Sustainable Pervious Concrete: Enhancing Urban Drainage With Black Marble Waste Aggregate

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ABSTRACT

The rapid urbanization and expansion of infrastructure have led to compactly built environments, limiting natural rainwater percolation and contributing to groundwater depletion. Conventional concrete, characterized by its impermeable nature, exacerbates this issue by preventing water infiltration. Pervious concrete, a sustainable alternative, offers a solution by allowing water to pass through its interconnected voids, thereby promoting efficient drainage. The study explores the feasibility of utilizing black marble waste as a replacement for natural coarse aggregate in pervious concrete. With the rising cost of aggregate production and the depletion of natural resources, incorporating industrial waste into construction materials presents an eco-friendly and cost-effective alternative. The research investigates the performance of pervious concrete incorporating black marble waste in varying proportions (0%, 20%, 40%, 60%, 80%, and 100%) as a substitute for conventional coarse aggregate. Through comprehensive experimental analysis, key properties such as permeability, strength, and durability are evaluated to determine the suitability of this novel approach for sustainable urban infrastructure. The findings of the study could significantly contribute to reducing construction waste while enhancing environmental sustainability. By repurposing marble waste in pervious concrete, this research paves the way for greener construction practices, improved stormwater management, and a step toward resource-efficient building materials.

KeyWords : Black Marble Waste, Groundwater Recharge, Porous Pavement, Low-Impact Development

1. INTRODUCTION

Concrete, the most widely used construction material globally, is a composite of cement, sand, coarse aggregate, and water. While it possesses high compressive strength, its impermeable nature contributes to environmental challenges such as reduced groundwater recharge. With growing concerns over resource depletion and sustainability, integrating waste materials into concrete production has become a priority. Pervious concrete, designed with interconnected voids for enhanced water permeability, offers a viable solution for stormwater management. This study explores the use of black marble waste as a replacement for natural coarse aggregate in pervious concrete, aiming to enhance sustainability without compromising structural performance. By evaluating various replacement proportions (0%, 20%, 40%, 60%, 80%, and 100%), this research seeks to optimize material utilization while maintaining strength and durability, contributing to environmentally conscious construction practices. The study further investigates key properties such as permeability, compressive strength, and durability to assess the feasibility of marble waste in pervious concrete applications. Ultimately, this research aims to provide an innovative solution that balances performance, cost-effectiveness, and environmental responsibility in concrete technology.

2. LITERATURE SURVEY

Jing et al. (2002) used smaller sized aggregate, silica fume (SF), and super plasticizer (SP) in pervious concrete to considerably improve the strength of pervious concrete. The composite has a compressive strength of 50 MPa and a flexural strength of 6 MPa.

Sung-bum park et al., (2004) conducted an experiment on compressive strength and water purification properties of porous concrete. Two sizes of coarse aggregate were used, namely 5 to 10mm and 10 to 20mm.The absolute volume ratios of pasteaggregate were used, namely 30%,40%,50% for a given size of aggregate. The compressive strength is found higher when paste aggregate ratio is smaller. Water purification of porous concrete is evaluated by the removal amount of total phosphorous and total nitrogen. Results from this study show that porous concrete using industrial by products is able to purify water efficiently.

Karthik H. Obla (2007) has given an complete overview of the pervious concrete regarding application, materials, properties, design and testing. The aggregate utilized in porous concrete were either single sized or grading between 19 & 9.5 mm. Regarding the properties, pervious concrete can develop compressive strength in a range of 3.5 MPa to28 MPa which is suitable for wide range of applications. Typically values are about 17 MPa. The permeability values are in the range of 0.134 cm/s to 1.202 cm/s.

Chindaprasirt et al. (2008) studied the pervious concrete properties. With a void ratio of 15 to 25%, pervious concrete with a high strength was produced. The strength of pervious concretes with void ratios of 15%, 20%, and 25% ranges between 38 and 44 MPa, 29 and 35 MPa, and 15 and 22 MPa, respectively.

Lian and Zhuge (2010) investigated the impact of three types of aggregates, as well as chemical additives and fine aggregate to develop the permeable concrete with improved structural strength. It was found that dolomite achieved higher compressive strength compared to quartzite and limestone. The addition of silica fume to concrete does not improve its strength since it causes the mixture to segregate. Silica fume combined with a super plasticizer, on the other hand, results in more pervious concrete. The use of quarry sands improves the compressive strength properties of pervious concrete.

Kevern et al. (2011) examined the pervious concrete's performance utilizing a variety of concrete materials and mix proportions. For overlay applications, a w/c ratio of 0.27 to 0.33 was investigated. The selected w/c ratio 0.29 yielded a maximum compressive strength of 17.9 MPa. Furthermore, pervious concrete containing angular aggregate has shown to be more resistant to freezing and thawing.

Xiang Shu et al. (2011) studied the various parameters of pervious concrete mixtures in both laboratory and field situations using lime stone and granite as coarse aggregate. It has been discovered that adding admixtures and fibres such as latex to pervious concrete, improves its overall performance. The mixes with high air voids and low strength demonstrated lower abrasion resistance than the mixes with low porosity and high compressive strength.

Aoki et al. (2012) conducted an experimental investigation on pervious concrete by replacing cement with fly ash up to 50%. To improve the mechanical properties, fine aggregate is included up to 10%. According to the findings, replacing 50% of Portland cement with fly ash reduces compressive strength by 40% while also lowering drying shrinkage. Pervious concrete with 100% cement had a 28-day compressive strength of 10.06 MPa, while pervious concrete with 50% fly ash had a compressive strength of 5.66 MPa. It also claims that the density of pervious concrete is unaffected by fly ash concentration or aggregate grading.

S.O.Ajamu et.al (2012) , studied the effects of varying aggregate size on the porosity, compressive strength and specific gravity of pervious concrete as this study covers the simple use of pervious concrete as pavement as material in the construction of pedestrian walk ways and parking lots. They produced three batches of test specimens to conduct the study from the aggregates of different size, aggregate cement ratios having different weights of aggregates, weight of concrete and volume produced. The pervious concrete blocks of different mixes were tested for compressive test at specific age of 7, 14, 21 & 28days of curing by the use of compression testing machine. Result infers that from the tests conducted the compressive strength of the pervious concrete increases with age and as the aggregate cement ratio reduces.

M. Aamer Rafique Bhutta et.al, (2012) conducted a study to estimate properties of high performance porous concrete. The results showed that, the larger the coarse aggregate, lower is the strength. Further the compressive strength of HPPC was higher compared to CPC, this is because bonding between cement paste to aggregate had enhanced by adding cohesive agent in HPPC. Effect of aggregate size on permeability of porous concrete was also studied and it showed the permeability values between 0.25 and 3.3 cm/s which were high enough to be used as a drainage layer porous concrete blocks. The aggregate gradation did show consistent influence on permeability that is smaller the aggregate size lower the permeability.

N. Venkata Ramana (2012) discussed replacement of stone waste (CA) with natural aggregate in different proportions of 0, 25, 50, 75 and 100%. Concrete mix designed for work as per ACI 522R-06 provisions. Cube compressive strength was decreased from 38 to55%. ACI recommends that the compressive strength of pervious concrete should be in range of 2.8 to 28Mpa and the split tensile strength is decreased from 3 to 27% respectively. The predicted values by proposed equation were about 0.9 to 1.1 and the permeability of concrete increases with replacement.

M.Uma Maguesvari et.al, (2013) took up the study on the important parameter that effects the voids in aggregate that is its angularity, which is characterized by its sharp edges. If the aggregate is angular, voids in the aggregate will increase. This surface property is very significant in assessment of volume of voids in the aggregate, which in turn influences compression and permeability characteristics of porous concrete. From their test results they found that as the fine aggregate increases the strength parameter increases due to the reduction of volume of voids. For the angularity number 8 to 4 compressive strength is found to be between 10MPa to 26MPa and the coefficient of permeability was found to increase from 1.26cm/s to 0.4cm/s.

Yuwadee Zaetang et al. (2013) studied the performance of Light Weight Pervious Concrete. According to the test results, Light weight aggregates reduce density and thermal conductivity by around 3-4 times when compared to natural aggregate concrete. The densities ranged from 558 to 775 kg/m3, which is suitable for use as insulating concrete because it is less than 800 kg/m3. Concrete made using diatomite light weight aggregate has the best strength properties and the lowest water permeability of all the aggregates tested. The compressive strength at the age of 28 days has range from 2.47 – 5.99 MPa.

Carsana et al. (2013) studied the strength and durability properties of pervious concrete with embedded steel bars and found the compressive strength is in the range of 7 to 30 MPa. However, pervious concrete with reinforcing bar and no fine particles is susceptible to carbonation and corrosion.

Darshan S. Shah, Jayeshkumar Pitroda (2014) discussed the hardened properties of pervious concrete related to construction industry applications. To study the hardened properties of pervious concrete the pervious concrete mixture with cement, coarse aggregate/gravel and water was prepared and casted with different concrete mix proportions, with different gravel sizes and with different grades of cement (OPC Grade 53, PPC Grade 53). After the required period of curing i.e., 7, 14, 28 days the casted blocks were subjected to compressive strength test and flexural strength test.

Shivakumar (2014), done research on buildings demolished waste is increasing now a days, the paper discussed strength characteristics for different replacement levels and recommends aggregate ratio of 1:8 50% of BDW is recommended for low traffic volume. It is inferred that BDW porous concrete is more comparable than conventional concrete.

Deepika et al. (2015) evaluated the effect of recycled aggregate as coarse aggregate in pervious concrete using fly ash as a binder. When compared to natural aggregate, recycled aggregate pervious concrete provided significantly lower compressive strength, yet the usage of recycled aggregate achieved the desired compressive strength and permeability properties required for pervious concrete. It has been observed that the optimum cement content should be between 300 to 400 kg/m3 with maximum fly ash replacement as 20%.

Weichung Yeih, (2015) Carried out an experimental study on properties of pervious concrete with replacement of aggregate with EAFS(air-cooling electric arc furnace slag) and the results showed higher compressive strength and higher permeability than gravel. The pervious concrete made with EAPS can take a permeability coefficient greater than 0.01cm/s and compression strength greater the 21N /mm2 .

3. PROPOSED SYSTEM

The proposed system focuses on the development and evaluation of pervious concrete incorporating black marble waste as a partial or full replacement for natural coarse aggregate. This system aims to enhance the sustainability of concrete production while ensuring its functional performance for permeable pavement applications. The methodology involves a systematic experimental investigation to determine the optimum proportion of marble waste aggregate that balances permeability, strength, and durability.

Key components of the proposed system include:

1. **Material Selection & Preparation:**
    - Collection of black marble waste from industrial processing units.
    - Crushing and sieving of marble waste to achieve the required aggregate size.
    - Selection of other key ingredients, including cement, water, and any necessary admixtures.

2. **Mix Proportions & Concrete Preparation:**
   - Designing multiple concrete mixes with varying percentages of black marble waste (0%, 20%, 40%, 60%, 80%, and 100%).
   - Maintaining a consistent water-to-cement ratio to ensure comparability of results.
   - Mixing and casting specimens following standard pervious concrete preparation methods.
3. **Experimental Analysis & Testing:**
   - **Permeability Test:** Evaluating the water infiltration rate to assess the effectiveness of pervious concrete.
   - **Compressive Strength Test:** Determining the load-bearing capacity of the prepared concrete specimens.
   - **Durability Test:** Assessing the resistance of concrete to environmental factors such as weathering and abrasion.
   - **Void Ratio & Porosity Analysis:** Measuring the interconnected voids to understand water retention and drainage capabilities.
4. **Performance Evaluation & Optimization:**
   - Comparing experimental results to identify the most suitable percentage of black marble waste that provides an optimal balance between strength and permeability.
   - Analyzing the feasibility of full replacement of natural coarse aggregate with marble waste.
   - Assessing the environmental and economic benefits of using marble waste in construction.

The proposed system aligns with the principles of sustainable construction by reducing dependency on natural resources, minimizing industrial waste disposal issues, and promoting eco-friendly infrastructure solutions. The research findings will help in developing cost-effective and environmentally responsible pervious concrete suitable for various applications such as pedestrian pathways, parking lots, and drainage systems.

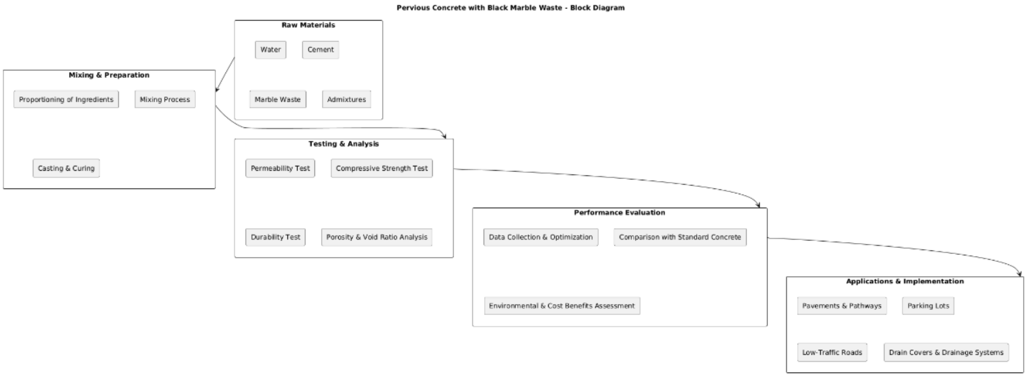

Figure 1 Presents the Block Diagram of Proposed System.

4. RESULTS AND DISCUSSIONS

The results of the experimental investigation for the various tests are discussed in this chapter.

4.1 Slump cone test

The slump Values of the concrete for replacement of natural aggregate with BMSWA by 0, 20, 40, 60, 80 and 100 % are shown in table 6.1 and graphically represented in Fig 6.1.

Table 4.1: Slump Values (mm) for different mixes

S.No	**Replacement of Natural Aggregate with Marble waste (%)**	**Slump (mm)**	**Increment / decrement**
1	0	91	-
2	20	102	+ 12.08 %
3	40	110	+ 20.88 %
4	60	115	+ 26.37 %
5	80	123	+ 35.16 %
6	100	130	+ 42.85 %

It is observed that there is increase in the workability of the concrete when the natural aggregate is replaced with BMSWA. The percentage increase of slump values for 20% to 100% replacement of natural aggregate with BMSWA are 12.08 % to 42.85 % respectively. Based on the observations, all of the slump values are in the medium to high workability range.

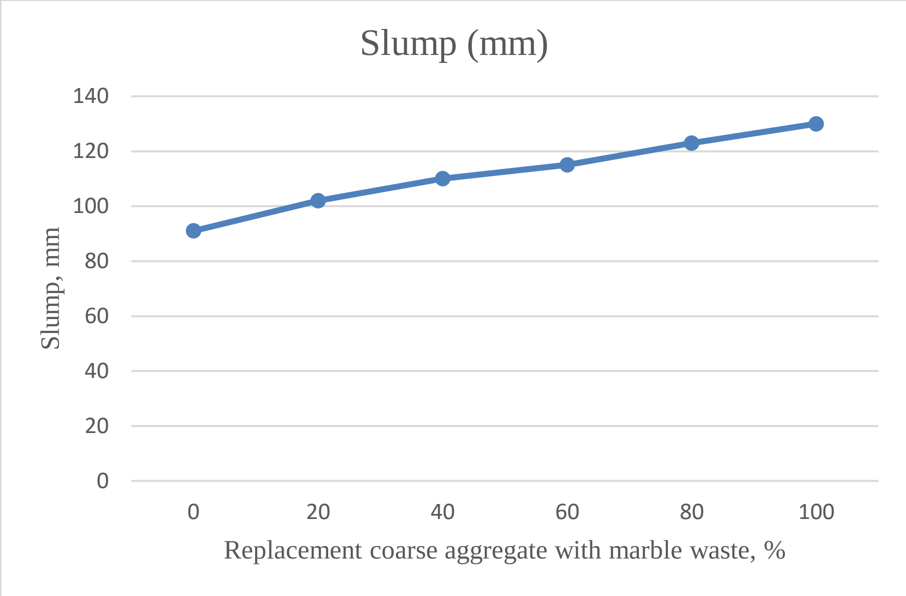

Fig 4.1 Slump Values Vs % replacement coarse aggregate with marble waste

4.2 Compressive strength test

The compressive strength values of the concrete for replacement of natural aggregate with BMSWA by 0, 20, 40, 60, 80 and 100 % are shown in table 6.2 and graphically represented in Fig 4.2.

Subba reddy et.al (2017) recommended that BMSWA may be used upto 50% replacement for concrete works. K.Obla (2010) conducted experiments on pervious concrete and compressive strength varies from 3 to 17 Mpa.

It is observed that there is increase in the compressive strength of the concrete when the natural aggregate is replaced with BMSWA. The percentage increase of compressive strength values for 20%, 40%, 60%, 80% and 100% replacement of natural aggregate with BMSWA are 5.03%, 15.45%, 14.21%, 11.73%, 6.41% respectively. Based on the observations, all of the compressive strength values are higher for BMSWA replacement. The optimum dosage of BMSWA replacement in natural coarse aggregates is 40%.

Table 4.2: Compressive strength (Mpa) for different mixes

S.No	**Replacement of Natural Aggregate with Marble waste (%)**	**7days**	**14days**	**28days**	**Increment / decrement**
1	0	8.13	12.21	13.72	-
2	20	8.45	12.89	14.41	+ 5.03 %
3	40	9.48	14.18	15.84	+ 15.45 %
4	60	9.36	13.97	15.67	+ 14.21 %
5	80	9.11	13.69	15.33	+ 11.73 %
6	100	8.67	13.15	14.60	+ 6.41 %

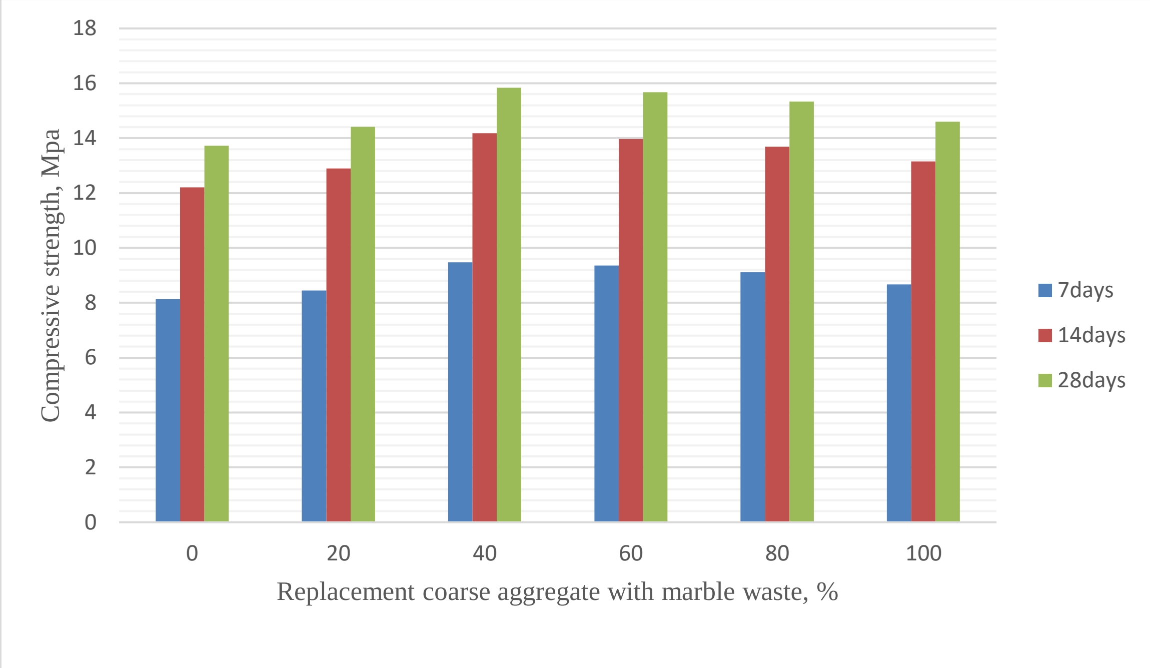

Fig 4.2 Compressive strength Values Vs % replacement coarse aggregate with marble waste

4.3 Permeability test

The Permeability of the concrete by constant head method for replacement of natural aggregate with BMSWA by 0, 20, 40, 60, 80 and 100% for 28 days of curing was done. The Permeability values are shown in table 6.3 and graphically represented in Fig 6.3.

Rama et.al (2016) conducted constant head permeability test on pervious concrete with two different w/c ratios and value ranges from 0.86 mm/s to 2.21mm/s.

Table 4.3: 28 days Permeability Values (mm/sec) for different mixes

S.No	Replacement of Natural Aggregate with Marble waste (%)	Permeability Values (mm/sec)	Increment / decrement
1	0	4.51	-
2	20	4.83	+ 7.09 %
3	40	5.40	+ 19.73 %
4	60	5.75	+ 27.49 %
5	80	6.08	+ 34.81 %
6	100	6.31	+ 39.91%

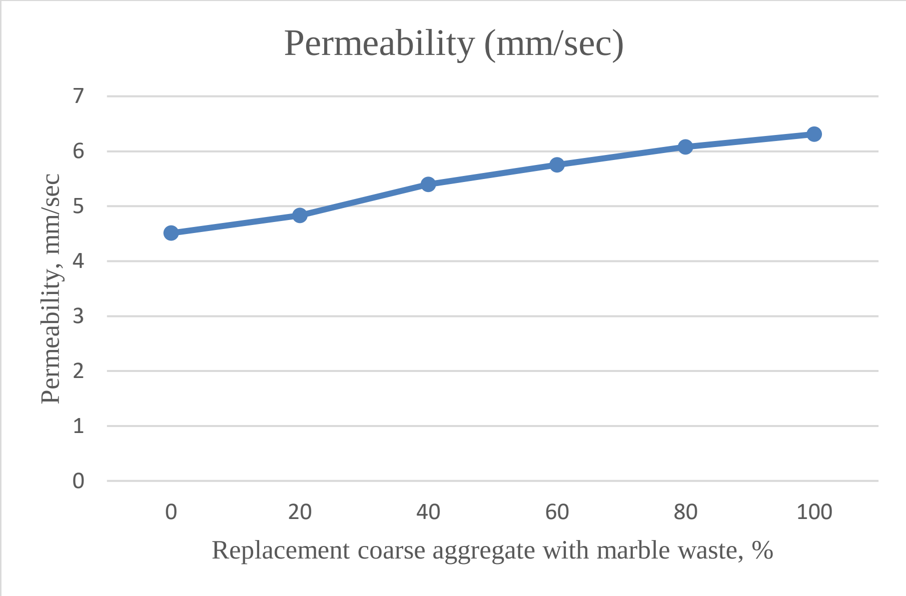

Fig 4.3 Permeability Values Vs % replacement coarse aggregate with marble waste

It is also observed that there is increase in the Permeability of the concrete when the natural aggregate is replaced with BMSWA. The percentage increase in permeability values for 20%, 40%, 60%, 80% and 100% replacement of natural aggregate with BMSWA are 7.09%, 19.73%, 27.49%, 34.81%, 39.91% respectively. Based on the observations, all of the Permeability of the concrete values are higher for BMSWA replacement.

From the results, it is observed that as the natural aggregate is replaced with BMSWA is increases, the pore space in the specimen increases, reducing the flow time and therefore increasing permeability.

4.4 Effect of elevated temperature

The compressive strength results of cubes exposed to temperature of 300^oC and 600^oC for replacement of natural aggregate with BMSWA by 0, 20, 40, 60, 80 and 100 % are shown in table 6.4 and graphically represented in Fig 6.4.

H.A.M Bishar (2008) conducted experiment and concluded that compressive strength of concrete at elevated temperatures decreases with increase in temperature and residual compressive strength was 50% of original strength. Rama et.al (2016) conducted temperature test and concluded that there is less reduction in compressive strength for pervious concrete.

It is observed that the compressive strengths are decreasing by increasing the temperature and as the percentage reduction in natural aggregate increases, the strengths are also decreasing.

Table 4.4: Compressive strengths (Mpa) after exposure to temperature for different mixes

S. No	Replacement of Natural Aggregate with Marble waste (%)	32ºC	Increment / decrement	300ºC	Increment / decrement	600ºC	Increment / decrement
1	0	10.5	-	10.1	-	9.7	-
2	20	9.4	- 10.47 %	9.2	- 8.91 %	9.0	- 7.21 %
3	40	8.2	- 21.9 %	7.9	- 21.78 %	7.5	- 22.68 %
4	60	6.5	- 38.09 %	6.0	- 40.59 %	5.8	- 40.20 %
5	80	5.7	- 34.81 %	5.3	- 34.81 %	5.0	- 48.45 %
6	100	5.0	- 52.38%	4.7	- 53.46%	4.5	- 53.60%

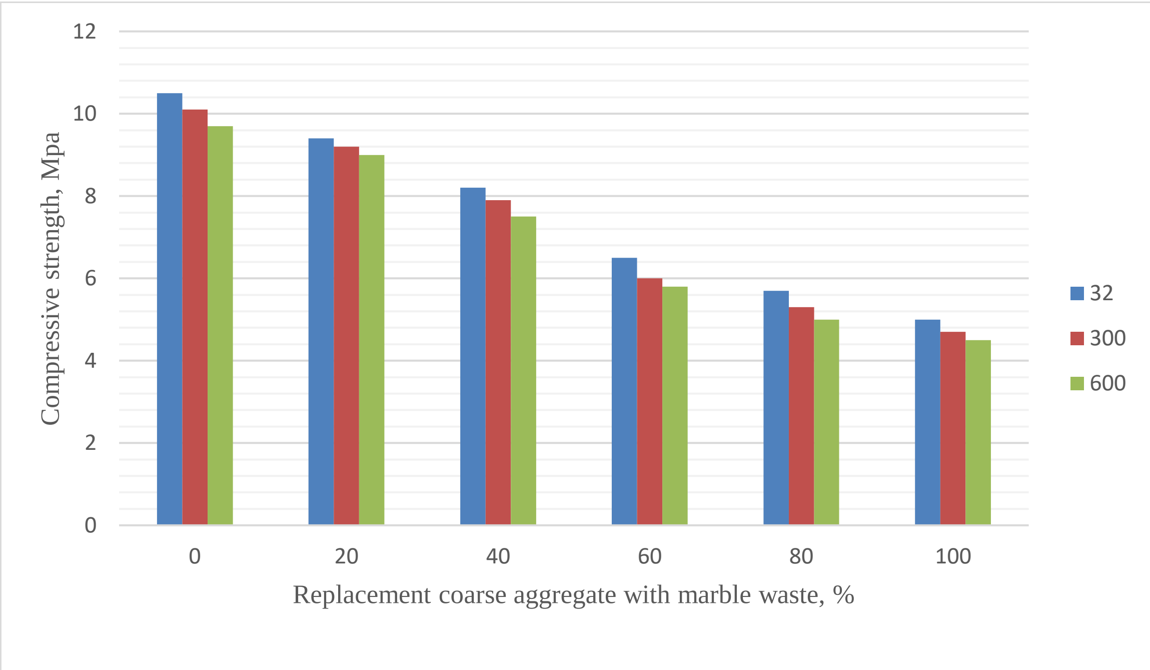

Fig 4.4 Compressive strength Values for elevated temperature Vs % replacement coarse aggregate with marble waste

4.5 Water Absorption test

The Water absorption values of the concrete for replacement of natural aggregate with BMSWA by 0, 20, 40, 60, 80 and 100 % are shown in table 6.5 and graphically represented in Fig 6.5.

It is observed that there is decrease in the water absorption value of the concrete when the natural aggregate is replaced with BMSWA. The percentage decrement of water absorption values for 20%, 40%, 60%, 80% and 100% replacement of natural aggregate with BMSWA are 15.56%, 20.75%, 36.02%, 47.83%, 91.46% respectively. Based on the observations, all of the water absorption values are lesser for BMSWA replacement.

Table 4.5: Water Absorption values (%) for different mixes

S.No	Replacement of Natural Aggregate with Marble waste (%)	Initial weight (kg)	Final weight (kg)	Water Absorption values (%)	Increment / decrement
1	0	7.5	7.77	3.47	-
2	20	7.62	7.85	2.93	- 15.56 %
3	40	7.78	8.0	2.75	- 20.75 %
4	60	7.92	8.1	2.22	- 36.02 %
5	80	8.1	8.25	1.81	- 47.83 %
6	100	8.4	8.425	0.296	- 91.46%

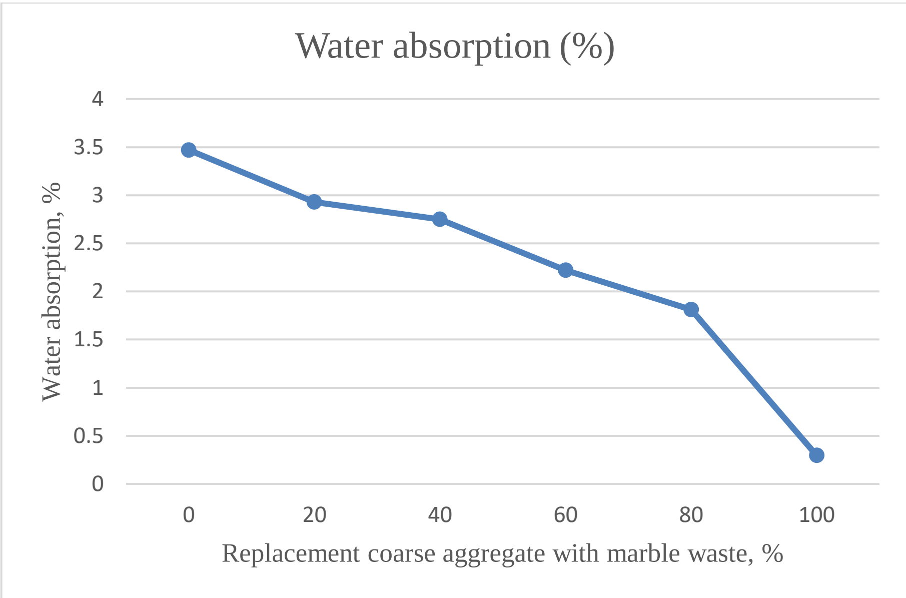

Fig 4.5 Water absorption Values Vs % replacement coarse aggregate with marble waste

5. CONCLUSION

The study demonstrates the potential of **black marble stone waste aggregate (BMSWA)** as a sustainable alternative to natural coarse aggregate in pervious concrete. The findings reveal that while the workability of concrete improves due to the smoother surface of BMSWA, compressive strength decreases with higher replacement percentages, with **40% BMSWA replacement yielding the optimal balance of strength and sustainability**. The increase in permeability with higher BMSWA content enhances its functionality for stormwater management, making it a viable solution for urban drainage systems. Additionally, the significant reduction in water absorption, reaching near-zero at **100% replacement**, suggests improved resistance to moisture-related deterioration. However, the strength of pervious concrete is influenced by temperature variations, necessitating further studies for broader applications. Overall, integrating BMSWA into pervious concrete not only promotes **eco-friendly waste utilization and resource conservation** but also offers a **practical approach to enhancing sustainable infrastructure** by optimizing permeability and environmental impact without significantly compromising structural integrity.

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