Universal Testing Machine

3.2.3. Ultrasonic pulse velocity: Ultrasonic pulse velocity testing is a non-destructive method that can be used in situ to assess the quality of concrete. The standard protocol for ultrasonic testing is NF EN 12504-4. A frequency of 54 kHz and a voltage of 500 V were used for the test. The device is displayed in Figure 3-a. The device includes an ultrasonic pulse sending and receiving processor unit that measures the time interval between the two processes. Two probes on the device are used to transfer the sound energy. The pulse flow rate is ascertained by measuring the duration between two events: sound energy is released into the concrete by the probe that is sent there, and this energy is received by the probe that is received. Figure 3-b shows how opposite surfaces are used in this study to determine the pulse flow rate. After 28 days, ultrasonic pulse velocity tests are carried out on concrete cube samples.

a b

Figure 3. Ultrasonic pulse velocity testing procedure: a - sonic inspection device, b - direct transparency measurements

3.2.4. Schmidt Rebound Hammer: The Schmidt Rebound Hammer (Figure 4) is a tool used to measure the compressive strength of concrete by measuring the rebound of a spring-driven hammer that strikes the concrete surface. A concrete strength estimate that complies with NF EN 12504-2 is produced by this non-destructive control method. Using conversion charts that the

manufacturer provides, the rebound hammer readings are correlated with the compressive strength of the concrete.

Figure 4. Schmidt Rebound Hammer

4. RESULTS AND CONVERSATIONAL ANALYSIS

4.1. Impact of coarse marble aggregates and fly ash on workability

In this investigation, the workability of concrete blends was evaluated by incorporating fly ash instead of sand at rates ranging from 10% to 50%, with increments of 10%, and by replacing natural coarse aggregates with marble coarse aggregates ranging from 10% to 90%, with increments of 20%. These measurements were then juxtaposed with those obtained from conventional concrete. The mixtures' replacement rates and slump values are detailed in Table 4 and Figure 5. The slump values of fresh concrete varied between 61 and 75 mm, which fell within the target slump range of S2 (Plastic concrete) based on the norm NF EN 12350–2.

Mix designation	Slump (mm)
MCA0SFS0	75
MCA10SFS10	70
MCA30SFS20	64
MCA50SFS30	61
MCA70SFS40	63
MCA90SFS50	62

Table 4. Slump values

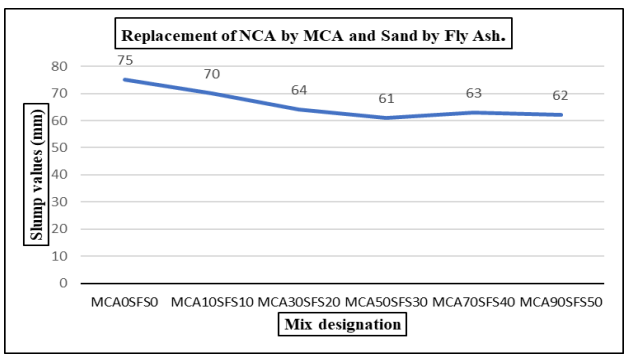

Figure 5. Workability of mixtures when NCA and sand are replaced by MCA and Fly Ash

The mixtures combining marble coarse aggregates and fly ash show intermediate slump values, with a notable 18.66% decrease for the mixture containing 50% marble coarse aggregates and 30% fly ash. The combination of the two types of replacement materials tends to balance the opposing effects on workability, as the introduction of fly ash in place of sand tends to decrease workability, this is because fly ash has a lower density compared to sand, which can increase the viscosity of the mix. Additionally, compared to sand, fly ash can absorb more water, while the introduction of marble coarse aggregates tends to increase workability, this is explained by the smooth surfaces of the marble coarse aggregates, which effectively diminish friction between particles, thus facilitating the flow and mobility of the mixture. The same observations were made by Aliabdo (2014), Ashish (2018), and Vardhan (2019). These results can guide the optimization of concrete mixes to achieve the desired workability properties.

4.2. Impact of coarse marble aggregates and fly ash on compressive strength (Rc)

Tests of compressive strength were carried out on concrete samples. During the process, the specimens underwent water curing. Before analysing each concrete specimen at days 7, 14, 28, and 56, samples were given a full day to dry. Three specimens were used to obtain the average result. Utilizing the universal testing machine (UTM), compressive strength results were acquired. Table 5, displays the compressive strength values for every test specimen.

Mix designation	Concrete's Compressive Strength (MPa)			
	7 days	14 days	28 days	56 days
MCA0SFS0	18,50	23,88	27,94	30,72
MCA10SFS10	20,92	27,02	31,6	35,55
MCA30SFS20	23,54	30,38	35,56	39,72
MCA50SFS30	25,33	32,72	38,26	42,86
MCA70SFS40	28,96	37,37	43,73	49,22
MCA90SFS50	23,71	30,62	35,81	40,12

Table 5. Compressive Strength (MPa)

The combination of substituting sand with fly ash and natural coarse aggregates with marble coarse aggregates in the concrete mixes significantly improves compressive strength. The mix MCA70SFS40, proves to be the most effective, showing maximum strengths at all measured ages. It should also be noted in Figure 6, that the compressive strength shows an increase of 56.5%, 56.49%, 56.51%, and 60.22% in contrast to the control mixture at 7, 14, 28, and 56 days, respectively.

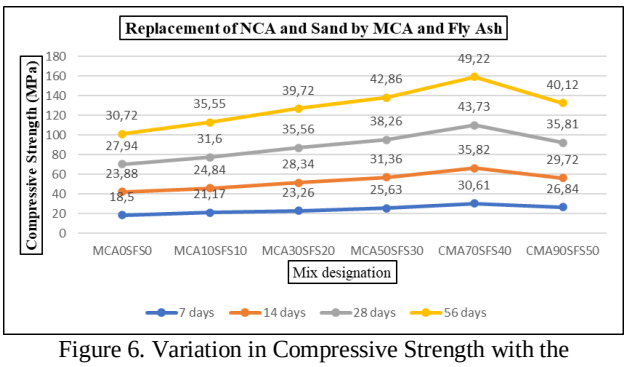

Figure 6. Variation in Compressive Strength with the replacement of NCA and Sand by MCA and Fly Ash in Concrete

Given that the MCA70SFS40 sample yielded the greatest level of compressive strength, substituting 70% of natural coarse aggregates with marble coarse aggregates and 40% of sand with

fly ash represents a practical and effective partial solution for replacing natural cementitious materials with by-products.

4.3. Impact of coarse marble aggregates and fly ash on the split tensile strength

The specimens are tested using a universal testing machine (UTM) on days 7, 14, 28, and 56. Table 6 displays the tensile strength measurements for the various mixtures at the ages under investigation.

Mix designation	Concrete's Split tensile strength (MPa)			
	7 days	14 days	28 days	56 days
MCA0SFS0	2,76	3,09	3,43	3,60
MCA10SFS10	3,06	3,39	3,82	4,06
MCA30SFS20	3,32	3,68	4,12	4,42
MCA50SFS30	3,51	3,84	4,28	4,52
MCA70SFS40	3,74	4,18	4,62	4,92
MCA90SFS50	3,72	3,88	4,06	4,32

Table 6. Split tensile strength (MPa)

The combination of substituting sand with fly ash and natural coarse aggregates with marble coarse aggregates in the concrete mixes significantly improves split tensile strength. The mix MCA70SFS40, proves to be the most effective, showing split tensile maximum strengths at all measured ages. It should also be noted in Figure 7, that the split tensile strength shows an improvement of 35.50%, 35.27%, 34.69%, and 36.66% compared to the control mix at 7, 14, 28, and 56 days, respectively.

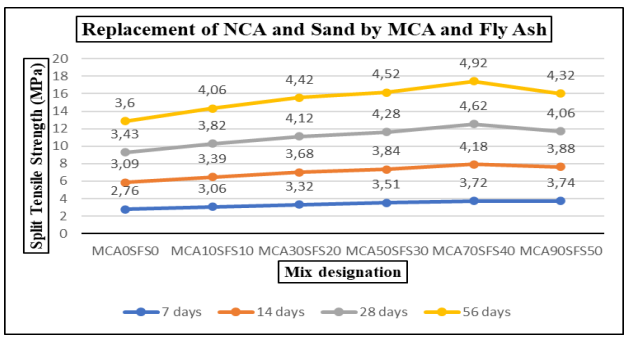

Figure 7. Variation in split tensile strength with the replacement of NCA and Sand by MCA and Fly Ash in concrete

This partial substitution of natural cementitious materials with marble coarse aggregates and fly ash is feasible and effective; since the MCA0SFS40 sample produced the greatest level of Split tensile strength. To assess the split tensile strength and compressive strength of concrete incorporating marble coarse aggregates and fly ash, experimental findings were contrasted with empirical data, as depicted in Figure 8.

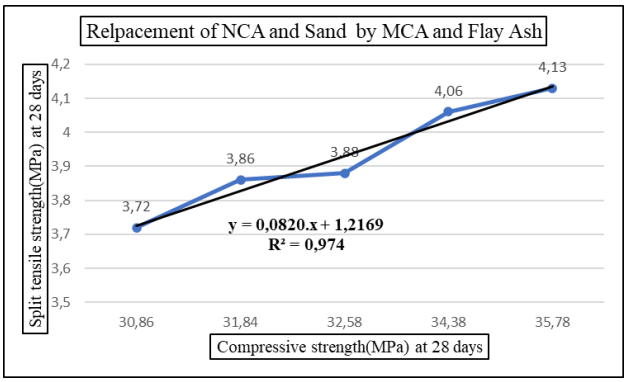

Figure 8. Relationship between split tensile strength and compressive strength in the case of replacing NCA with MCA and Sand by Fly Ash

To obtain data close to reality, a regression analysis applying the method of least squares, a mathematical concept, was conducted to examine the correlation between split tensile strength and compressive strength. In this context, the formula shown in Figure 8 allows for estimating the split tensile strength value based on the compressive strength.

4.4. Impact of coarse marble aggregates and Flay Ash on the flexural strength

The samples are examined utilizing a universal testing machine (UTM) on days 7, 14, 28, and 56. Table 7 displays the flexural strength values for the various mixtures at the ages under investigation. The combination of substituting sand with fly ash and natural coarse aggregates with marble coarse aggregates in the concrete mixes significantly improves flexural strength. The mix CMA70SFS40 turns out to be the most successful, as should be seen in Figure 9, displaying flexural maximum strengths at all measured ages.

Mix designation	Concrete's Flexural Strength (MPa)			
	7 days	14 days	28 days	56 days
MCA0SFS0	3,28	3,62	4,07	4,27
MCA10SFS10	3,52	3,84	4,32	4,60
MCA30SFS20	3,76	4,10	4,63	4,86
MCA50SFS30	3,93	4,32	4,76	5,05
MCA70SFS40	4,26	4,67	5,16	5,48
MCA90SFS50	3,98	4,25	4,62	4,87

Table 7. Flexural strength (MPa)

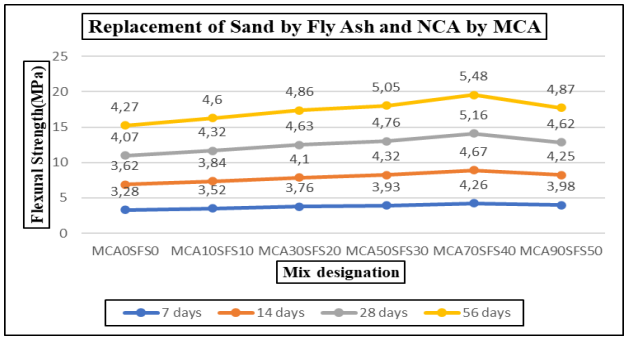

Figure 9. Variation in Flexural strength with the replacement of NCA by MCA and sand by Fly Ash in concrete

To assess the flexural strength and compressive strength of concrete incorporating marble coarse aggregates and fly ash, experimental findings were contrasted with empirical data, as depicted in Figure 10.

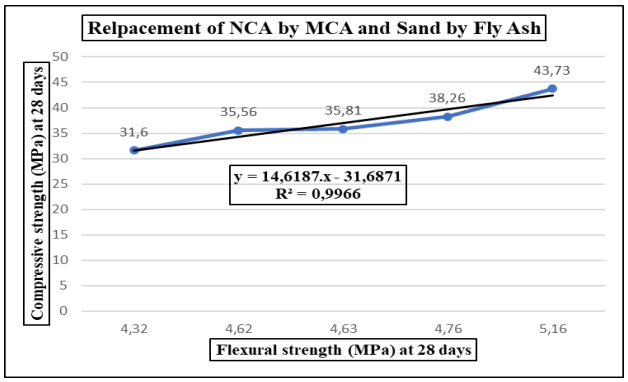

Figure 10. Relationship between Compressive strength and Flexural strength in the case of replacing NCA with MCA and Sand by Fly Ash

To obtain data close to reality, a regression analysis applying the method of least squares, a mathematical concept, was conducted to examine the correlation between flexural strength and compressive strength. In this context, the formula shown in Figure 10 allows for estimating the flexural strength value based on the compressive strength.

4.5. Impact of coarse marble aggregates and Flay Ash on the velocity of ultrasonic pulses (UVP)

The ultrasonic pulse velocity (UVP) tests on concrete cube samples were performed at 28 days. Table 8 presents the UPV results of the different mixes. All concrete, except for the MCA10SFS10 and CMA0SFS0 mixes, exhibit excellent velocity. This shows that adding fly ash in place of sand and using coarse marble aggregate in place of natural aggregates does not affect the concrete's quality.

Mix designation	UVP(Km/s)	Compressive Strength (MPa)
MCA0SFS0	3,68	27,94
MCA10SFS10	4,02	31,6
MCA30SFS20	4,64	35,56
MCA50SFS30	4,98	38,26
MCA70SFS40	5,72	43,73
MCA90SFS50	4,68	35,81

Table 8. Compressive Strength and UVP values

To assess the compressive strength and the ultrasonic pulse velocity of concrete incorporating marble coarse aggregates and fly ash, experimental findings were compared with empirical data, as depicted in Figure 11.

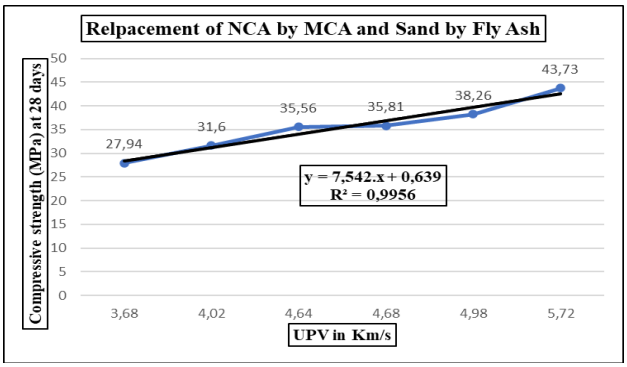

Figure 11. Relationship between UVP and Compressive strength in the case of replacing NCA with MCA and Sand by Fly Ash

To obtain data close to reality, a regression analysis applying the method of least squares, a mathematical concept, was conducted to examine the correlation between compressive strength and UVP. The correlation is illustrated in Figure 11, and represented by the equation:

$$Rc = 7.542 \cdot (UVP) + 0.639 \quad \text{with} \quad R^2 = 0.9956 \quad (1)$$

4.6. Impact of coarse marble aggregates and Flay Ash on the Schmidt Rebound Hammer (Rn)

Schmidt Hammer tests on concrete cube specimens are conducted at 28 days. Table 9 presents the rebound number results of the cement paste. The examination findings indicated that; the highest rebound number was observed when fly ash served as a cement substitute at a rate of 40%, and marble coarse aggregates were used at a rate of 70% instead of natural coarse aggregates, as shown in Figure 12.

Mix designation	Rebound Number	Compressive Strength (MPa)
MCA0SFS0	36,5	27,94
MCA10SFS10	40,1	31,6
CMA30SFS20	44,6	35,56
CMA50SFS30	47,5	38,26
CMA70SFS40	50,6	43,73
CMA90SFS50	44,7	35,81

Table 9. Compressive Strength and Rebound Number

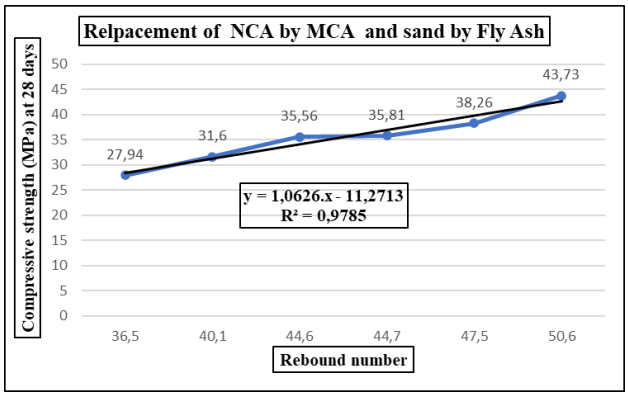

Figure 12. Relationship between Rebound number and Compressive strength in the case of replacing NCA with MCA and Sand by Fly Ash

An analysis of regression applying the method of least squares, a mathematical concept, was also employed to examine the correlation between compressive strength and Schmidt- Hammer test results, aiming to establish an equation for computing compressive strength based on the obtained results. The correlation is illustrated in Figure 12, and represented by the equation:

$$Rc=1.0626\cdot(Rn) - 11.2713 \quad \text{with} \quad R^2=0.9785 \qquad (2)$$

5. CONCLUSION

In this study, we investigated the effects of using fly ash (FA) and marble coarse aggregates (MCA) as replacements for natural sand and coarse aggregates in concrete. Our objective was to evaluate the impact of these sustainable materials on many characteristics, such as the Schmidt-hammer rebound number, ultrasonic pulse velocity (UPV), split tensile strength, compressive strength, flexural strength, and workability.

Concerning workability, the results show that the values ranged between 61 and 75 mm, which is within the target slump range of S2 (plastic concrete). Introducing 50% marble aggregates and 30% fly ash resulted in a notable 18.66% decrease in slump values. It is also worth noting that compressive strength increases significantly. In contrast to the control mixture, the increases were 56.5%, 56.49%, 56.51%, and 60.22% at 7, 14, 28, and 56 days, respectively. The combination of 70% marble aggregates and 40% fly ash showed the highest compressive strengths at all curing ages. The split tensile strength improved by 35.50%, 35.27%, 34.69%, and 36.66% compared to the control mix at the same curing ages. The majority of mixes demonstrated excellent UPV values, indicating that substituting FA and MCA does not negatively affect the quality of the concrete. Only MCA10SFS10 and CMA0SFS0 mixes showed velocities slightly below optimal. A strong correlation was observed between compressive strength and Schmidt hammer rebound numbers. The MCA70SFS40 mix emerged as the most effective, exhibiting exceptional durability and strength, making it a viable alternative to conventional materials.

This study highlights the potential of employing industrial by-products, such as marble waste and fly ash, not only to improve concrete properties but also to contribute to more sustainable waste management practices. These findings confirm that optimizing the use of substitute materials can enhance concrete performance while providing significant environmental benefits, offering a novel approach to sustainable construction.

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References

Aliabdo, AA., Abd Elmoaty, AEM and Auda, EM., 2014. Re-use of waste marble dust in the production of cement and concrete. *Construction and Building Materials* 50, 28-41.

André, A., 2012. Performance in Durability Terms of Concrete Incorporating Waste Coarse Aggregates from the Marble Industry. *Instituto Superior Tecnico, Universidade Tecnica de Lisbona, Lisbon.*

André, A., Brito. De., J., Rosa, A., Pedro, D., 2014. Durability Performance of Concrete Incorporating Coarse Aggregates from Marble Industry Waste. *Journal of Cleaner Production,* 65, pp.389–396.

Anwar, A., Mohd, S., Husain, A., and Ahmad, S.A.,2015. Replacement of Cement by Marble Dust and Ceramic Waste in Concrete for Sustainable Development. *International Journal of Innovative Research in Science, Engineering, and Technology*, 2, pp. 496–503.

Aruntas, H. Y., Gürü, M., Dayi, M., and Tekin, I., 2010. Utilization of Waste Marble Dust as an Additive in Cement Production. *Materials & Design*, 31, pp. 4039–4042.

Ashish, D.K., 2018. Concrete Made with waste Marble Powder and Supplementary Cementitious Material for Sustainable Development. *Journal of Cleaner Production*, 211, pp.716-729.

Belaïd, F., 2022. How Does Concrete and Cement Industry Transformation Contribute to Mitigating Climate Change Challenges? Resources, Conservation & Recycling Advances, Volume 15, 200084. https://doi.org/10.1016/j. rcradv.2022.

Binici, H., Kaplan, H., and Yilmaz, S., 2007. Influence of Marble and Limestone Dust as Additives on Some Mechanical Properties of Concrete. *Scientific Research and Essays*, 2, pp. 372–379.

Binici, H., Shah, T., Aksogan, O., and Kaplan, H., 2008. Durability of Concrete Made with Granite and Marble as Recycle Aggregate. *Journal of Materials Processing Technology*, pp.299-308.

Gaurav, S., Kishan, L.J., and Shruti, B., 2020. Mechanical and Durability Performance of Concrete Made with Waste Marble and Fly Ash. *Jordan Journal of Civil Engineering*, Vol. 14, No. 3.

Ghazali, N., Muthusamy, K., Embong, R., Rahim, I.S. A., Muhamad Razali, N. F., Yahaya, F. M., Ariffin, N. F., and S. Wan Ahmad, S., 2021. Effect of Fly Ash as Partial Cement

Replacement on Workability and Compressive Strength of Palm Oil Clinker Lightweight Concrete. *Earth and Environmental Science*,682.

Hebhoub, H., Aoun, H., Belachia, M., Houari, H., and Ghorbel, E., 2011. Use of waste marble aggregates in concrete. *Const. Build. Mater* 25, 1167-1171

Jang, J.G. and H.K. Lee., 2016. Microstructural densification and CO2 uptake promoted by the carbonation curing of belite-rich Portland cement. *Cem. Concr. Res*, 82, pp. 50–57.

Kemer, H., Bouras, R., Mesboua, N., Sonebi, M., Kinnane, O.,2021. Shear-thickening behavior of sustainable cement paste - controlling physical parameters of new sources of supplementary cementitious materials, *Construction and Building Materials*, Volume 310.

Kumar Mehta, P., Paulo, P., and Monteiro, J.M., 2014. Concrete: Microstructure, Properties, and Materials. Fourth ed.

Martins, P., De Brito, J., Rosa, A., Pedro, D.,2014. Mechanical performance of concrete with the incorporation of coarse waste from the marble industry. *Mater. Res*, 17(5), pp. 1093-1101.

Rashad, A.M., 2013. Metakaolin as Cementitious Material: History, Scours, Production, and Composition—A Comprehensive Overview. *Construction and Building Materials*, 41, 303-318.

Sankh, A.C., Biradar, P.M., Naghathan, S.J., Ishwargol, M.B., 2014. Recent Trends in Replacement of Natural Sand with Different Alternatives. *Journal of Mechanical and Civil Engineering*, PP:59-66.

Temesgen, F., Getasew, A., Getachew, K., Yeshi, A., Senthil, K.S., and Velmurugan, P.,2021. Experimental investigation of compressive strength for fly ash on high strength concrete C-55 grade. *Materials Today: Proceedings*, 46, pp. 7507–7517.

Ullah, K., Qureshi, M. I., Ahmad, A. and Ullah, Z., 2022. Substitution potential of plastic fine aggregate in Concrete for sustainable production. *Structures* 35, pp. 622–637.

Vardhan, K., Siddique, R., and Goyal, S.,2019. Influence of marble waste as partial replacement of fine aggregates on strength and drying shrinkage of concrete. *Constr. Build. Mater*. 228, 116730.

Zaryab, A.R., Syed, N.R.S., Muhammad, J.M., Ashfaque, A.J., Manthar, A.K., Wan, I.J., 2022. Evaluation of combined utilization of marble dust powder and fly ash on the properties and sustainability of high-strength concrete. *Environmental Science and Pollution Research*, Volume 29, pp. 28005–28019.