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Effect of Cement, Brick, and Marble Dust Fillers on the Moisture Sensitivity of Asphalt Mixtures under Extended Sewage and Fresh-Water Immersion

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Abstract: *The urban roads in Upper Egypt suffer from sewage-related issues due to the prolonged accumulation of wastewater—often exceeding 24 hours—on asphalt surfaces. Such exposure accelerates the deterioration of pavement layers, particularly in areas with limited drainage systems, high groundwater levels, and frequent leakage from aging sewage networks. Despite several studies addressing moisture damage in asphalt mixtures, limited evidence exists regarding the comparative effects of sewage and fresh water when using waste-derived fillers. This study investigates the performance of asphalt mixtures incorporating cement dust, brick dust, and marble dust as mineral fillers. These fillers were selected as locally available waste materials in Upper Egypt, providing both economic and environmental benefits by reducing disposal problems and replacing conventional fillers. A total 45 specimens were prepared using the Marshall mix design method to determine the optimum asphalt content for each filler type and were subsequently submerged in either sewage or fresh water for 28 days. It was hypothesized that sewage water, due to its organic matter, salts, and acidic content, would cause greater deterioration, while cement dust would provide higher resistance to moisture-induced damage compared to marble and brick dust. Marshall Stability and Indirect Tensile Strength tests were conducted under both dry and wet conditions. The results confirmed this hypothesis, demonstrating that mixtures with cement dust exhibited superior stability and retained strength, effectively mitigating the negative effects of sewage exposure.*

1. Introduction

Road infrastructure plays a vital role in supporting national development, economic growth, and social connectivity [1–3]. To ensure long-term pavement performance, designers must consider environmental conditions, traffic loads, and the selection of asphalt concrete materials [4,5]. One of

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the major challenges affecting Hot Mix Asphalt (HMA) pavements is moisture-induced damage, which weakens the adhesive bond between the binder and aggregate, leading to stripping, loss of cohesion, and accelerated deterioration [6]. Prolonged water ponding on the pavement surface—particularly for more than 24 hours—intensifies this damage, as illustrated in Fig. 1, which shows wastewater accumulation on urban roads resulting from drainage and sewage network failures, leading to surface deterioration and reduced service life and driving safety [7]. Sewage ponding presents an even more critical problem, especially in Upper Egypt, where limited drainage systems, high groundwater levels, and aging sewage networks frequently result in wastewater accumulation on urban roads. In hot climates, such exposure accelerates deterioration compared to ordinary fresh water. Unlike freshwater, wastewater contains a complex mix of chemicals and biological agents, including sulfates (SO_4^{2-}), chlorides (Cl^-), organic acids, and microbial contaminants, which react with the asphalt binder and aggregates [8-10]. These compounds cause oxidation, binder softening, and stripping at the binder–aggregate interface, reducing the cohesive and adhesive strength of asphalt mixtures. Typical wastewater from municipal catchments in Upper Egypt exhibits pH values of 6.7–7.4, total dissolved solids (TDS) of 2,000–2,500 mg/L, chloride concentrations of 600–700 mg/L, sulfate levels of 350–450 mg/L, and chemical oxygen demand (COD) and biological oxygen demand (BOD) ranging between 450–600 mg/L and 200–300 mg/L, respectively. Such characteristics make wastewater more aggressive than Fresh water, posing a significant durability challenge. [7-11]. Water infiltration is widely recognized as a key factor in the premature failure of asphalt pavements [12-14]. However, most previous studies have focused on moisture damage caused by rainwater or distilled water, with limited attention to wastewater's long-term chemical effects. Wastewater exposure in urban areas—especially under ponding conditions—combines chemical, thermal, and biological degradation mechanisms, until now its comparative influence with freshwater remains underexplored [15–17]. This research gap highlights the need for a deeper understanding of wastewater-induced deterioration and how waste-derived fillers might mitigate such effects. Mineral fillers play a vital role in asphalt mixture design by filling micro-voids, enhancing stiffness, and improving moisture resistance [18-21]. Among locally available waste materials, cement dust, marble dust, and brick dust are abundant by-products of construction industries in Egypt and represent sustainable alternatives to conventional limestone filler [22-25]. Cement dust, due to its hydraulic and alkaline properties, enhances mixture stiffness and binder adhesion [26].; marble dust contributes to higher density and smoother texture [27-29].; whereas brick dust, being more porous, may reduce stiffness but improve flexibility [29]. Utilizing such materials supports circular economy principles by reducing landfill waste, lowering environmental pollution, and conserving natural resources [24,25]. Several studies have investigated the use of waste-derived fillers such as fly ash, silica fume, and cement kiln dust [22,23,28].; however, there remains limited evidence regarding their comparative performance under wastewater versus freshwater exposure [7,9,10]. The present study addresses this knowledge gap by evaluating the mechanical behaviour and moisture susceptibility of asphalt mixtures containing cement, marble, and brick dust fillers when immersed in sewage and fresh water. The main objectives of this study are to:

a. Quantify the reduction in Marshall Stability (MS) and Indirect Tensile Strength (ITS) after exposure to sewage and fresh water;
b. Rank the tested fillers according to their retained strength and moisture resistance;

c. Relate the chemical composition of the immersion water (Cl^-, SO_4^{2-}, COD, pH) to the observed deterioration; and
d. Identify the filler type most effective in maintaining TSR ≥ 80%.

The working hypotheses are as follows:

H1: Sewage water causes a greater reduction in TSR than fresh water due to its chemical aggressiveness. H2: Cement dust improves adhesion and moisture resistance more effectively than marble or brick dust. H3: Performance loss is correlated with the concentration of chloride, sulfate, and organic contaminants. H4: Interactions exist between filler type and exposure duration affecting mixture durability.

Overall, this research provides a systematic comparative evaluation of wastewater and freshwater effects on asphalt mixtures with different waste-derived fillers. The findings contribute to sustainable pavement design strategies in regions such as Upper Egypt, where wastewater exposure poses a persistent challenge to road durability and public safety.

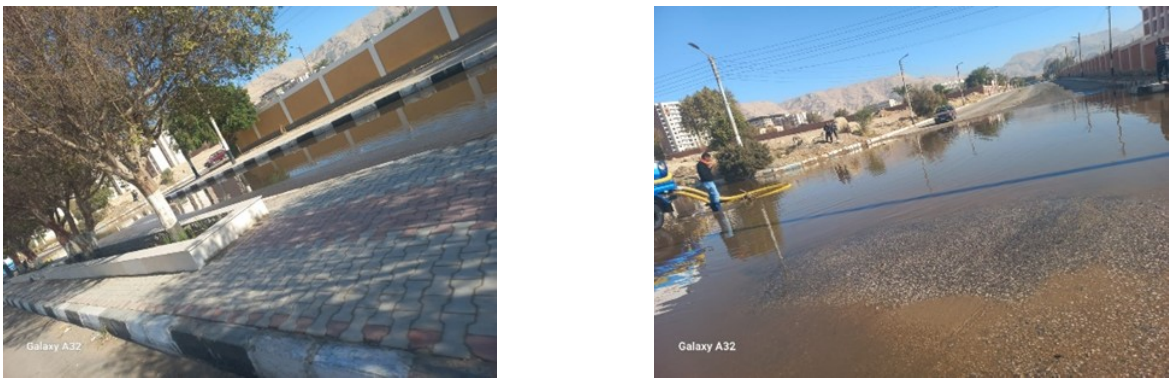

Fig.1: Appearance of accumulation of sewage water and fresh water over

2. Research Objective

This study aims to evaluate the deterioration behaviour of asphalt concrete mixtures incorporating three types of mineral fillers—cement dust, brick dust, and marble dust—when subjected to freshwater (rainwater) and wastewater (sewage) exposure. To replicate long-term moisture conditions, the specimens were submerged in each water type for a duration of 28 days. The performance of the mixtures was then assessed through Marshall Stability and Flow tests, in addition to the Indirect Tensile Strength (ITS) test, to determine their moisture susceptibility and mechanical integrity under both exposure scenarios.

3. Material Characterization

3.1. Asphalt Binder

In this study, AC 60/70 asphalt binder, which is the conventional binder commonly used in Egypt, was utilized. The key physical properties of the binder are summarized in Table 1, showing that the penetration grade 60/70 bitumen used in this study exhibited a penetration value of 65 (0.1 mm), a softening point of 45.4 °C, and a specific gravity of 1.01, which are within the specifications required for hot mix asphalt in Egypt.

3.2. Aggregates

The coarse and fine aggregates used in this study were crushed dolomite, while the sand was natural siliceous sand. The physical properties of the aggregates used in this study are summarized in Table 2. The specific gravity values were 2.62 for both coarse aggregates (crushed stone types 1 and 2) and 2.53 for the fine aggregate (sand*)* , confirming their suitability for use in asphalt mixtures. Table 3*.* presents the final selected aggregate gradation along with the corresponding specification limits. The gradation satisfied the Type 4C requirements with a nominal maximum aggregate size (NMAS) of 12.5 mm and a target void in mineral aggregate (VMA) of not less than 14%.

3.3. Mineral filler

Cement dust, brick dust, and marble dust were used separately as mineral fillers in the asphalt mixtures, as illustrated in Fig. 2. The selected fillers—cement dust, marble dust, and brick dust—were chosen due to their local availability, cost-effectiveness, and potential to improve mechanical properties. Cement dust is known for its pozzolanic activity, marble dust enhances stiffness due to its high calcium carbonate content, and brick dust contributes to increased surface roughness, improving binder adhesion. Their chemical composition and particle size distribution were characterized prior to use to better interpret their influence on asphalt mixture performance, all fillers passing the 0.075mm sieve.

Table 1: Physical properties of the conventional asphalt

Test	Result	Standard Test Method	Acceptable limits
Penetration (25 °C, 100g, 5s) (dmm)	65	ASTM D5	60–70
Softening point (°C)	45.4	ASTM D36	≥ 45
Flash point (°C)	250	ASTM D92	≥ 232
Ductility (cm)	100	ASTM D113	≥ 100
Specific gravity	1.01	ASTM D70	1.0 – 1.1

Table 2: Physical Properties of Aggregates

Test	Result				Standard test Method	Acceptable limits
	Aggr. #1	Aggr. #2	Sand	Filler		
Bulk specific gravity	2.583	2.576	2.51	…..	ASTM C127	2.5 – 2.75
SSD specific gravity	2.624	2.622	2.53	…..	ASTM C128	2.5 – 2.75
Apparent specific gravity	2.65	2.705	2.6	2.7	ASTM D854	2.6 – 2.8
Water absorption (%)	1.95	2.04	2.89	…..	ASTM C127 / C128	≤ 2% (coarse aggr.), ≤ 3% (fine aggr.)
Los Angeles abrasion (%)	27.9	33.3	…..	…..	ASTM C131	≤ 30–35%

Table 3. Selected Mix Gradation

Sieve size	% Passing	
	Used gradation	Gradation limits (Egypt Specs. (4C))
1	100	100
¾	94.46	80-100
3/8	64.93	60-80
No.4	48.56	48-65
No.8	43.25	35-50
No.30	19.05	19-35
No.50	13.22	13-23
No.100	7.56	7-15
No.200	6.82	0-8

(a) (b) (c)

Fig. 2: Appearance of the difference type of fillers. (a) Cement dust, (b) Marble dust, (c) Brick dust

4. Experimental Framework

Fig. 3, illustrates the overall research methodology adopted in this study, which includes material characterization, mixture design using the Marshall method, conditioning in fresh and sewage water, and subsequent performance evaluation through Marshall Stability and Indirect Tensile Strength tests.

4.1. Specimen preparation

The Marshall mix design method was employed to determine the Optimum Asphalt Content (OAC) for three different asphalt mixtures incorporating cement dust, brick dust, and marble dust as fillers. A total of 45 specimens were prepared—15 for each filler type. Each specimen was composed of 1200 g of washed and oven-dried aggregates, which were sieved according to the gradation outlined in Table 3. The gradation of the mixtures met the Type 4C specification with a nominal maximum aggregate size (NMAS) of 12.5 mm and a target void in mineral aggregate (VMA) ≥ 14%. Mixing and compaction temperatures were justified based on the viscosity–temperature relationship for AC 60/70 asphalt binder. According to literature [30-32], the viscosities of 0.17 ± 0.02 Pa.s (mixing) and 0.28 ± 0.03 Pa.s (compaction) correspond approximately to 155–160 °C and 145–150 °C, respectively. Therefore, the adopted temperatures of 150 °C for mixing and 140 °C for compaction fall within the ±10 °C tolerance recommended by ASTM D6926, confirming that they represent realistic viscosity conditions for AC 60/70. To ensure uniformity among mixtures, the same temperatures were used for all filler types, with fillers pre-dried to minimize moisture variation. The hot aggregates were mixed with five bitumen contents—4%, 4.5%, 5%, 5.5%, and 6%—until a homogeneous blend was achieved. For each bitumen percentage, three specimens were prepared and compacted with 75 blows on each face using a Marshall compactor. After a 24-hour curing period at room temperature, the samples were immersed in water baths. The immersion temperature of 25 ± 2 °C was selected to maintain consistency with standard laboratory conditioning procedures (ASTM D6931 and D4867), enabling evaluation of moisture-induced damage without thermal effects on binder viscosity or aging. The intent was to isolate the effect of water type (fresh vs. sewage) and filler chemistry rather than the combined influence of moisture and temperature.

All specimen preparation and testing procedures followed the relevant ASTM standards: Marshall specimens were prepared per ASTM D6926, and stability/flow were measured per ASTM D6927 at a loading rate of 50 mm/min after conditioning at 60 °C for 30 min. Indirect tensile strength (ITS) testing was performed per ASTM D6931 at 25 °C for retained ITS after immersion. Bulk and maximum specific gravities were determined per ASTM D2726 and ASTM D2041, respectively. Mixing and compaction temperatures were set from binder viscosity per ASTM D4402 at 0.17 Pa.s and 0.28 Pa.s. The final specimen dimensions were approximately 64 mm in height and 102 mm in diameter.

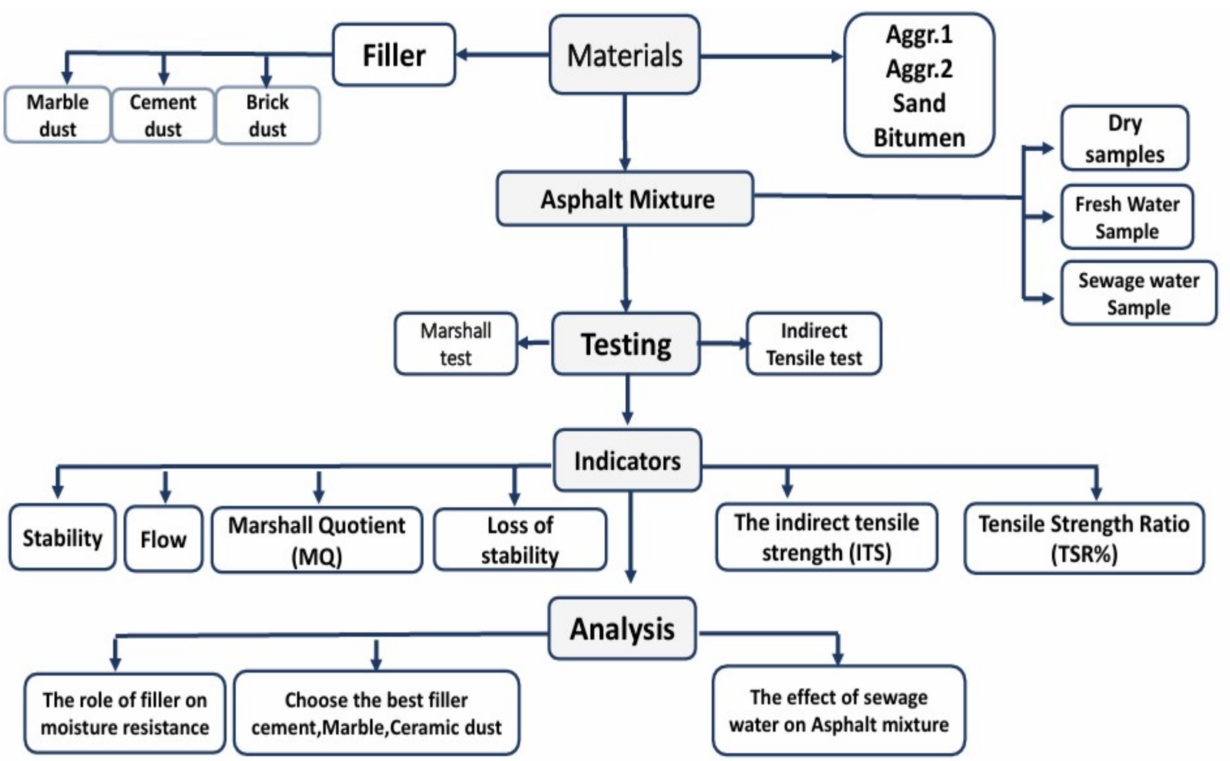

Fig.3: Methodology scheme used for this work

4.2. Water ponding

Two different immersion conditions were simulated in this experiment: specimens were submerged in fresh water and sewage water, as illustrated in Fig.4, the asphalt specimens were immersed in both fresh and sewage water to evaluate the influence of water type on their moisture susceptibility. These conditions reflect the real environmental scenario in the study area—a city characterized by minimal cross and longitudinal slopes. Consequently, both fresh water and sewage tend to accumulate and remain on the road surface for extended periods, resulting in full pavement submersion. Fresh water sources include rainfall and the routine practice of spraying roads with water. The characteristics of the sewage and fresh water used in the experiment are presented in Table 4. The sewage water showed higher salinity and contamination levels, with pH = 7.2, TDS =690 mg/L, and COD =750 mg/L, whereas the fresh water exhibited much lower concentrations of dissolved solids and ions, as shown in Table 5, which lists the detailed chemical composition of fresh water, including pH, TDS and Cl^{-} values.

Fig.4: Immersed sample in fresh and sewage water

Table 4. The characteristics of sewage water.

The Properties of sewage water	The value
PH	7.2
TDS	690
TSS	300
BOD	370
COD	750
NH3	35
ON	15
TKN	50
S	5.5
P	6.5
O and G	70

Table 5. The characteristics of Fresh water.

The Properties of Fresh water	The value
PH	7.7
TDS	210
Temperature	25 ºC
chlorides	18
Alkalinity	130
conductivity	328
Total Hardness	150
Ca. Hard.	95
Mg. Hard.	55
Fe	0.05
Mn	0.01
Residual Chlorine	1.5
Turbidity	0.2

4.3. Testing Scheme

Based on the determined Optimum Asphalt Content (OAC), the selected materials were used to prepare the specimens for the experimental testing program. A total of 45 specimens were prepared to undergo both Marshall Stability and Indirect Tensile Strength (ITS) testing. For each filler type—cement dust, brick dust, and marble dust—15 specimens were prepared. The specimens were divided into three conditioning groups: dry, fresh water immersion, and sewage water immersion, with five specimens allocated to each group. The samples assigned to the immersion conditions were submerged in either fresh or sewage water for a period of 28 days before testing. The selection of fresh and sewage water as immersion media reflects the environmental conditions commonly encountered in Upper Egypt, where road surfaces are often exposed to wastewater infiltration due to inadequate drainage systems. This approach provides a realistic simulation of long-term exposure scenarios affecting local pavement performance. The immersion tests were conducted at a controlled temperature of 25 ± 2 °C to simulate the typical ambient conditions of the study area. Maintaining a consistent temperature during immersion was essential to minimize variability and ensure accurate assessment of the moisture-induced damage in asphalt mixtures. All testing devices, including the Marshall stability apparatus and the indirect tensile strength setup, were calibrated prior to testing in accordance with ASTM standards to ensure measurement accuracy. Quality control procedures were implemented throughout the experimental work to maintain consistency among specimens, including verifying specimen dimensions, uniform compaction, and controlled temperature during testing. All tests were performed in triplicate, and the average values were reported to minimize random errors and ensure the consistency and reliability of the results. The obtained data were analysed based on comparative trends among different filler types and conditioning environments rather than through formal statistical testing.

4.3.1. Marshall testing

The Marshall testing apparatus was utilized to evaluate the strength characteristics of all specimens, specifically Marshall stability (kg) and flow (mm). Based on the measured values, the Marshall Quotient—defined as the ratio of stability to flow—was also calculated. This parameter is particularly useful for assessing the loss of strength resulting from prolonged water exposure. All procedures were conducted in accordance with the standard Marshall testing method [32]. For the Marshall Stability and Flow test, the compacted specimens were first immersed in a water bath at 60 °C for 30 minutes. Following conditioning, each specimen was individually placed on the breaking head of the Marshall testing machine for evaluation. According to ASTM D6927, the loading was applied at a constant rate of 50 mm/min, and both stability (recorded in kg) and flow (recorded in 0.25 mm units) were measured using a calibrated flow meter. Before testing, the wet specimens were carefully surface-dried with a damp cloth to remove excess water, ensuring consistent handling conditions. The Marshall Quotient (MQ) was computed as the ratio of Stability to Flow (MQ = Stability / Flow), which serves as an indicator of mixture stiffness and resistance to plastic deformation. It is acknowledged that the 28-day immersion followed by conditioning at 60 °C may lead to partial desorption of absorbed water from the specimens. However, this procedure was intentionally adopted to maintain consistency with the standard ASTM D6927 conditioning protocol and to enable direct comparison with previous studies.

4.3.2. Indirect tensile strength test (IDT)

The Indirect Tensile Strength (ITS) test was conducted on specimens conditioned in three states—dry, fresh water, and sewage water—to evaluate the effect of moisture on the tensile strength of asphalt mixtures. The test was carried out in accordance with AASHTO T283-14 [33]. For each filler type, 15 specimens were prepared with the same dimensions as the Marshall samples. Each specimen was compacted using 75 blows per side according to the Marshall compaction procedure (ASTM D69**27)** before conducting the Indirect Tensile Strength (ITS) test. The air void content of the specimens ranged between 6% and 8%. The samples were divided into three groups:

- The first group was tested in a dry condition at a temperature of 25 °C, using a loading rate of 50.8 mm/min until failure occurred. The failure load was recorded for each specimen.
- The second and third groups were tested after being conditioned for 28 days in fresh water and sewage water, respectively.

The Indirect Tensile Strength (ITS) was calculated using Equation 1. Additionally, the Tensile Strength Ratio (TSR), which serves as an indicator of the mixture's moisture susceptibility, was computed as the ratio of the tensile strength of the conditioned (wet) specimens to that of the dry specimens, as shown in Equation 2 [34].

$$\text{ITS} = \frac{2P}{\pi H D} \quad \text{.................................} \quad (1)$$

$$\text{TSR\%} = 100\left(\frac{ITS_{wet}}{ITS_{dry}}\right) \quad \text{.................................} (2)$$

Where,

P= failure load, Kg

H= thickness of the sample, mm

D= diameter of the sample, mm

ITS dry = average indirect tensile strength for the first group samples, kPa.

ITS wet = average indirect tensile strength for the second group samples, kPa.

4.3.3. Loss of stability test

The Loss of Stability (LOS) test, commonly referred to as the Immersion Marshall Test, was performed to assess the moisture damage resistance of asphalt mixtures, following the procedures outlined in [35]. Specimens incorporating the three types of fillers—cement dust, brick dust, and marble dust—were prepared for this purpose. For each filler type, the specimens were divided into two groups:

- Group 1: Samples were tested using the Marshall apparatus after being conditioned in a water bath at 60 °C for 30 minutes.
- Group 2: Samples were immersed in water at 60 °C for 28 days before being tested.

The Loss of Stability (LOS) represents the percentage reduction in Marshall Stability (Ms) between the short-term conditioned group and the long-term immersed group. It reflects the degradation in mechanical strength due to extended water exposure. The LOS value is calculated using Equation 3.

$$LOS\% = 100\left(1 - \frac{Ms_1}{Ms_2}\right) \text{.................} (3)$$

Where,
Ms1 = average Marshall stability of the second group samples.
Ms2 = average Marshall stability of the first group samples.

4.4. The Optimum Asphalt Content (OAC)

The Marshall mix design procedure was utilized to determine the Optimum Asphalt Content (OAC) for three different asphalt mixtures incorporating cement dust, brick dust, and marble dust as mineral fillers. A total of 45 samples were prepared—15 samples for each filler type. The optimum asphalt content (OAC) for each mixture was determined in accordance with the Marshall mix design procedure specified in ASTM D1559. Five asphalt contents were initially selected with increments of 0.5%, and for each content, three specimens were prepared and tested for Marshall Stability, flow, bulk density, and air voids. The OAC was identified as the asphalt content corresponding to the maximum stability value and acceptable limits of other volumetric properties.
It was observed that the mixture containing cement dust required a higher OAC compared to those incorporating marble and brick dust. This can be attributed to the finer particle size and higher surface activity of cement dust, which increase the absorption of the asphalt binder and hence require more bitumen to achieve proper coating and mixture performance. The determined optimum asphalt content (OAC) values were 5.3% for cement dust, 5.0% for brick dust, and 4.75% for marble dust, as illustrated in Fig. 5, which shows the variation of Marshall Stability, flow, and air voids with binder content for the three mixtures.

4.4.1. Variation of Bulk Density with Bitumen Content for Different Filler Types

As illustrated in Fig. (5 – a), the bulk density of the brick dust filler was the highest among the three types, followed by marble dust and then cement dust, indicating a denser packing and lower porosity for the brick dust particles. This trend can be explained by the differences in the physical characteristics and mineral composition of the fillers. Brick dust, being derived from fired clay materials, contains dense crystalline structures and relatively coarse particles, resulting in higher packing efficiency and consequently greater bulk density. Marble dust, mainly composed of calcium carbonate, has smoother and less angular particles, which slightly reduce the packing density compared to brick dust. In contrast, cement dust consists of finer and lighter particles with higher porosity and lower specific gravity, leading to a lower bulk density. Therefore, the observed variation in bulk density reflects the intrinsic particle size distribution, surface texture, and mineral composition of each filler type.

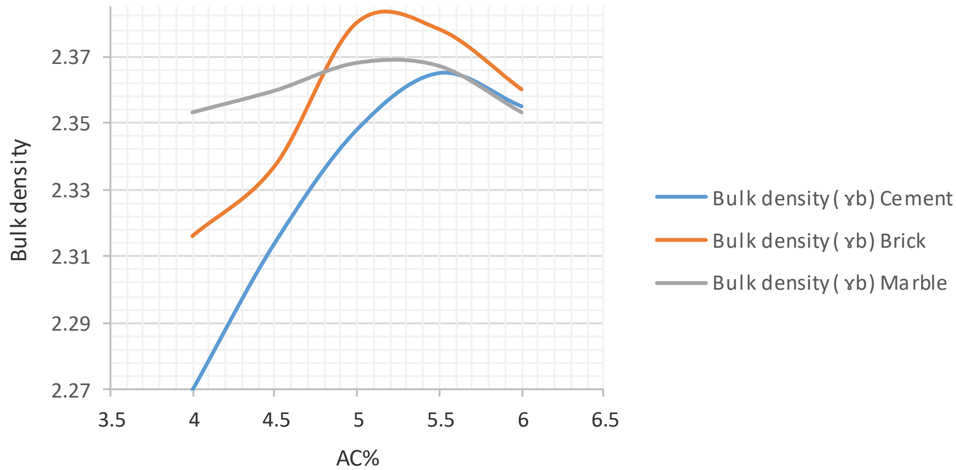

Fig. (5 - a): Relationship between Bulk density and Bitumen Content.

4.4.2. Variation of Stability with Bitumen Content for Different Filler Types

As illustrated in Fig. (5 – b), the mixtures containing cement dust exhibited the highest Marshall stability values, followed by those with marble dust and brick dust, indicating that the pozzolanic activity of cement dust enhanced the binder–aggregate bonding and overall mixture strength. This can be attributed to the superior adhesive and stiffening properties of cement particles, which enhance the binder–aggregate interaction and improve load-bearing capacity. The alkaline and fine nature of cement allows it to react with bitumen, forming a denser mastic that strengthens the interfacial bonding and reduces internal deformation under loading. Marble dust, composed primarily of calcium carbonate, also contributes to improved stability due to its relatively high density and ability to fill micro-voids; however, its smoother texture limits its bonding effectiveness compared to cement dust. In contrast, brick dust contains more porous and irregular particles with lower specific gravity, which weakens the binder adhesion and reduces stiffness, leading to lower stability values. Therefore, the observed trend (cement > marble > brick) reflects the combined effects of filler chemistry, surface texture, and interaction with the bituminous binder.

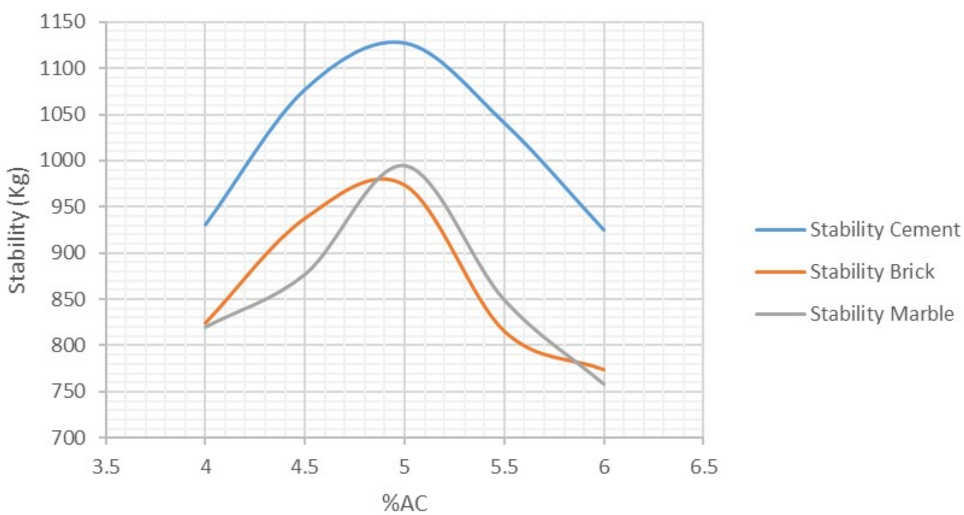

Fig. (5 – b): Relationship between Stability and Bitumen Content.

4.4.3. Variation of Flow with Bitumen Content for Different Filler Types

As illustrated in Fig. (5 – c), the flow values followed the trend brick dust > marble dust > cement dust, indicating that mixtures with brick dust were more deformable, whereas those with cement dust exhibited higher stiffness. This behaviour is attributed to the lower stiffness and higher deformability of mixtures containing brick dust, as its porous structure and weak adhesion with the binder allow greater plastic deformation under load. Marble dust mixtures exhibited moderate flow due to their smoother particles and intermediate stiffness. In contrast, cement dust mixtures showed the lowest flow values because of their strong filler–binder interaction and higher rigidity, which restricted deformation during loading.

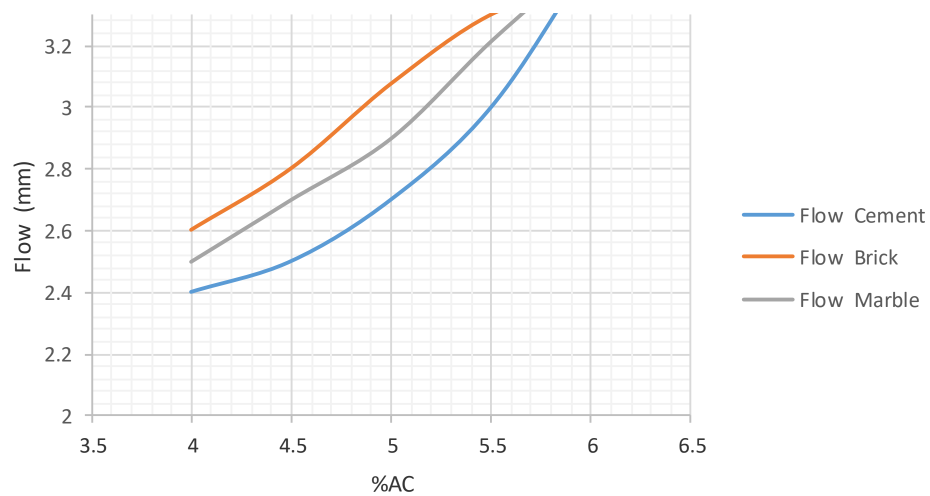

Fig. (5 – c): Relationship between Flow and Bitumen Content.

4.4.4. Variation of Air voids with Bitumen Content for Different Filler Types

As illustrated in Figure (5 – d), the air voids content (%V_air) was highest in mixtures containing cement dust, followed by those with brick dust and marble dust. This trend indicates that cement dust mixtures had a relatively lower compatibility, likely due to the angularity and finer texture of the cement particles. This can be attributed to the finer and more angular particles of cement dust, which increase the mixture's stiffness and reduce its workability, leading to slightly higher entrapped air during compaction. Brick dust, having a porous and irregular texture, also retained some air voids, but to a lesser extent. In contrast, marble dust's smooth and dense particles enhanced the packing and compaction efficiency, resulting in the lowest %V_air values.

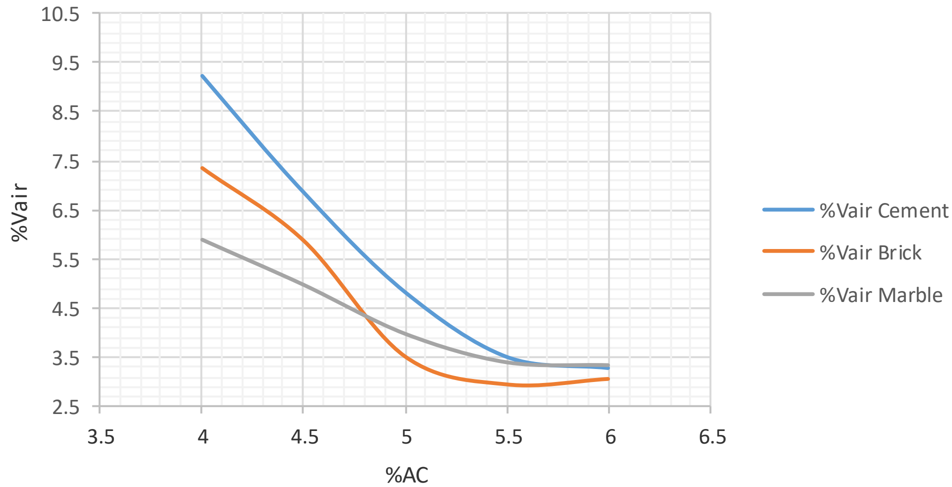

Fig. (5 – d): Relationship between %Vair and Bitumen Content.

4.4.5. Variation of Void filled with Bitumen Content for Different Filler Types

As illustrated in Fig. (5 – e), the voids filled with bitumen (%Vfb) were highest in mixtures containing brick dust, followed by those with marble and cement dust. This behaviour suggests that brick dust improved the coating and binder absorption, leading to a higher proportion of voids filled with bitumen**.** This trend is due to the porous and absorptive nature of brick dust, which allows more bitumen to fill the available voids. Marble dust, with its smoother and denser texture, exhibited moderate bitumen absorption, resulting in intermediate %Vfb values. Conversely, cement dust mixtures had the lowest %Vfb because their fine and stiff particles limited bitumen penetration and filling, leaving a larger portion of air voids unfilled.

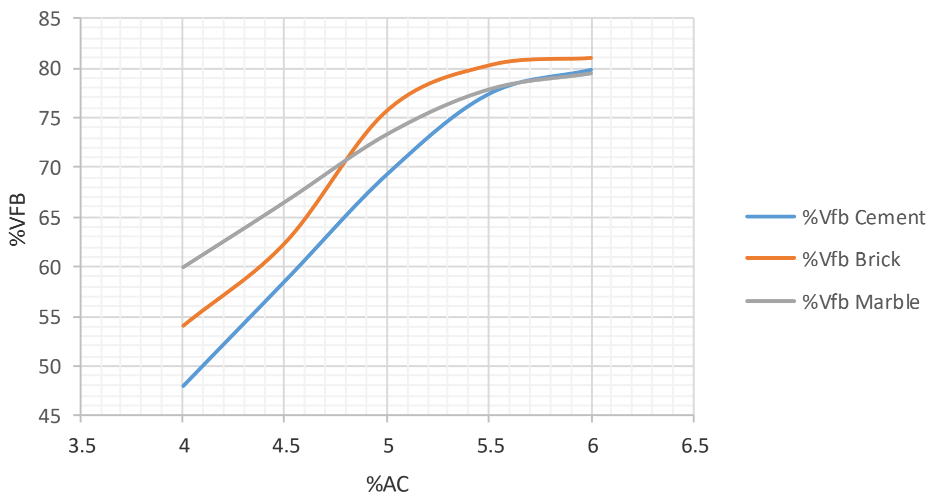

Fig. (5 – e): Relationship between %Vfb and Bitumen Content.

5. RESULTS AND DISCUSSION

5.1. Marshal test

5.1.1. Stability

The stability and flow of the samples immersed in freshwater and sewage water were evaluated after a 28-day conditioning period. Fig. 6, presents the stability values for mixtures containing different fillers under three conditions: dry state, freshwater immersion, and sewage water immersion. The mixtures with cement dust exhibited the highest stability in all conditions, while those with brick dust showed the lowest values, particularly after sewage water exposure. The Marshall test results revealed a noticeable decrease in stability for specimens subjected to both types of water immersion. Notably, samples immersed in sewage water exhibited a significantly greater reduction in stability compared to those immersed in freshwater. In the dry state, the stability of the cement dust mixture was higher by 12.12% and 17.54% compared to the marble dust and brick dust mixtures, respectively. Under freshwater immersion, cement dust showed an increase of 24.26% over marble dust and 29.31% over brick dust. Under sewage water immersion, the increases were 37.33% and 47.92% respectively. Overall, the cement dust mixture demonstrated the highest stability across all tested conditions, outperforming both marble dust and brick dust mixtures. The higher stability of the cement dust mixture is mainly due to its alkaline and hydraulic properties, which improve adhesion between binder and aggregates and reduce stripping. Marble dust, rich in calcium carbonate, provides good density but limited chemical bonding, resulting in moderate water resistance. Brick dust, being porous and silica-rich, absorbs more water and weakens the binder–aggregate interface. The greater loss of stability in sewage water compared to freshwater is attributed to chemical attacks from sulfates, chlorides, and organic acids that accelerate binder degradation. Consequently, cement dust mixtures exhibited the best resistance, followed by marble and brick dust mixtures[31].

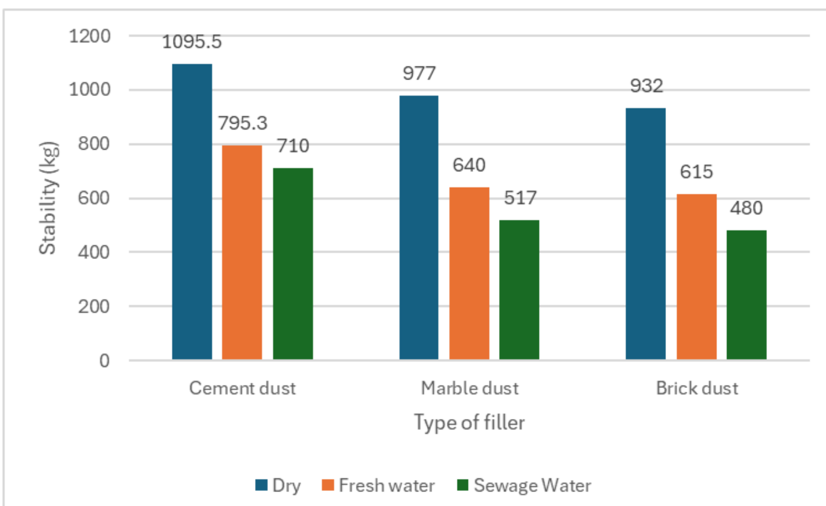

Fig. 6: Stability for samples with different filler

5.1.2. Flow

Flow represents the maximum deformation exhibited by an asphalt mixture at the point of failure under load. During the Marshall test, the flow values were measured for all mixtures, and the results are presented in Fig. 7, The mixtures containing brick dust showed the highest flow values, indicating greater plasticity, while those with cement dust exhibited lower flow, reflecting higher stiffness. According to the Asphalt Institute, acceptable flow values for pavements under heavy traffic conditions should range between 2–4 mm [36,37]. The observed flow behaviour mirrored the trend noted in the stability results: samples immersed in freshwater and sewage water exceeded the recommended upper flow limit after 28 days of immersion. Among all mixtures, the cement dust samples exhibited the lowest flow values compared to those with marble and brick dust. Additionally, cement dust samples immersed in freshwater had lower flow values than those immersed in sewage water, indicating better resistance to deformation. The lower flow values of mixtures containing cement dust can be attributed to its stiffening and adhesive properties, which enhance cohesion between bitumen and aggregates and reduce deformation. In contrast, marble and brick dust mixtures showed higher flow due to their lower surface activity and weaker bonding with the binder. The notable increase in flow after sewage water exposure is mainly due to chemical reactions between wastewater contaminants (sulfates, chlorides, and organic acids) and bitumen, which soften the binder and weaken the internal structure of the mixture, making it more deformable under load

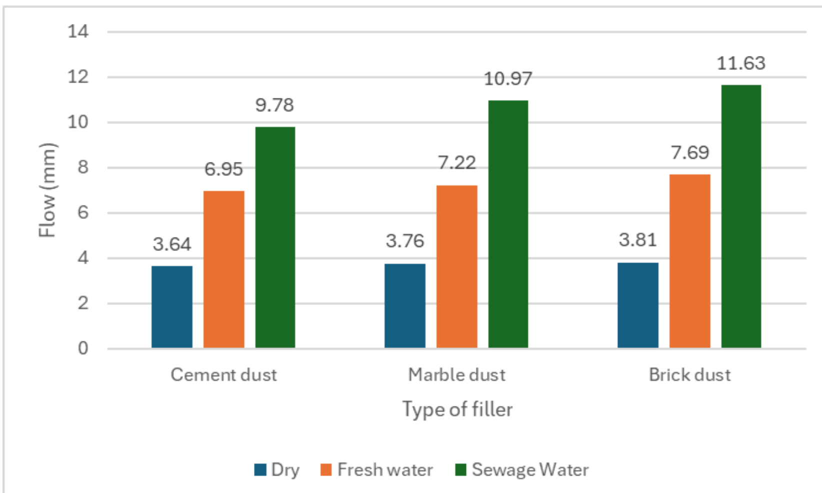

Fig.7: Flow for samples with different filler

5.1.3. Marshall Quotient (MQ)

In addition to stability and flow, the Marshall test provides insights into the mixture's resistance to rutting through the Marshall Quotient (MQ), which is calculated by dividing the stability by the flow. Higher MQ values indicate increased stiffness of the asphalt mixture, which corresponds to greater resistance to permanent deformation, such as rutting [38]. As illustrated in Fig. 8, incorporating cement dust as a mineral filler significantly increased the stiffness of the mixtures, indicating enhanced resistance to rutting. This improvement is particularly advantageous for asphalt pavements in hot climatic regions. In the dry state, cement dust samples recorded the highest MQ, with increases of 15.83% and 23.03% compared to marble and brick dust, respectively. When immersed in fresh water, the increases reached 29.1% and 43.1%, while under sewage water conditions, cement dust samples showed the greatest improvement in rigidity, with increases of 54.04% and 75.9% over marble and brick dust, respectively. The improvement in the Marshall Quotient (MQ) for mixtures containing cement dust can be attributed to the filler's chemical and physical characteristics. Cement particles possess a finer texture and higher alkalinity, which enhance the binder–aggregate adhesion and increase the stiffness of the mastic phase, thus improving the mixture's resistance to plastic deformation. In contrast, marble and brick dust contain more inert or porous particles that contribute less to stiffness, leading to lower MQ values. The significant drop in MQ under sewage exposure is mainly due to the penetration of acidic and saline compounds (such as sulfates and chlorides) that weaken the adhesive bond and soften the bitumen film, resulting in reduced rigidity. Similar findings were reported by Tapkin et al., who observed that alkaline fillers improve rutting resistance by enhancing binder cohesion and reducing stripping potential [31].

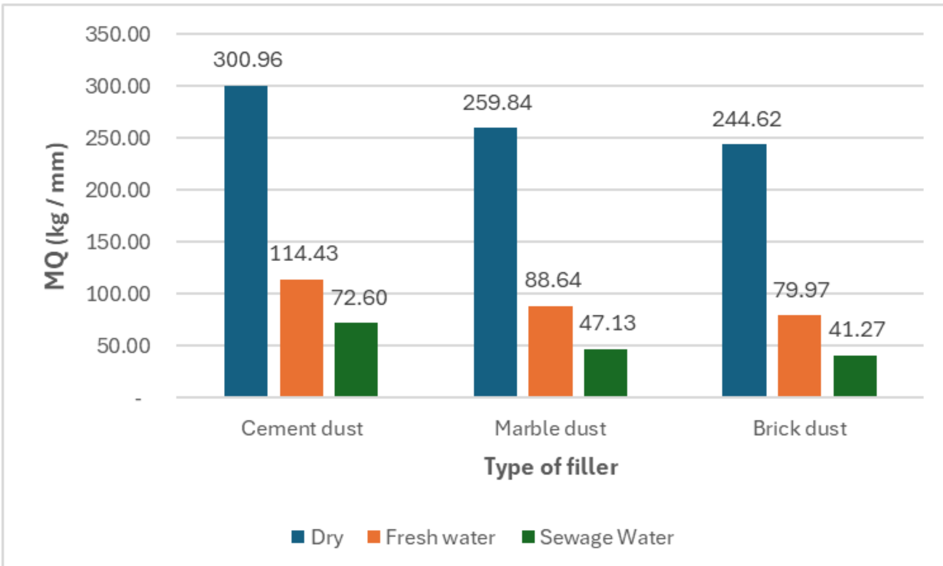

Fig. 8: MQ for samples with different filler

5.1.4. Loss of stability

Fig.9 illustrates the percentage loss in average Marshall stability values for mixtures containing cement dust, marble dust, and brick dust under dry, freshwater, and sewage water conditions. The mixtures with cement dust showed the lowest stability loss, indicating superior moisture resistance, whereas those with brick dust exhibited the highest loss, especially under sewage exposure. The results clearly indicate that mixtures incorporating cement dust exhibited the lowest loss of stability, demonstrating superior resistance to moisture-induced damage when compared to those containing marble or brick dust fillers. the percentage loss in average Marshall stability for mixtures containing cement, marble, and brick dust under dry, fresh water, and sewage conditions. Mixtures with cement dust exhibited the lowest stability loss, indicating superior resistance to moisture-induced damage. This performance is attributed to the fine texture and high alkalinity of cement, which enhance binder–aggregate adhesion and mastic stiffness. In contrast, marble and brick dust, being more inert or porous, contributed less to stiffness, resulting in higher stability loss. Exposure to sewage water caused the greatest reduction in stability due to acidic and saline compounds weakening the binder.

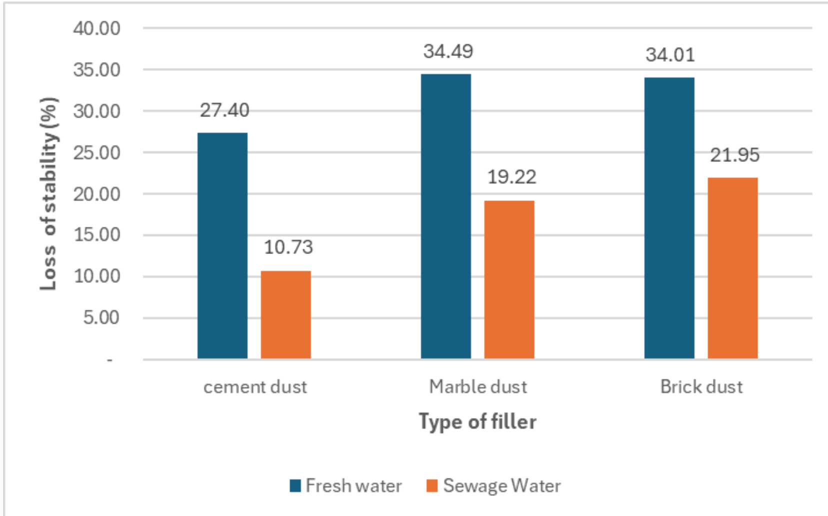

Fig.9: Loss of stability for samples with different filler

5.2. Indirect tensile strength test (IDT)

5.2.1. The indirect tensile strength (ITS)

As shown in Fig. 10, the mixtures containing cement dust exhibited the highest indirect tensile strength (ITS) values among all tested fillers under both dry and wet conditions. This indicates that cement dust enhances the cohesion and bonding within the asphalt matrix, resulting in improved tensile performance. cement dust samples immersed in fresh water demonstrated superior resistance compared to those in sewage water and to samples containing other types of fillers. For cement dust samples, the ITS decreased by 13.11% in fresh water and by 27.26% in sewage water compared to the dry state. For marble dust samples, the reduction in ITS was 18.65% in fresh water and 24.13% in sewage water. Brick dust samples exhibited the greatest decrease, with ITS values dropping by 39.86% in fresh water and 42.8% in sewage water compared to their dry state values. These findings highlight the superior tensile strength and moisture resistance of mixtures containing cement dust, particularly under harsh environmental conditions. The ITS results indicate that mixtures containing cement dust exhibited the highest tensile strength under both dry and wet conditions, demonstrating superior moisture resistance. Cement dust samples showed only a 13.11% reduction in ITS in fresh water and 27.26% in sewage water, reflecting enhanced binder–aggregate adhesion and mastic stiffness due to the fine texture and alkalinity of cement. Marble dust mixtures experienced moderate ITS reductions (18.65% in fresh water and 24.13% in sewage water), while brick dust mixtures showed the greatest losses (39.86% and 42.8%, respectively), attributable to their porous and chemically inert particles. Overall, these findings highlight the effectiveness of cement dust in improving tensile strength, particularly under harsh environmental conditions.

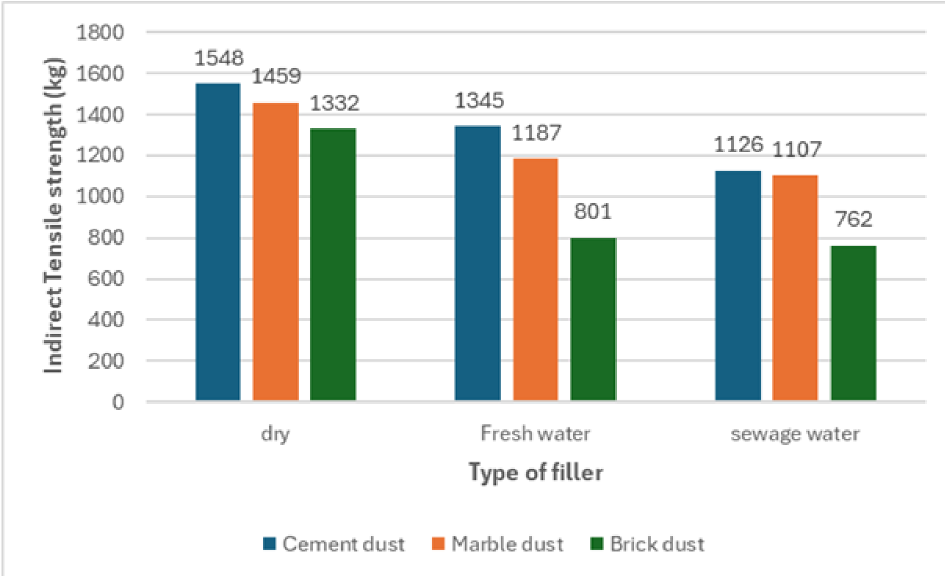

Fig. 10: ITS for samples with different filler

5.2.2. Tensile Strength Ratio (TSR%)

Fig. 11, presents the Tensile Strength Ratios (TSR) of the mixtures incorporating different fillers. The mixtures containing cement dust exhibited the highest TSR values, indicating superior moisture resistance and durability compared to those with marble or brick dust. As observed, the cement dust mixtures exhibited higher TSR values compared to those containing marble or brick dust. This indicates that using cement dust as a filler enhanced the binder–aggregate bonding, thereby resulting in improved moisture resistance of the asphalt mixtures. The elevated TSR values confirm the superior durability of cement-filled mixtures under moisture-induced conditions. The TSR results indicate that mixtures containing cement dust consistently exhibited higher values compared to those with marble or brick dust, reflecting enhanced moisture resistance. This improvement is primarily attributed to the fine particle size and high alkalinity of cement, which strengthen the binder–aggregate adhesion and increase the stiffness of the mastic phase. Consequently, cement-filled mixtures are better able to retain tensile strength under wet conditions, reducing the risk of stripping and moisture-induced damage. In contrast, marble and brick dust, being more inert and porous, contribute less to binder cohesion, resulting in lower TSR values. These findings confirm that cement dust improves the durability and resistance to moisture-related deterioration in asphalt mixtures. Although the immersion period was limited to 28 days, this duration was selected to capture the initial phase of moisture damage. Future research will focus on extended conditioning periods and aging simulations to evaluate the long-term durability of the mixtures under field-like environmental stresses.

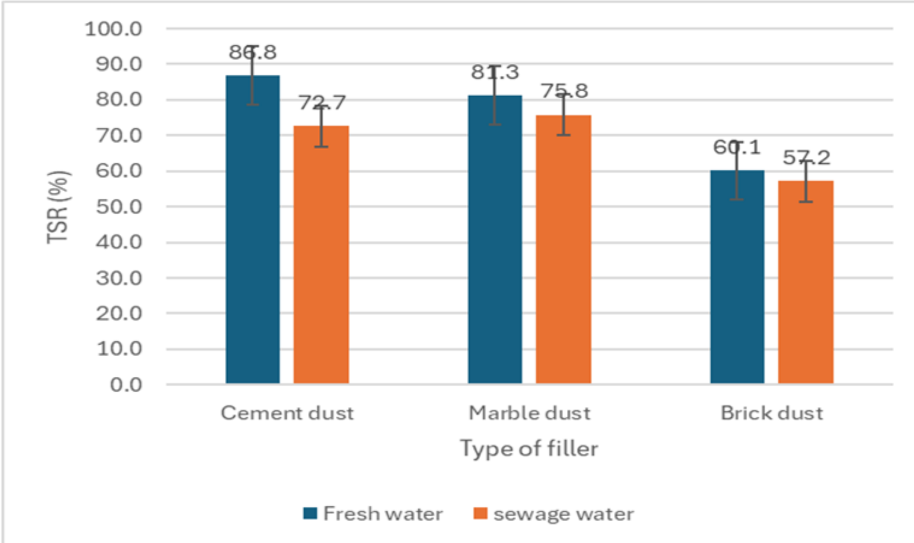

Fig.11: TSR (%) for samples with different filler

6. Conclusion

This study investigated the influence of sewage water on the performance of asphalt mixtures incorporating three different mineral fillers: cement dust, marble dust, and brick dust. The key findings can be summarized as follows:

1. Cement dust exhibited superior performance across all evaluated parameters, including Marshall stability, flow, and indirect tensile strength (ITS), indicating enhanced mechanical properties relative to the other fillers. Quantitative results: Marshall Stability decreased from 1095.5 Kg (dry) to 795.3 Kg after 28-day immersion in fresh water, and to 710 Kg after 28-day sewage water exposure (RMS ≈ 65%). ITS decreased from 1548 Kg (dry) to 1345 Kg (fresh water) and 1126 Kg (sewage), yielding TSR values of 86.8% (fresh) and 72.7% (sewage).
2. Cement dust effectively mitigated the detrimental effects of sewage water, maintaining higher strength and structural integrity under both dry and wet conditions compared to marble and brick dust.
3. Marble and brick dust mixtures showed significant degradation under sewage exposure. Marble dust: Marshall stability 977 Kg(dry) → 640 kg (fresh water) → 517 kg (sewage), RMS ≈ 53%; ITS 1459 kg → 1187 kg → 1107 kg, TSR ≈ 75.8% (sewage). Brick dust: Marshall stability 932 kg (dry) → 615 kg (fresh water) → 480 kg (sewage), RMS ≈ 50%; ITS 1332 kg → 801 kg → 762 kg, TSR ≈ 57.2% (sewage).
4. Among alternative fillers, marble dust outperformed brick dust, offering relatively improved resistance to moisture damage (≈4.8% higher stability, ≈9.5% higher ITS under sewage exposure).
5. Future work is focused and feasible, including:
   - Hamburg wheel-tracking under water at 50 °C,
   - T283 TSR with freeze–thaw cycles,
   - Aging effects using RTFO/PAV,
   - Microstructural analysis (SEM/XRD) of cement dust mastics,
   - Dose–response evaluation of cement dust content on mixture performance.

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