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Impact of Cement Dust Filler on the Durability of Asphalt Mixtures under Moisture Conditions

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ABSTRACT

Moisture damage remains one of the primary causes of premature asphalt pavement failure, leading to stripping and strength loss under prolonged water exposure. This study investigates the effect of using cement dust as a waste-derived filler compared to traditional limestone dust on the moisture susceptibility of asphalt mixtures. Both materials were selected based on their local availability and environmental benefits. A total of 30 Marshall specimens were prepared to determine the Optimum Asphalt Content (OAC) and were subsequently immersed in freshwater and sewage water for 28 days to simulate extended moisture exposure. Performance was evaluated through Marshall Stability and Indirect Tensile Strength (ITS) tests under dry and wet conditions. The results showed that mixtures containing cement dust exhibited higher stability and retained strength than those with limestone dust, confirming its superior resistance to moisture-induced damage. Overall, cement dust presents a sustainable and effective alternative filler for improving asphalt pavement durability.

Keyword: Cement dust; Asphalt mixtures; Moisture susceptibility; Freshwater; Marshall Stability

1. INTRODUCTION

Moisture-induced damage is among the most persistent problems affecting the performance and durability of asphalt pavements. Water penetration into asphalt layers weakens the adhesive bond between bitumen and aggregates, leading to stripping, cohesion loss, and premature deterioration [1–3]. Prolonged exposure to moisture accelerates this deterioration through combined physical and chemical effects, ultimately resulting in rutting, cracking, and raveling [4–6]. The severity of moisture-induced damage depends on multiple factors, including binder characteristics, aggregate type, filler properties, and environmental conditions [7–9]. Water infiltration through microcracks or air voids can cause debonding at the binder–aggregate interface, reducing mixture strength and stiffness [10]. Moreover, moisture may contain dissolved ions such as sulfates and chlorides, which can react with bituminous components, promoting oxidation and binder hardening [11,12]. This process compromises load-bearing capacity and accelerates fatigue damage, especially under repeated traffic loading [13,14]. Several researchers have reported that moisture-induced stripping is one of the main causes of premature pavement failure worldwide [15,16]. To enhance pavement resistance to moisture damage, various strategies have been developed, including anti-stripping agents, hydrated lime, polymers, and modified binders [17,18]. Recent studies have also focused on modifying asphalt mixtures with recycled plastics or polyethylene-based additives to improve moisture susceptibility and sustainability [19,20]. The selection of an appropriate mineral filler remains a key factor influencing mixture cohesion, stiffness, and permeability [21,22]. Fillers occupy micro-voids between aggregate particles, contributing to a denser structure and improved binder–aggregate adhesion [23,24]. Their effectiveness depends on fineness, chemical composition, and surface activity [25]. Limestone powder has traditionally been used as the standard filler in hot mix asphalt (HMA) due to its abundance, low cost, and compatibility with bitumen [26]. Nevertheless, environmental awareness and industrial development have encouraged the search for waste-derived alternatives to promote sustainability in pavement engineering [27,28]. Among these alternatives, cement dust**,** a fine particulate by-product of cement manufacturing, has gained attention for its potential to improve the mechanical and durability properties of asphalt mixtures [29,30]. Its high alkalinity, fineness, and pozzolanic reactivity can enhance the binder–aggregate bond and reduce moisture susceptibility by forming a more cohesive mastic [31]. Several studies have shown that cement-based waste fillers can increase stability, stiffness, and moisture resistance compared to conventional limestone [32,33]. However, the comparative performance of cement dust and limestone powder under wet conditions remains insufficiently explored. Understanding this comparison is crucial, as filler type directly affects mixture workability, compatibility, and stripping resistance [34,35]. Therefore, this research focuses on evaluating the effect of cement dust and limestone powder on moisture susceptibility of asphalt mixtures, aiming to identify which filler provides better performance under moisture exposure. The study hypothesizes that cement-dust-containing mixtures will exhibit superior Marshall Stability and Indirect Tensile Strength (ITS) values compared to limestone-containing mixtures, even after water conditioning. It is further hypothesized that the alkaline and hydraulic nature of cement dust improves binder–aggregate adhesion and maintains a Tensile Strength Ratio (TSR) ≥ 80%**,** which is generally considered the threshold for good moisture resistance [36,37]. To verify these hypotheses, asphalt mixtures with both fillers were designed using the Marshall mix design method, followed by moisture conditioning and mechanical testing to quantify strength reduction and retained performance [38]. The results are expected to contribute to sustainable pavement design practices by highlighting the potential of cement dust as an environmentally beneficial and technically effective substitute for traditional limestone filler.

2. RESEARCH SIGNIFICANCE

This study investigates the effect of using two types of mineral fillers—cement dust and conventional limestone dust—on the performance of asphalt concrete mixtures under moisture exposure. The research focuses on evaluating the potential of cement dust as a sustainable alternative to traditional limestone filler in improving the resistance of asphalt mixtures to moisture-induced damage and maintaining mechanical stability. To simulate long-term exposure to environmental moisture, the specimens were submerged in freshwater (rainwater) and wastewater (sewage) for 28 days. The mechanical performance and moisture susceptibility of the mixtures were then assessed using Marshall Stability and Flow tests, along with the Indirect Tensile Strength (ITS) test, providing a comprehensive comparison of the effectiveness of the two filler types under both wet conditions.

3. MATERIALS AND TEST SPECIMENS

3.1 Materials

3.1.1 Asphalt Binder

In this study, a conventional AC 60/70 asphalt binder was used, representing the standard grade commonly applied in hot mix asphalt production across Egypt. The main physical properties of the binder are presented **in Table 1**. The 60/70 penetration-grade bitumen exhibited a penetration value of 62 (0.1 mm), a softening point of 45.4 °C, and a specific gravity of 1.01, all of which comply with the standard specifications for hot mix asphalt applications in Egypt.

3.1.2 Aggregates

Crushed dolomite was utilized as both the coarse and fine aggregates in this study, whereas natural siliceous sand served as the fine component. The physical properties of the aggregates are presented in **Table 2**. The specific gravity values were determined to be 2.7 for the coarse aggregates (crushed stone types 1 and 2) and 2.65 for the fine aggregate (sand), indicating their conformity with the standard requirements for asphalt mixture production. The final aggregate gradation satisfied the Type 4C specification limits, with a nominal maximum aggregate size (NMAS) of 12.5 mm and a minimum void in mineral aggregate (VMA) of 14%, ensuring adequate internal structure and durability of the asphalt mixtures, **Fig.1**. Show the Specification Limits and Combined Aggregate Gradation for 4C Wearing Surface Mix and **Fig. 2**, Coarse and Fine Aggregate Fractions Obtained from Sieve Analysis.

3.1.3 Mineral filler

Cement dust and limestone dust were employed separately as mineral fillers in the asphalt mixtures. These fillers were selected based on their local availability, cost-effectiveness, and potential to enhance the mechanical and durability properties of asphalt mixtures. Cement dust, a by-product generated from the cement manufacturing process, is characterized by its pozzolanic and alkaline nature, which can improve binder adhesion and mixture stiffness. Limestone dust, on the other hand, represents the conventional filler commonly utilized in asphalt mixtures due to its high calcium carbonate content and consistent performance. The chemical composition and particle size distribution of both fillers were characterized prior to their use to facilitate interpretation of their influence on the performance of asphalt mixtures. All filler materials passed through the 0.075 mm sieve.

TABLE 1. PHYSICAL PROPERTIES OF CONVENTIONAL ASPHALT BINDER USED IN THE STUDY

Test	Result	Standard Test Method	Acceptable limits
Penetration (25 °C, 100g, 5s) (dmm)	62	ASTM D5	**60–70**
Softening point (°C)	45.4	ASTM D36	**≥ 45**
Flash point (°C)	240	ASTM D92	**≥ 232**
Ductility (cm)	100	ASTM D113	**≥ 100**
Specific gravity	1.01	ASTM D70	**1.0 – 1.1**

TABLE 2. CHARACTERIZATION OF PHYSICAL PROPERTIES OF AGGREGATES FOR MIX DESIGN

Test	Result				Standard test Method	Acceptable limits
	Agg. #1	Agg. #2	Sand	Filler		
Bulk specific gravity	2.71	2.71	2.65	…..	ASTM C127	**2.5 – 2.75**
SSD specific gravity	2.73	2.72	2.67	…..	ASTM C128	**2.5 – 2.75**
Apparent specific gravity	2.76	2.75	2.68	2.7	ASTM D854	**2.6 – 2.8**
Water absorption (%)	1.1	1.2	1.8	…..	ASTM C127 / C128	**≤ 2% (coarse aggr.), ≤ 3% (fine aggr.)**
Los Angeles abrasion (%)	27.8	30.5	…..	…..	ASTM C131	**≤ 30–35%**

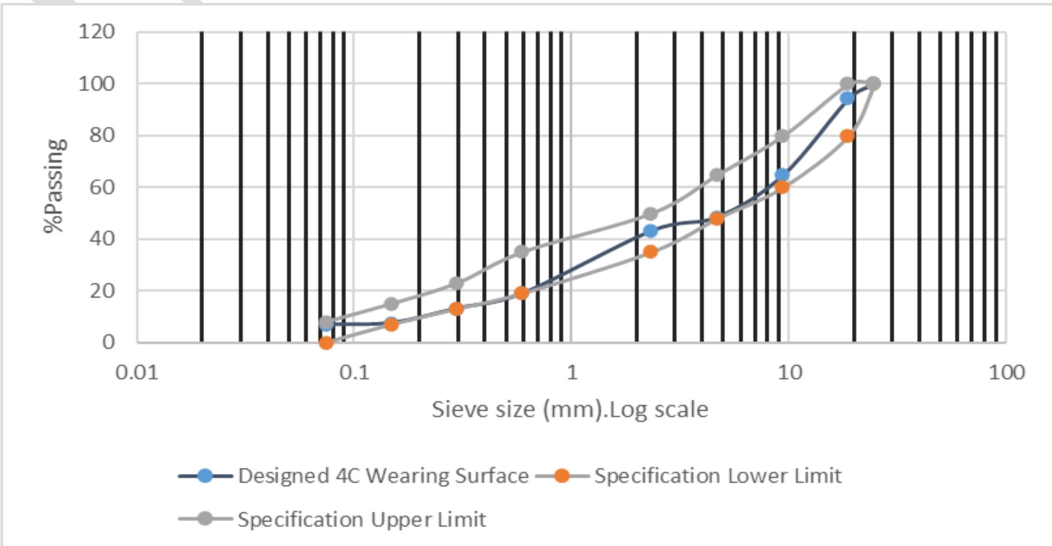


Fig. 1. Specification Limits and Combined Aggregate Gradation for 4C Wearing Surface Mix

Fig. 2. Coarse and Fine Aggregate Fractions Obtained from Sieve Analysis

3.2 Specimen preparation

To assess the influence of filler type and water exposure on the performance of asphalt mixtures, the Marshall mix design method was employed to determine the Optimum Asphalt Content (OAC) for mixtures incorporating cement dust and limestone dust as mineral fillers. A total of 30 specimens (15 for each filler type) were prepared using a Type 4C aggregate gradation with a nominal maximum aggregate size (NMAS) of 12.5 mm and a minimum void in mineral aggregate (VMA) of 14%. The AC 60/70 asphalt binder, commonly used in hot mix asphalt, was adopted, with mixing and compaction temperatures set at 150 °C and 140 °C, respectively, based on the binder's viscosity–temperature relationship in accordance with ASTM D6926. Aggregates were oven-dried and blended with five bitumen contents (4.0, 4.5, 5.0, 5.5, and 6.0%) to ensure uniform coating and proper compaction. Each specimen was compacted with 75 blows per face using a standard Marshall hammer, followed by 24-hour curing at room temperature. Conditioning was performed by immersing the specimens in freshwater and wastewater baths maintained at 25 ± 2 °C for 28 days, simulating prolonged moisture exposure in service. All testing procedures complied with the relevant ASTM standards, including ASTM D6927 for Marshall Stability and Flow, ASTM D6931 for Indirect Tensile Strength (ITS), and ASTM D2726/D2041 for bulk and maximum specific gravities. The final compacted specimens had dimensions of approximately 102 mm in diameter and 64 mm in height.

3.3 Water ponding

To assess the moisture susceptibility of asphalt mixtures, specimens were submerged in freshwater and sewage water, as shown in **Fig.3**, simulating extended exposure conditions commonly occurring on poorly drained pavements. This setup reflects real environmental scenarios where water can remain on pavement surfaces for prolonged periods due to minimal slopes, leading to full submersion of the asphalt layer. Freshwater represented typical rainfall and routine road spraying, with moderate ionic content (pH = 7.5, TDS = 200 mg/L, Cl^- = 22 mg/L), As Showen in **Table 3**. Sewage water was characterized by higher salinity and organic content (pH = 7.1, TDS = 710 mg/L, BOD = 300 mg/L, COD = 650mg/L), As shown in **Table 4** providing a more aggressive chemical environment for asphalt degradation. The immersion period was 28 days at 25 ± 2 °C, ensuring consistent laboratory conditioning while isolating the effects of water type on mixture performance. This approach enables a systematic comparison of cement dust and limestone dust fillers under controlled freshwater and sewage exposure.

Fig.3. Moisture Conditioning of Specimens Under Freshwater and Sewage Water

TABLE 3. PHYSICO-CHEMICAL CHARACTERISTICS OF FRESHWATER

The Properties of Fresh water	The value
PH	7.5
TDS	200
Temperature	25 ºC
chlorides	22
Alkalinity	120
conductivity	320
Total Hardness	140
Ca. Hard.	85
Mg. Hard.	54
Fe	0.05
Mn	0.01
Residual Chlorine	1.2
Turbidity	0.3

TABLE 4. PHYSICO-CHEMICAL CHARACTERISTICS OF SEWAGE WATER

The Properties of sewage water	The value
PH	7.1
TDS	710
TSS	350
BOD	300
COD	650
NH3	30
ON	20
TKN	40
S	6.1
P	7
O and G	60

3.4 Testing Scheme

Specimens were prepared based on the determined Optimum Asphalt Content (OAC) to evaluate mechanical performance and moisture susceptibility. A total of 30 cylindrical samples were fabricated, 15 for each filler type—cement dust and limestone dust. Samples were divided into three conditioning groups: dry, fresh water immersion, and sewage water immersion, with five specimens per group. Immersion lasted 28 days at 25 ± 2 °C to simulate prolonged environmental exposure. Fresh and sewage water represented typical field conditions with potential pavement flooding. All specimens were prepared under strict quality control, including verification of dimensions, uniform compaction, and calibration of the Marshall stability apparatus and ITS setup according to ASTM standards. Tests were conducted in triplicate, and mean values were reported. Comparative analysis was performed to assess the effectiveness of cement dust relative to limestone dust under different moisture conditions.

3.4.1 Marshall testing

The mechanical performance of asphalt mixtures containing cement dust and limestone dust was evaluated using the Marshall testing apparatus, specifically measuring Marshall Stability (kg) and Flow (mm). The Marshall Quotient (MQ), defined as the ratio of stability to flow, was calculated for each specimen to assess mixture stiffness and quantify strength loss due to prolonged water exposure. Testing was conducted following the standard Marshall method [34]. Prior to testing, compacted specimens were conditioned in a 60 °C water bath for 30 minutes. Each specimen was then positioned on the Marshall breaking head, and a load was applied at a constant rate of 50 mm/min according to ASTM D6927. Stability and flow values were recorded using a calibrated flow meter, and wet specimens were carefully surface-dried to ensure consistent handling. The MQ was subsequently determined to provide an indicator of resistance to plastic deformation and overall structural integrity under loading. Although 28-day immersion followed by 60 °C conditioning may induce partial water desorption, this procedure was intentionally employed to align with ASTM D6927 standards and enable meaningful comparison with prior research.

3.4.2 Indirect tensile strength test (ITS)

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. 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 D6927) 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.

$$\textbf{ITS} = \frac{2P}{\pi HD} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(1)}$$

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

Where,

P= failure load, Kg

H= thickness of the sample, mm

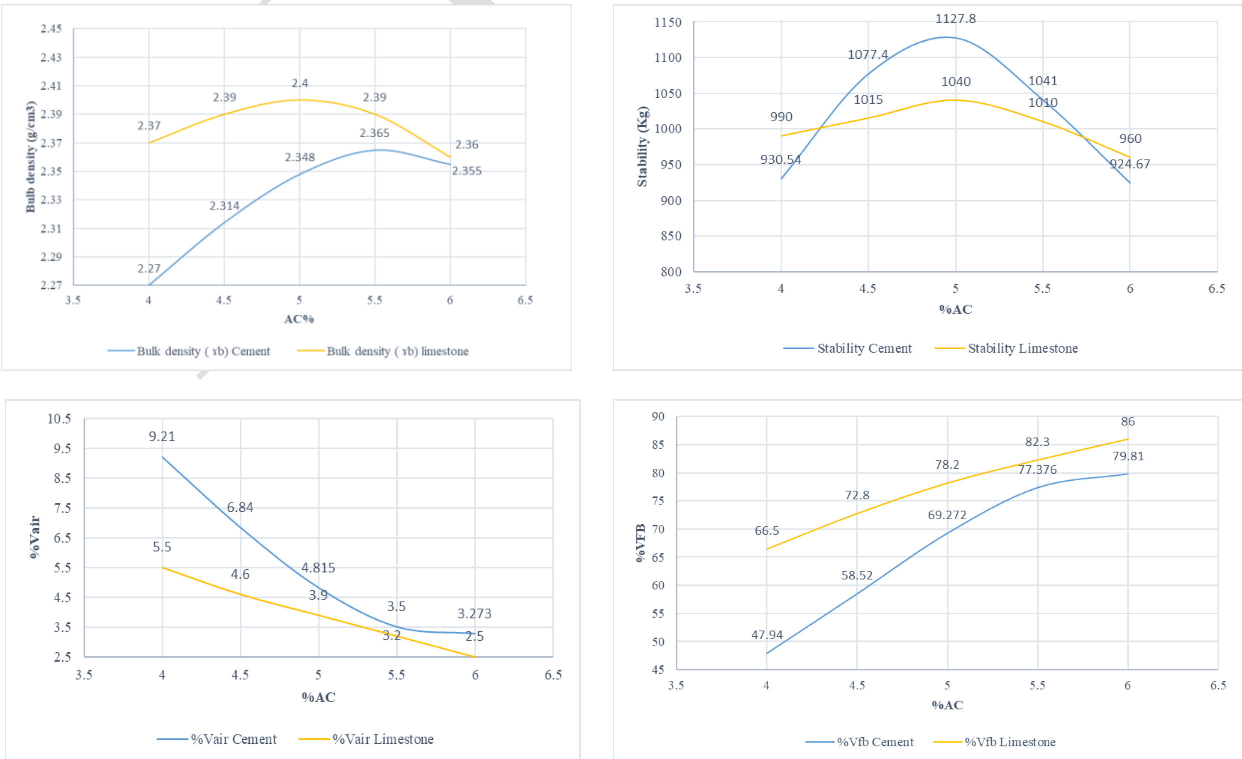
D= diameter of the sample, mm

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. THE OPTIMUM ASPHALT CONTENT (OAC)

The Marshall mix design method was implemented to establish the Optimum Asphalt Content (OAC) for two asphalt mixtures incorporating cement dust and limestone dust as mineral fillers. A total of 30 specimens were fabricated, with 15 specimens allocated for each filler type. Five binder contents, increasing in 0.5% increments, were selected for initial evaluation, and three specimens were prepared and tested for each content. The Marshall Stability, flow, bulk density, and air voids were measured in accordance with ASTM D1559, and the OAC was identified as the binder content corresponding to the maximum stability while satisfying acceptable limits for volumetric properties, as illustrated in **fig. 4.** The mixture containing cement dust required a slightly higher OAC than that with limestone dust, which can be attributed to the finer particle size and higher surface activity of cement dust. These properties enhance binder absorption, necessitating additional asphalt to achieve sufficient coating and optimal mechanical performance. The determined OAC values were 5.2% for the cement dust mixture and 4.9% for the limestone dust mixture



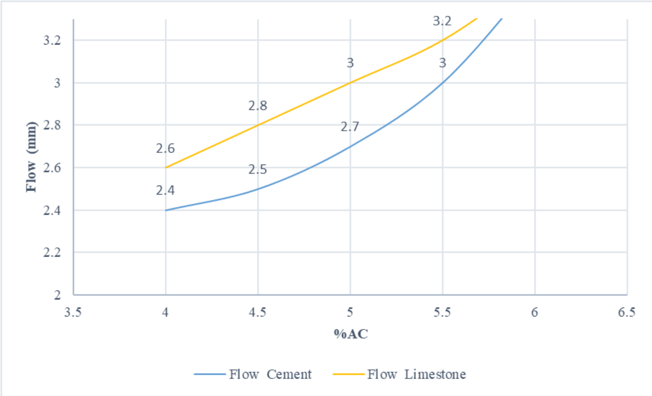


Fig. 4. Optimum Asphalt Content (OAC) for the Designed Asphalt Mixture

5. RESULTS AND DISCUSSION

5.1 Marshal test

5.1.1 Stability

The Marshall Stability of asphalt mixtures containing cement dust and limestone dust was evaluated after a 28-day immersion period in freshwater and sewage water. The cement dust mixture exhibited higher stability than the limestone dust mixture in all conditions, as shown in **fig.5**. Specifically, in the dry state, the cement dust mixture recorded a stability of 1102 kg, which is approximately 9.3% higher than the limestone dust mixture (1008 kg). Under freshwater immersion, the cement dust mixture achieved 800 kg, representing a 10.6% increase compared to the limestone dust mixture (723.4 kg). Similarly, after sewage water immersion, the stability of the cement dust mixture was 712 kg, about 7.4% higher than that of the limestone dust mixture (663.2 kg). These results indicate that cement dust enhances the mechanical performance and moisture resistance of asphalt mixtures relative to traditional limestone filler. The improved performance can be attributed to the alkaline and hydraulic nature of cement dust, which promotes stronger adhesion between the asphalt binder and aggregates, reducing moisture-induced stripping. In contrast, limestone dust exhibits lower chemical reactivity and weaker binder interaction, making the mixture more susceptible to water-related weakening. The observed greater reduction in stability under sewage water, compared to freshwater, highlights the aggressive chemical environment of sewage, including sulfates, chlorides, and organic compounds, which accelerates binder degradation. Overall, the cement dust mixture demonstrates superior durability and retained strength under both freshwater and sewage exposure.

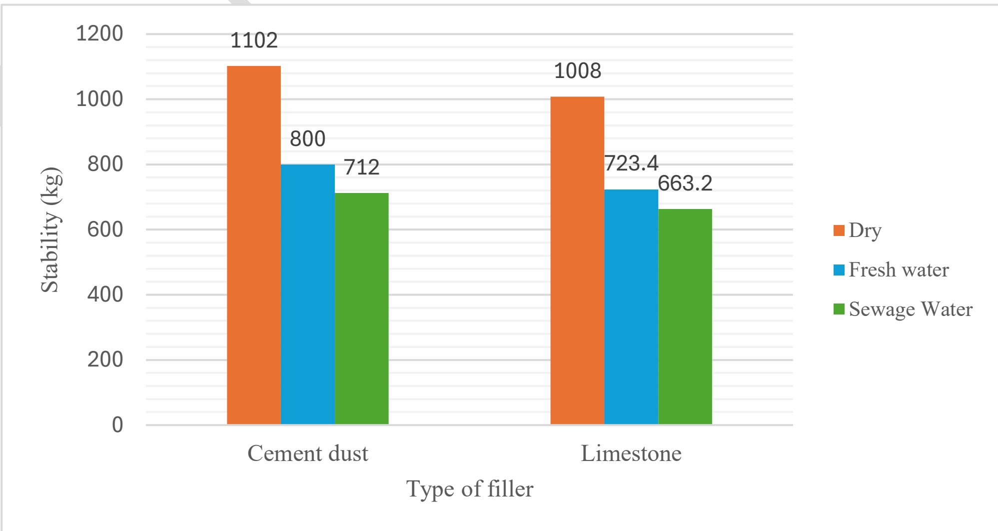


Fig. 5. Marshall Stability of Asphalt Mixtures Containing Different Fillers

5.1.2 Flow

Flow represents the maximum deformation an asphalt mixture undergoes at the point of failure under load. The measured flow values for mixtures containing cement dust and limestone dust are presented **in Fig. 6**. The cement dust mixture consistently exhibited lower flow values compared to the limestone dust mixture, indicating higher stiffness and better resistance to deformation. Specifically, in the dry state, the cement dust mixture recorded a flow of 3.2 mm, approximately 13.5% lower than the limestone dust mixture (3.7 mm). Under freshwater immersion, the cement dust mixture showed 5.53 mm, about 21.6% lower than the limestone dust mixture (7.05 mm). Similarly, after sewage water immersion, the flow of the cement dust mixture was 8.78 mm, representing an 11.5% reduction compared to the limestone dust mixture (9.92 mm). These results are consistent with the stability trends, demonstrating that cement dust enhances mixture stiffness and reduces deformation under both dry and wet conditions. The lower flow values can be attributed to the adhesive and stiffening properties of cement dust, which improve binder–aggregate cohesion and limit plastic deformation. Conversely, limestone dust, with lower surface activity and weaker chemical interaction with bitumen, exhibited higher flow, indicating greater deformability. The pronounced increase in flow after sewage water exposure reflects the aggressive effect of chemical constituents, such as sulfates, chlorides, and organic acids, which interact with the binder, soften it, and weaken the internal structure of the mixture. Overall, the cement dust mixtures displayed superior resistance to deformation under both freshwater and sewage exposure compared to the limestone dust mixtures.

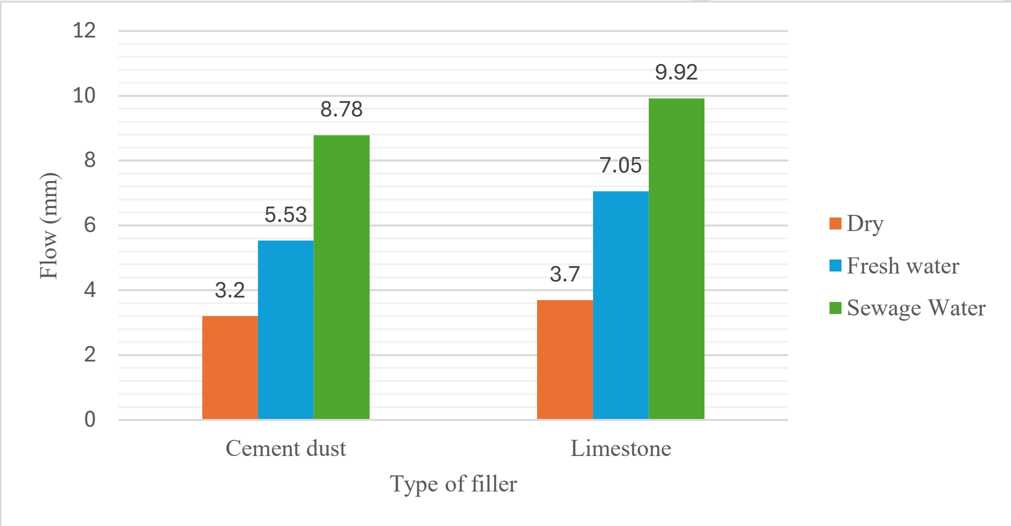


Fig. 6. Flow Values of Asphalt Mixtures Containing Different Fillers

5.2 Indirect tensile strength test (ITS)

5.2.1 The indirect tensile strength (ITS)

As shown in Fig. 7, asphalt mixtures incorporating cement dust exhibited the highest Indirect Tensile Strength (ITS) values under both dry and wet conditions, indicating enhanced cohesion and improved binder–aggregate bonding within the asphalt matrix. The cement dust mixture recorded ITS values of 1621 kPa in the dry state, 1411 kPa under freshwater immersion, and 1150 kPa under sewage water immersion. In comparison, the limestone dust mixture showed lower ITS values of 1490 kPa, 1205 kPa, and 1015 kPa under the same conditions. Consequently, the cement dust mixture outperformed the limestone dust mixture by approximately 8.8% in the dry state, 17.0% under freshwater, and 13.3% under sewage water. The reduction in ITS due to water exposure was 13.0% and 29.1% for the cement dust mixture under freshwater and sewage water, respectively, whereas the limestone dust mixture experienced reductions of 19.1% and 31.9% under the same conditions. These results indicate that cement dust enhances resistance to moisture-induced damage, maintaining higher tensile strength compared to conventional limestone dust. The improved performance can be attributed to the fine particle size, alkaline nature, and hydraulic properties of cement dust, which increase mastic stiffness and strengthen binder–aggregate adhesion. In contrast, limestone dust, with lower surface reactivity, exhibited greater ITS losses due to weaker chemical interaction with the binder and higher susceptibility to moisture damage. Overall, the ITS results confirm that cement dust is more effective in preserving tensile strength under both freshwater and sewage exposure, highlighting its potential as a sustainable alternative filler in asphalt mixtures subjected to moisture-prone environments.

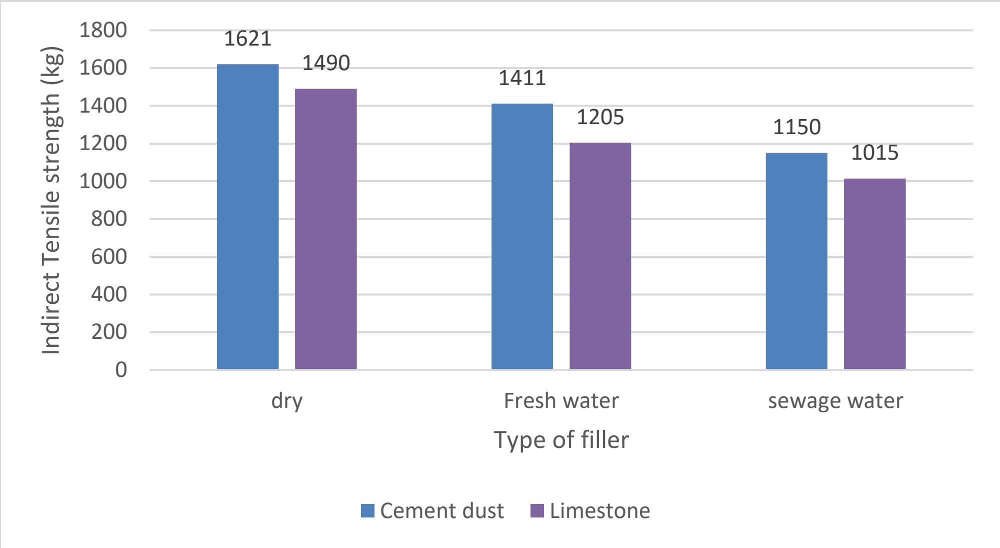


Fig. 7. Indirect Tensile Strength (ITS) of Asphalt Mixtures Containing Different Fillers

5.2.2 Tensile Strength Ratio (TSR%)

As shown in Fig. 8, presents the Tensile Strength Ratios (TSR) of asphalt mixtures incorporating cement dust and limestone dust as fillers. The cement dust mixtures demonstrated superior TSR values, recording 87.0% under freshwater immersion and 70.9% under sewage water immersion, compared to the limestone dust mixtures, which exhibited TSR values of 80.9% and 68.1%, respectively. These results indicate that cement dust enhances moisture resistance and durability, outperforming conventional limestone dust by approximately 6.1% under freshwater and 2.8% under sewage exposure. The higher TSR values observed for cement dust mixtures can be attributed to the fine particle size and alkaline nature of the cement, which improve binder–aggregate adhesion and increase the stiffness of the mastic phase. Consequently, these mixtures are more effective at retaining tensile strength under wet conditions, reducing the risk of stripping and moisture-induced deterioration. In contrast, limestone dust, being less reactive and more inert, contributes less to mastic cohesion, resulting in lower TSR values. Although the immersion period was limited to 28 days to capture the initial phase of moisture damage, the findings clearly indicate the superior performance of cement dust as a sustainable alternative filler. Future studies should consider extended conditioning periods and aging simulations to further assess long-term durability under field-representative environmental conditions.

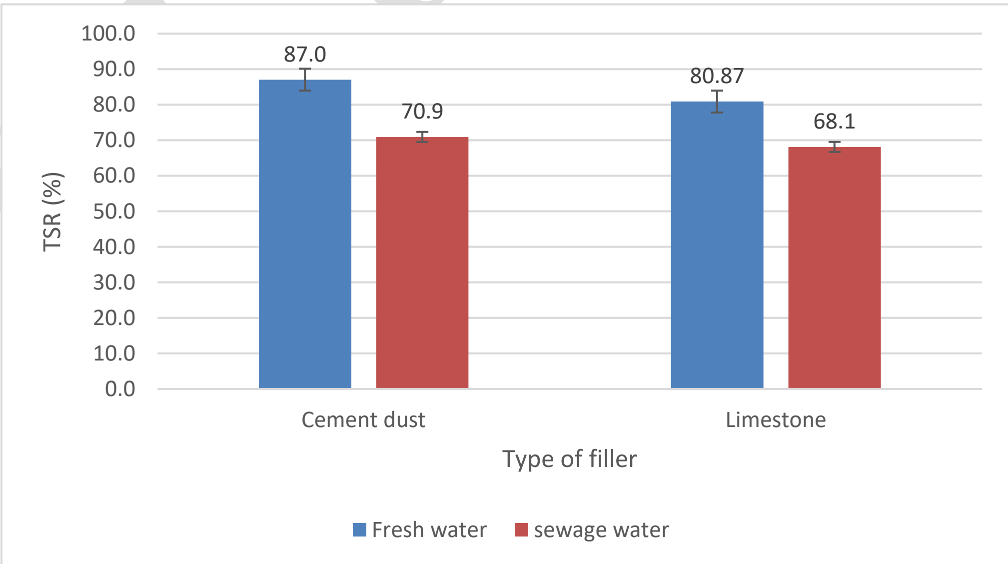


Fig. 8. Tensile Strength Ratio (TSR%) of Asphalt Mixtures Containing Different Fillers

6. CONCLUSION

This study investigated the effects of freshwater and sewage water exposure on the mechanical performance of asphalt mixtures incorporating cement dust and limestone dust as mineral fillers. The key findings are 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 limestone dust. Specifically, cement dust mixtures showed Marshall Stability of 1102 kg (dry), 800 kg (freshwater), and 712 kg (sewage), corresponding to reductions of 27.5% under sewage exposure, whereas limestone dust mixtures recorded 1008 kg (dry), 723.4 kg (freshwater), and 663.2 kg (sewage), highlighting the superior stability of cement-filled mixtures by 9.5%, 10.6%, and 7.3% under dry, freshwater, and sewage conditions, respectively.
2. Flow measurements demonstrated that cement dust mixtures exhibited lower deformation under load compared to limestone dust, confirming higher stiffness and improved resistance to plastic deformation. The flow values for cement dust were 3.2 mm (dry), 5.53 mm (freshwater), and 8.78 mm (sewage), whereas limestone dust mixtures recorded higher flows of 3.7 mm, 7.05 mm, and 9.92 mm, respectively. These results indicate that cement dust enhances resistance to moisture-induced softening and deformation.
3. Indirect Tensile Strength (ITS) tests further confirmed the enhanced performance of cement dust mixtures. Cement dust mixtures maintained ITS values of 1621 kPa (dry), 1411 kPa (freshwater), and 1150 kPa (sewage), whereas limestone dust mixtures exhibited 1490 kPa, 1205 kPa, and 1015 kPa, respectively. This corresponds to reductions of 13.1% and 27.1% for cement dust under freshwater and sewage, compared to 19.1% and 31.9% for limestone dust, demonstrating the improved tensile performance and moisture resistance of cement-filled mixtures.
4. Tensile Strength Ratio (TSR) results corroborated these findings, with cement dust mixtures achieving 87.0% (freshwater) and 70.9% (sewage), outperforming limestone dust mixtures, which reached 80.9% and 68.1%, respectively. This indicates that cement dust enhances binder–aggregate adhesion and mitigates moisture-induced deterioration more effectively than conventional limestone filler.
5. Implications and future research: The promising performance of cement dust as a sustainable filler highlights its potential to improve the durability of asphalt pavements exposed to moisture. Future work should focus on (i) extended conditioning periods and freeze–thaw cycles to simulate long-term environmental effects, (ii) Hamburg wheel-tracking tests under water to evaluate rutting resistance, (iii) aging assessment using RTFO and PAV procedures, (iv) microstructural analysis of asphalt mastic with SEM/XRD, and (v) optimization of cement dust content to balance mechanical performance and cost-effectiveness.

Overall, the study confirms that cement dust is an effective alternative to limestone dust, offering superior stability, stiffness, tensile strength, and moisture resistance, making it a promising sustainable filler for asphalt mixtures exposed to water-related deterioration.

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