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Investigating the Influence of Rigden Void of Fillers on the Moisture Damage of Asphalt Mixtures

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Abstract

Moisture damage and bond loss are major factors in pavement degradation, often stemming from excessive moisture accumulation due to weather events. Water infiltrates the gap between asphalt binder and aggregate, weakening the asphalt bond. Rigden Void (RV) has emerged as a crucial parameter in assessing the susceptibility of asphalt mastic-aggregate systems to moisture-induced damage. However, numerous waste natural fillers have been researched as potential aggregate filler replacements, yet their role in moisture damage remains unexplored. Therefore, this study aimed to understand how different fillers, including waste natural materials like coconut peat and bagasse, affect asphalt mixture performance and moisture damage. Results showed that Rigden Voids were positively correlated with pore size and negatively correlated with surface area. Larger pores contributed to higher Rigden Voids, while greater surface areas led to lower values. Limestone had the highest Rigden Void percentage due to its larger pore size and lower surface area. The research also explored contact parameters between fillers and asphalt, revealing varying interactions based on filler and asphalt types. Moisture damage testing demonstrated that all mixtures, both dense and porous, displayed good resistance to moisture damage. The correlation analysis between Rigden Voids and moisture damage revealed varying degrees of influence, dependent on asphalt type and aggregate gradation.

Keywords: Rigden Void; Moisture Damage; Fillers; Image Processing; Analysis System.

1. Introduction

Moisture damage and bond loss have been significant contributing factors to the degradation of pavement infrastructure. The degradation was primarily attributed to the excessive accumulation of moisture, typically resulting from precipitation or flooding events, which was identified as the primary cause of pavement damage. Within the pavement structure, water infiltrated the gap between the asphalt binder and aggregate, leading to the degradation of the asphalt bond. A previous investigation conducted by Cheng et al. (2002) examined the phenomenon of adhesion loss between the surfaces of asphalt and aggregate, providing evidence of the predictability of strength reduction under such conditions [1]. This investigation included comparative analyses between the bond strength in the absence of moisture and the bond strength when subjected to moisture between the asphalt and aggregate interfaces. Furthermore, a study by Chaturabong & Bahia (2016) suggested that the Binder Bond Strength (BBS) test served as a valuable tool for evaluating mastic cohesion loss mechanisms [2]. This study emphasized the significant influence of aggregates and dust on the susceptibility of asphalt mixtures to damage induced by moisture.

The Rigden Void (RV) concept was instrumental in investigating the filling characteristics and flow behavior of fillers or dust, facilitating the quantification of the void fraction in dry compacted fillers. Anderson's modified Rigden

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approach, as outlined by Harris & Stuart (1995) [3], robustly established a correlation between the void fraction during dry compaction and the hardening effect of the filler on asphalt. Notably, this approach emerged as the sole independent parameter capable of effectively distinguishing suitable fillers from unsuitable ones. Furthermore, Romeo et al. (2016) validated the utility of Rigden Void as an indicator of asphalt hardening filler [4]. Their study highlighted those fillers with larger Rigden Void values exhibited an enhanced capacity for absorbing and dispersing independent asphalt, consequently improving the frictional characteristics of the filler particles, as documented by Zhang et al. (2019) [5]. Additionally, it is noteworthy that Rigden Voids were identified as a critical factor in the susceptibility of moisture-induced damage within asphalt mastic-aggregate systems [6].

Rigden (1947) introduced the measurement of fractional voids, commonly known as the "Rigden Voids test" [7-9]. Rigden's approach involved distinguishing fixed asphalt, which fills the voids in the dry compacted sample, from excess asphalt, termed free asphalt [7]. He proposed that the percentage of free asphalt is the primary factor determining the consistency of filled systems and observed that changes in viscosity are independent of asphalt properties or any filler characteristics, except for fractional voids. The addition of fillers, irrespective of their intrinsic properties, is recognized to enhance the stiffness of asphalt. DeSmedt pioneered the intentional use of fillers to replicate rock asphalt in Washington, D.C., during the 1870s [10]. Subsequent studies revealed that filler gradation influences the extent of mastic stiffening [11–13]. The concept of free asphalt emerged as a comprehensive explanation for the stiffening effect of fillers in asphalt [14]. Several investigations concluded that the geometric attributes of fillers, including size, shape, angularity, and texture, affect Rigden Voids. Therefore, fractional voids serve as a valuable indicator of the interactive impact of these characteristics on binder stiffening [15–28].

Faheem et al. (2012) demonstrated that filler fractional voids exert an influence on mastic viscosity and nonrecoverable compliance, with strong correlations observed between these mastic properties and measures of mixture performance [29]. The Rigden Void of aggregate is influenced by several factors, including aggregate particle size, shape, and distribution; filler type and quantity; and asphalt binder viscosity. Determining Rigden Void requires the compaction of a mixture sample under controlled conditions, followed by various tests to measure its density, porosity, and permeability. These tests play a crucial role in ensuring that the mixture meets the required specifications and performs as expected in the field. Currently, research has been focused on analyzing the physical characteristics of recycled fillers, with studies identifying significant differences between fillers. Rigden Voids (RV) have been found to exert the most significant potential influence on the rheology of asphalt concretes [30, 31]. Therefore, the RV value was considered a measure of the stiffness of the filler-asphalt mix [30, 32]. Moreover, it has been observed that fillers with high Rigden Voids result in a stiff mix [33].

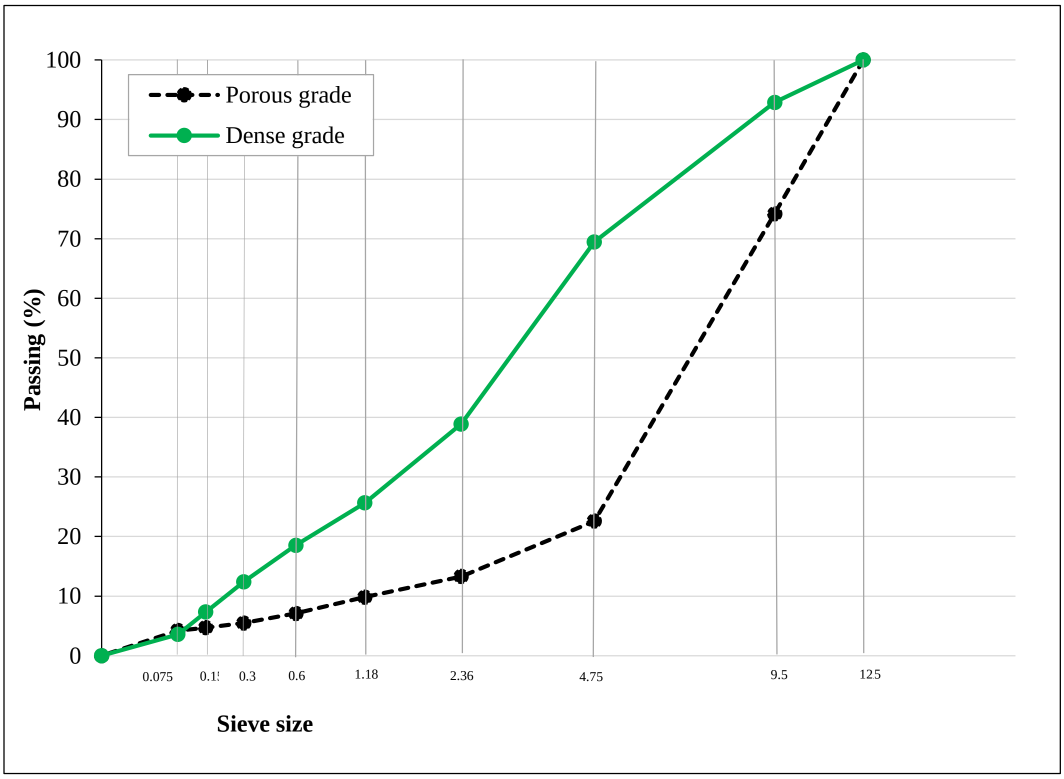
The extensive surface area of the mineral filler fraction in comparison to the coarser aggregates within the mixtures underscores the potential significance of physio-chemical interactions between the asphalt binder and fillers, making it a crucial parameter influencing mixture performance. The utilization of asphalt fillers in asphalt mixtures dates back to the 1870s [34]. Subsequent researchers delved into the use of asphalt mastic stiffening fillers, recognizing them as pivotal elements [35–37]. The attributes of these fillers, encompassing aspects such as filler shape, size, size distribution, surface texture, adsorption intensity, and chemical composition, are critical determinants of long-term asphalt mixture performance [38–41]. Additionally, several empirical studies have demonstrated that Rigden Voids exert an influence on the geometric characteristics of the filler.

Contemporary asphalt research increasingly incorporates waste natural materials, such as coconut peat and bagasse. Notably, some researchers have found that substituting asphalt with bagasse ash can enhance the stability of Hot Mix Asphalt (HMA) in Marshall specimens [4, 5, 42]. Recently, bagasse and coconut peat fillers were employed to assess workability and measure pull-off tensile strength [43]. Nevertheless, there is a notable gap in our understanding of how the physical properties of these waste natural fillers influence the performance of asphalt mixtures. Hence, this study seeks to compare the properties of fillers, which encompass both aggregates and waste natural materials, to ascertain their impact on moisture damage.

While numerous studies have explored the influence of Rigden Voids on the performance of asphalt mixtures, there remains a significant research void concerning the effect of Rigden Voids on moisture damage. Given this research gap, the primary aim of this study is to investigate the relationship between Rigden Voids and susceptibility to moisture-induced damage in asphalt mixtures used in pavements.

2. Material and Methods

In the material and methodology section, the study focused on two commonly used mix designs in road construction, which were dense and porous mixes. The air void content for the dense mix was kept at 4%, while the porous mix was designed to have an air void content of 20%. The aggregate gradation, as depicted in Figure 1, featured aggregate limestone from Chonburi as the chosen aggregate material for all mixtures.



This research utilized four dive
content constituting 20% by volume
of this specific filler content in prev
granite, bagasse, and coconut peat, which were sourced from local quarries and fields in Thailand. Table 1 shows that the densities of the natural fillers, bagasse, and coconut peat, were significantly lower than that of the mineral fillers, limestone, and granite. The low densities of natural fillers suggest that less of these fillers would be required by weight in asphalt mixture compared to mineral fillers.

Table 1. Type of filler using in this study

Factor	Filler Type	Density (g/cm^3)
Mineral Filler	Limestone	2.62
	Granite	2.58
Waste natural fillers	Bagasse	0.38
	Coconut peat	0.29

To obtain the natural fillers, the bagasse and coconut peat were ground using a grinding machine and sieved with a 200-mesh sieve. The aggregate used in the mixture was limestone, and its gradation was based on Superpave specifications for large traffic volumes. The filler-to-asphalt ratio (F/A) is usually dependent on the density of the mineral filler, ranging from 0.6 to 1.6. However, in the case of natural fillers, the F/A ratio is expected to be lower due to their lower densities. The asphalt mastic viscosity was determined to identify the optimum content and impact of waste natural fillers with asphalt.

To determine the optimum asphalt content of the blends, the first series of asphalt specimens with specific asphalt content was used. The optimum asphalt content was selected based on the design criteria set by the Department of Highways (DOH). The second series, with an optimum asphalt content, was developed to determine the mechanical efficiency of the respective mixtures for each filler. According to ASTM D6926, the aggregates were heated overnight at 100 °C, and the mixture samples were heated at 150 °C for 2 hours to ensure a constant temperature. The specimens were then compacted with a diameter of 101.6 mm and a height of 65-75 mm, and volumetric measurements were taken after a 24-hour curing time.

2.1. Indirect Tensile Strength Test

The evaluation of moisture damage in asphalt concrete was carried out through the commonly used Indirect Tensile Strength (ITS) test in accordance with the American Association of State Highway and Transportation Officials

(AASHTO) T283 specification. The testing procedure involved two conditions: dry and wet. Under the dry condition, specimens were prepared at room temperature and tested without moisture conditioning. Conversely, the wet condition required specimens to be prepared in a water bath at 60±1 °C for 24 hours, followed by immersion in a water bath at room temperature for an additional 2 hours before testing. During the test, specimens underwent a constant rate of loading, and the force needed to fracture them was measured. The degree of moisture damage was assessed by calculating the tensile strength ratio (TSR), which compared the average tensile strength of moist specimens to that of dry specimens.

The testing procedure for the ITS test was based on the AASHTO T283 specification, which evaluated the resistance of compacted bituminous mixtures to moisture-induced damage. It involved subjecting specimens to a loading rate of 50 mm/min and calculating the maximum tensile strength value using a geometric factor, as shown in Equation 1. The ITS test was a reliable method for assessing moisture damage in asphalt mixtures, providing insights into tensile strength and the extent of damage caused by moisture. The results of this test were instrumental in optimizing asphalt mixture design and selecting materials that could effectively resist moisture-induced damage.

$$S_t = \frac{2000P}{\Pi t D} \tag{1}$$

where St is IDT strength (kPa), P is maximum load (N), t is specimen height immediately before test (mm.) and D is specimen diameter (mm.)

The moisture sensitivity of the asphalt mixture was assessed by subjecting specimens to two distinct conditions. In the first scenario, dry specimens were prepared by allowing them to cure at room temperature for 24 hours and then testing them without moisture conditioning. In the second scenario, wet specimens were created by immersing them in a water bath maintained at 60 ± 1 °C for 24 hours, followed by an additional 2 hours at room temperature. The moisture sensitivity of the asphalt mixture was determined using the Indirect Tensile Strength (ITS) test method in accordance with the Superpave system. An ITS tester was utilized for the testing, and the tensile strength was measured for samples subjected to both dry and wet conditions.

The assessment of moisture resistance was conducted by calculating the tensile strength ratio (TSR) through the application of Equation 2. The TSR served as an indicator of the asphalt mixture's susceptibility to moisture damage, where a lower TSR value signified a higher vulnerability to moisture-induced damage. The Superpave system recommended a minimum TSR value of 80% for asphalt mixtures to ensure adequate moisture resistance. The moisture resistance of the asphalt mixture was evaluated based on the ITS results obtained from both dry and wet conditions.

$$\text{TSR (\%)} = \frac{S2}{S1} \times 100 \tag{2}$$

where $S1$ is Average tensile strength of the dry subset (kPa); and $S2$ is Average tensile strength of the saturated subset (kPa).

2.2. Image Processing & Analysis System (IPAS)

Sefidmazgi et al. (2012) developed specialized analysis software featuring additional indices designed for the quantification of internal aggregate structure [45]. These internal aggregate structure indices were believed to play a pivotal role in determining the rutting resistance of asphalt mixtures. Among these indices, one particularly relevant to rutting resistance was the total proximity zone length (TPL), representing the number of contact lengths that reflect the degree of interlock within the asphalt mixture. An increase in TPL signified a corresponding increase in aggregate interlock. Laboratory tests, coupled with the utilization of the IPAS2 image processing and analysis software, which is widely employed for aggregate skeleton analysis, provided a valuable approach for investigating the distribution of fillers within asphalt concrete and the overall aggregate framework. A recent research endeavour aimed to uncover the relationship between permeability and aggregate contact length, as well as contact number, using the IPAS2 method. The results of this study revealed a substantial impact of both contact number and contact length within the aggregate skeleton on the permeability of the asphalt mixtures [46]. This research contributed to a comprehensive understanding of the aggregate skeleton within asphalt concrete and its interactions with fillers.

The system functioned by capturing the respective color intensities at each individual pixel. To begin the analysis, the image was initially converted into grayscale, allowing for the differentiation between the aggregate phase and the mastic and voids phase. Subsequently, this grayscale image was processed into a binary format, a crucial step for microstructure analysis accomplished by selecting an appropriate threshold value. The system further employed a series of image filtering techniques to enhance image quality and effectively separate the different material phases present. To ensure accurate analysis, the software required input data pertaining to the actual aggregate gradation, which was then compared to the gradation extracted from the image. Additionally, volumetric data, including the percentage of air voids, asphalt binder content, and the specific gravities of both the aggregate and asphalt binder, were essential for the analysis. These data were integrated to perform fundamental calculations based on volumetric relationships, resulting in the determination of a volumetric percentage of aggregates (Psv). The two-dimensional (2D) planar percentage of the aggregate area was subsequently estimated using the Psv value. These calculations played a pivotal role in confirming the selection of appropriate filter parameters for the identification of aggregate boundaries [46].

2.3. Rigden Voids

The Rigden Voids Test, conducted in accordance with the EN 1097-4 standard of European Norms, serves as a technique for evaluating the void volume within dry-compacted mineral fillers. This testing method operates under the fundamental premise that the densest possible packing, achieving the maximum bulk density of fines, can be attained by compacting dry fines within a mold. The bulk density of these compacted fines is formally defined as the dry weight of the fines divided by the bulk volume of the compacted fines. The bulk volume encompasses the combined measure of the solid volume occupied by the fine particles and the volume of the voids situated between these particles. These voids can be precisely determined using Equation 3.

$$V = \left(\frac{4\times10^3\times m2}{\pi\times\alpha^2\times pf\times h}\right)\times 100 \tag{3}$$

where, v is the voids in percent, m^2 is the mass of the compacted filler in grams, α is the inner diameter of the dropping block cylinder in millimeters, pf is the particle density of the filler in mega grams per cubic meter, and h is the height of the compressed filler in millimeters.

3. Results

3.1. Rigden Voids

The Rigden Voids test was conducted in accordance with the BS EN1097-4:2008 standard to assess the influence of fillers on the moisture damage resistance of asphalt concrete and to investigate the properties of each filler type. Figure 2 presents the Rigden Voids values obtained from three replicates of fillers with different densities. The Rigden Voids percent was found to be 23.35%, 30.24%, 9.51% and 6.03% for granite, limestone, bagasse, and coconut fillers, respectively. These results demonstrate that limestone filler has the highest Rigden Voids percent, while bagasse filler has the lowest. Additionally, the density of the filler as shown in Table 1 was directly proportional to the Rigden Voids, indicating that higher filler density results in increased Rigden Voids.

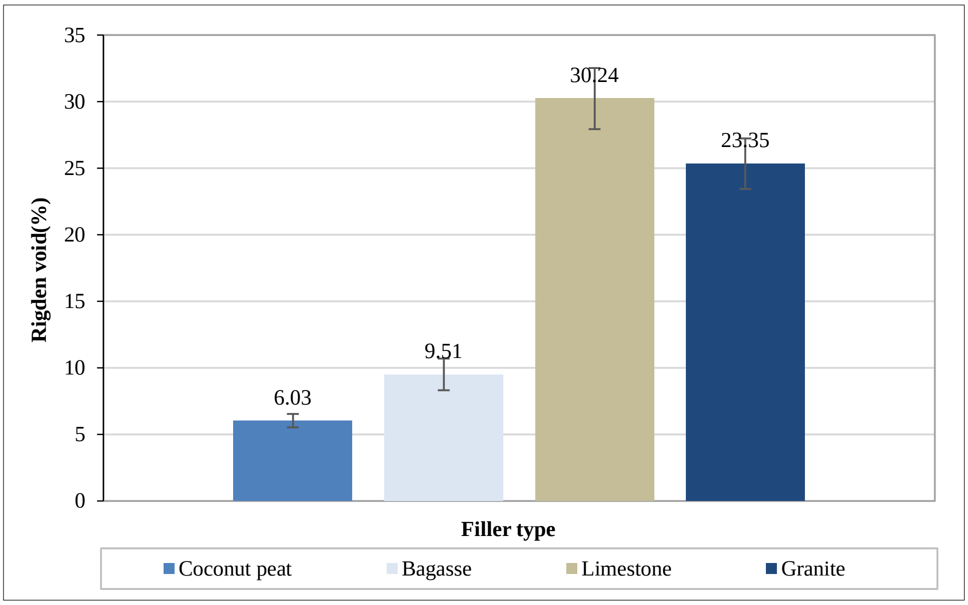


Figure 2. the percent of Rigden Voids in a dry-compacted filler

3.2. Relationship between the Percent of Rigden Voids in a Dry-compacted Fillers and BET

BET (Brunauer-Emmett-Teller) is a test method used to analyze the surface area, size, distribution, and volume of pores with a diameter between 2-50 nm (mesopores) and a diameter less than 2 nm (micropores). The method works by providing samples with absorption or spitting gas or emitting gas to analyze pore diameter. The surface area of the sample powder is based on the principle of Volumetric Gas Adsorption Method using non-corrosive gases such as N_2, Ar_2, CO_2, H_2. Up to three samples can be analyzed simultaneously and independently of each other, which increases the accuracy of the analysis. The analysis method used is AFSM, which provides high accuracy and reproducibility.

The table presented in this section displays the results of the BET analysis carried out on four distinct types of fillers: Coconut, Bagasse, Limestone, and Granite. The BET analysis procedure was utilized to gather data concerning the pore size and surface area of these fillers. The findings reveal that the Coconut filler exhibited a pore size of 3.93 nm and a surface area of 3.56 m^2/g, the Bagasse filler displayed a pore size of 4.28 nm and a surface area of 5.13 m^2/g, the Limestone filler showcased a pore size of 4.68 nm and a surface area of 3.65 m^2/g, while the Granite filler demonstrated a pore size of 4.52 nm and a 4.73 m^2/g surface area. These outcomes indicate that the Bagasse filler possesses the highest surface area, followed by the Granite filler, Coconut filler, and Limestone filler. It is noteworthy that the pore sizes of these four fillers fall within a similar range, with the Bagasse filler having the smallest pore size and the Limestone filler having the largest.

The study aimed to explore the connections between the pore size and surface area of mineral fillers and the percentage of void in asphalt concrete. An examination of the data in Table 2 and Figure 2 reveals a substantial correlation between Rigden Void and the physical attributes of the fillers. Specifically, a positive relationship is evident between the Rigden Void percentage and the pore size of the filler, indicating that an increase in pore size corresponds to a higher Rigden Void percentage. Furthermore, the results also illustrate an inverse relationship between Rigden Void and the surface area of the filler, suggesting that a higher surface area results in a lower percentage of Rigden Void. Among the four filler types under investigation, limestone exhibited the highest Rigden Void percentage (30.24%), which can be attributed to its relatively larger pore size and lower surface area when compared to the other two fillers, coconut and bagasse.

Table 2. The BET analysis conducted on four different types of fillers

Type of filler	Pore size (nm)	Surface area (m^2/g)
Coconut	3.93	3.56
Bagasse	4.28	5.13
Limestone	4.68	3.65
Granite	4.52	4.73

3.3. Relationship between the Percent of Rigden Voids in a Dry-compacted Fillers and Aggregate Contacts

The Image Processing & Analysis System (IPAS) utilized in this study provided a detailed representation of color intensity at each individual pixel. The images captured were initially converted into grayscale to facilitate the differentiation between the aggregate phase, mastic, and voids phase. Subsequently, the grayscale images were transformed into binary images through the selection of an appropriate threshold value. To improve the image quality and enable the separation of various material phases, several image filtering techniques were employed. To assess the performance of different fillers, namely coconut, bagasse, granite, and limestone, three types of asphalt binder, namely AC60/70 and AC60/70+Carbon Black (CB) in dense grades, and Polymer Modified Asphalt (PMA) in open grades, were tested. The filler content in the asphalt mixtures was maintained at 20% of the total asphalt content. Through these experimental procedures, valuable test results were obtained, enabling a comprehensive analysis of the impact of different fillers and asphalt binder types on the asphalt mixture's properties and performance.

The results of the comparative assessment of asphalt-filler contact characteristics are presented in Table 3. The contact number and contact length were evaluated for three different types of asphalt, namely AC60/70, CB, and PMA, when combined with four distinct fillers, namely coconut peat, bagasse, limestone, and granite.

Table 3. Contact Parameters of Different Fillers in AC60/70, CB, and PMA Asphalt Mixtures

Type of Asphalt	AC60/70		CB		PMA	
Filler	Contact No.	Contact length	Contact No.	Contact length	Contact No.	Contact length
Coconut peat	39,746	27,807	21,084	11,320	15,045	11,583
Bagasse	32,462	19,587	19,856	10,056	10,995	8,471
Limestone	34,585	22,752	16,597	7,224	11,610	7,095
Granite	34,663	21,678	17,345	8,564	11,102	7,321

Among the fillers tested, coconut peat exhibited the highest contact number with AC60/70 asphalt, recording a value of 39,746. In contrast, bagasse demonstrated the lowest contact number with AC60/70 asphalt, registering 32,462 contacts. The contact numbers for CB-modified asphalt were relatively lower, with the highest value observed for coconut peat (21,084 contacts) and the lowest value for limestone (16,597 contacts). Similarly, for PMA-modified asphalt, coconut peat exhibited the highest contact number (15,045 contacts), while bagasse again showed the lowest contact number (10,995 contacts).

Regarding the contact length, coconut peat also displayed the longest contact length with AC60/70 asphalt, measuring 27,807 units. Conversely, bagasse exhibited the shortest contact length with AC60/70 asphalt, measuring 19,587 units. For CB-modified asphalt, coconut peat yielded the longest contact length (11,320 units), while limestone had the shortest contact length (7,224 units). In the case of PMA-modified asphalt, coconut peat had the highest contact length (11,583 units), and bagasse exhibited the lowest contact length (8,471 units). Furthermore, the type of asphalt had a notable impact on the contact characteristics with various fillers. For instance, AC60/70 asphalt consistently demonstrated higher contact numbers and longer contact lengths with all tested fillers compared to CB and PMA asphalt types. These results provide important insights into the behavior of different fillers in various asphalt conditions. The contact parameters, including the number of contacts and the length of contacts, offer valuable information on the interlocking and bonding characteristics between fillers and asphalt.

Figures 3 and 4 display the correlation analysis between Rigden Void and contact number, as well as contact length, for different types of asphalt (AC60/70, CB, and PMA). The results demonstrated that the relationship between Rigden Void and contact parameters varies across the different asphalt types. For AC60/70 asphalt, weak positive correlations were observed between Rigden Void and both contact number and contact length. In contrast, CB asphalt exhibited strong positive correlations between Rigden Void and both contact number and contact length. PMA asphalt showed a moderate positive correlation between Rigden Void and contact number, while the correlation with contact length was weak. These findings suggest that the influence of contact parameters on Rigden Void differs depending on the specific asphalt composition.

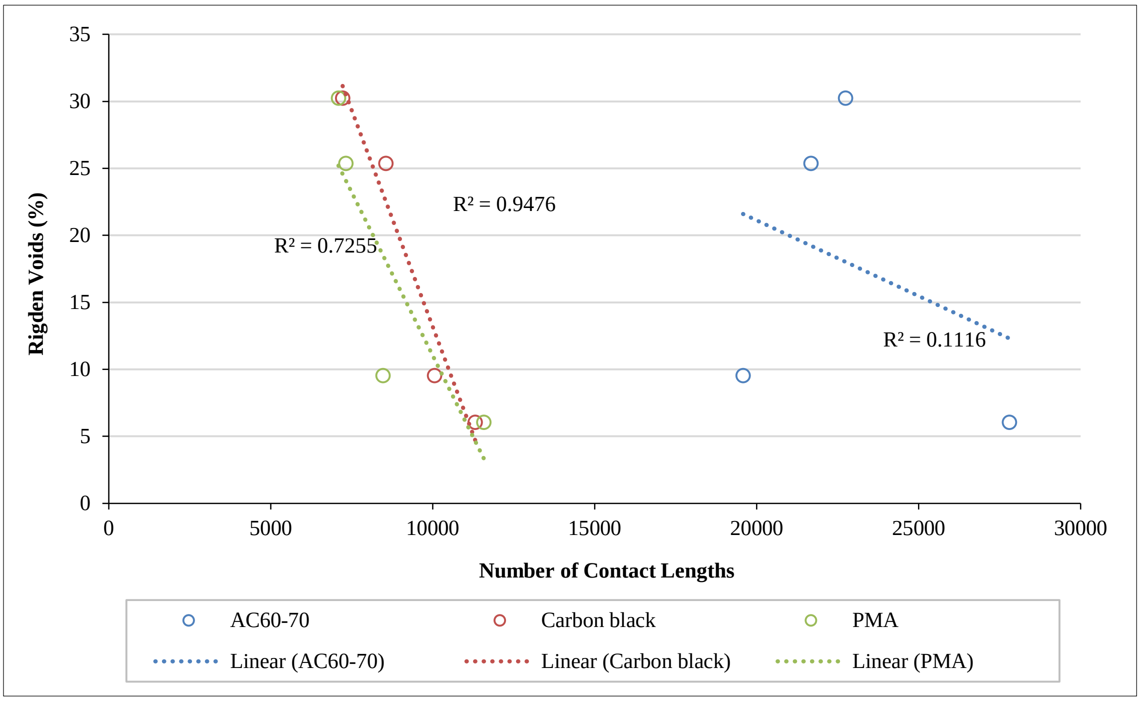


Figure 3. The correlation analysis between Rigden Void and No. of contact lengths

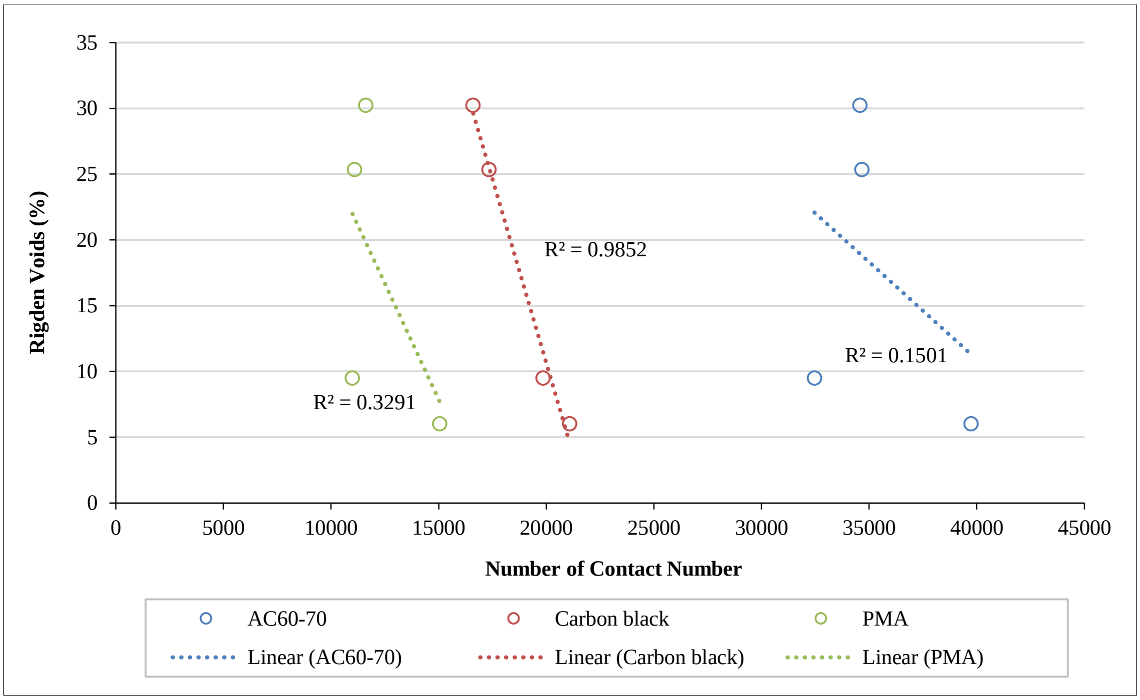


Figure 4. The correlation analysis between Rigden Void and No. of Contact Number

3.4. Relationship between the Percent of Rigden Voids in a Dry-Compacted Fillers and Moisture Damage Resistance

A previous study demonstrated that the selection of mineral fillers used in asphalt mixtures could impact their ability to withstand damage caused by moisture [36]. However, it had not been confirmed whether different fillers and varying water permeability, while maintaining consistent air void levels, affected the resistance to moisture-induced damage. Moisture infiltration into asphalt mixtures can result in two primary mechanisms: adhesive failure, where the bond between the asphalt binder and aggregate surface breaks, and cohesive failure, which occurs due to moisture interaction with the asphalt mastic.

To investigate the potential influence of permeability variations on moisture damage resistance, researchers utilized Indirect Tensile Strength (ITS) testing to calculate the Tensile Strength Ratio (TSR). Figure 5 illustrates the TSR values obtained from subjecting asphalt mixtures with limestone aggregate to wet conditioning for different filler types. In dense gradation, consistent TSR values of 0.83 and 0.86 were observed for AC60/70 and CB, respectively, both utilizing limestone filler. These values exceeded the minimum threshold of 0.7 specified in typical TSR standards. Similarly, AC60/70 with coconut peat filler also surpassed the threshold, with TSR values of 0.76 and 0.92 for AC60/70 and CB, respectively. However, AC60/70 with bagasse filler exhibited lower TSR values compared to the specification, while CB with bagasse filler demonstrated good resistance to moisture damage, indicated by a TSR of 0.89. These TSR values were subsequently analyzed in relation to the permeability coefficient.

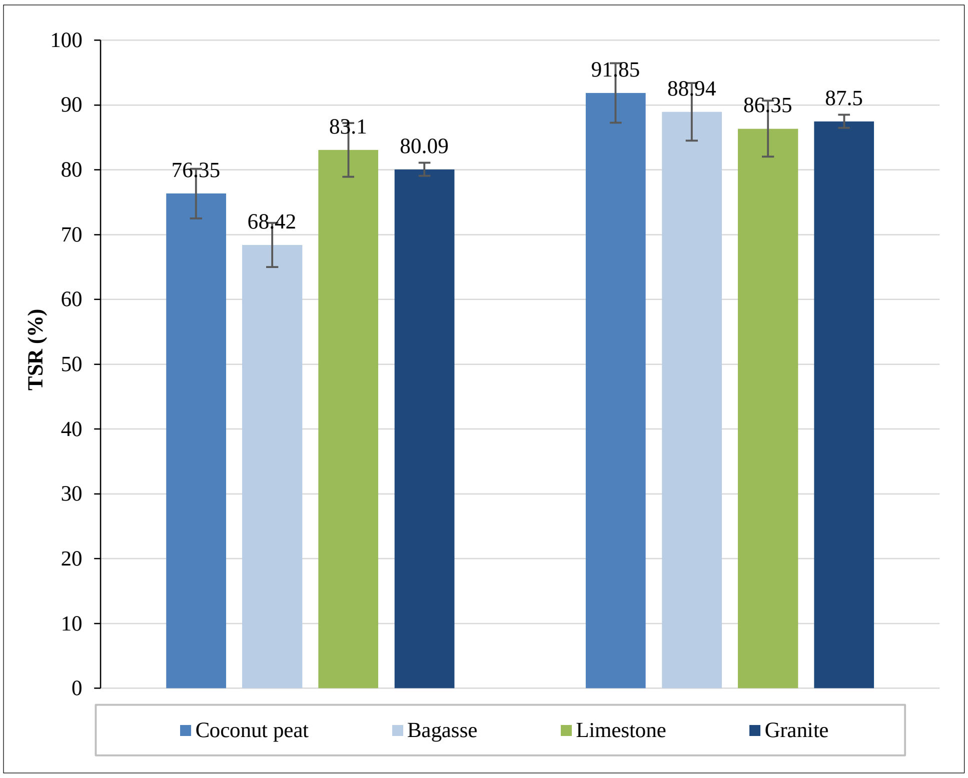


Figure 5. TSR in dense mixture samples

In porous asphalt mixtures, which had a higher presence of air voids, they were more prone to water infiltration. Nonetheless, the TSR outcomes have provided valuable insights into their resistance to moisture damage. Notably, the PMA sample with coconut peat filler exhibited a TSR result of 0.71, indicating relatively good resistance compared to AC60/70 with bagasse and limestone fillers, as shown in Figure 6.

The results obtained from the analysis yielded distinct levels of correlation between these variables across different gradations, as illustrated in the respective figures. For AC60/70 dense gradation, the correlation between TSR and Rigden Void exhibited an R^2 value of 0.64 (Figure 7). This suggests a moderate correlation between the two variables within this gradation. In the case of CB dense gradation, a stronger correlation was observed, with an R^2 value of 0.84 (Figure 8), indicating a significant relationship between TSR and Rigden Void. However, for PMA open gradation, the correlation between TSR and Rigden Void was found to be very weak, with an R^2 value of 0.08 (Figure 9).

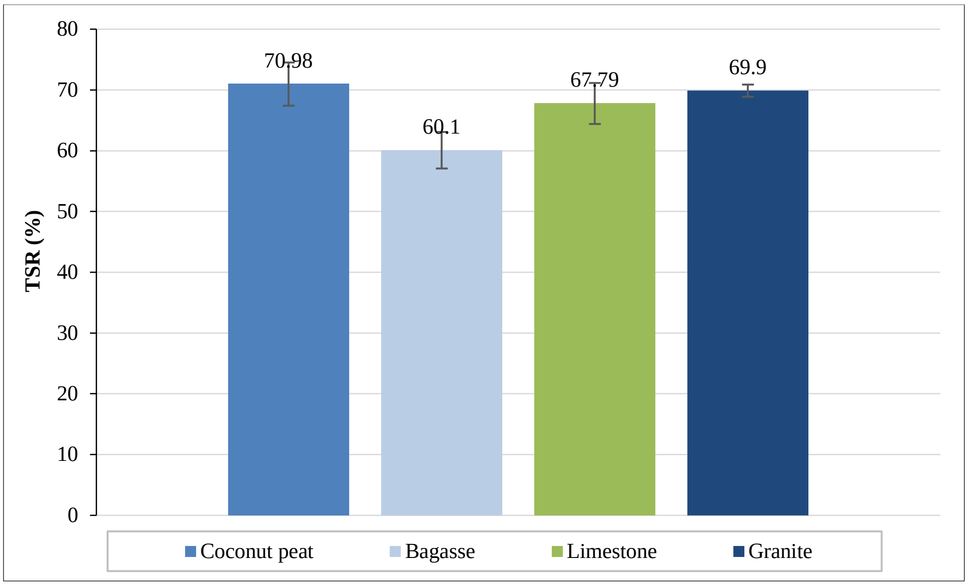


Figure 6. TSR in porous mixture samples

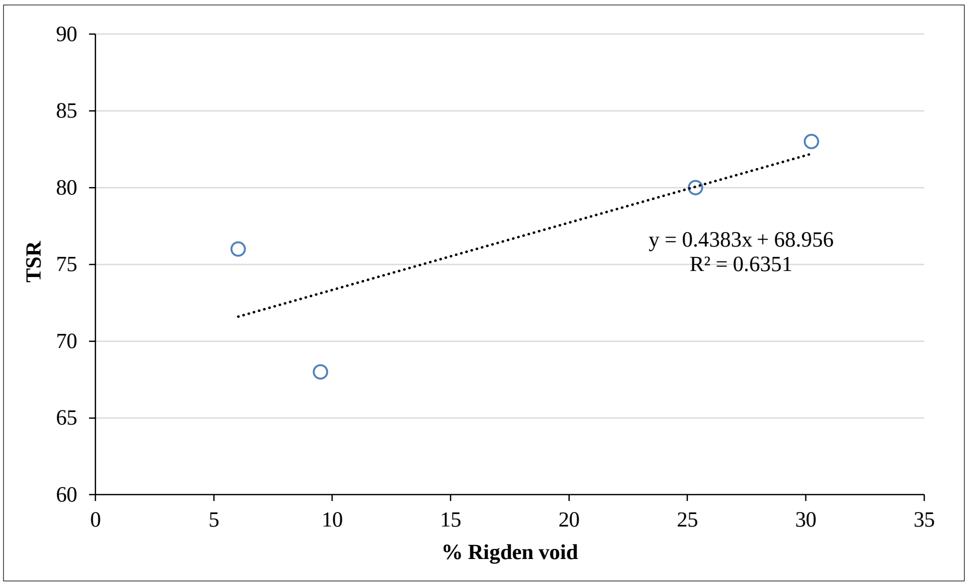


Figure 7. The correlation between TSR (Tensile Strength Ratio) and the percentage of void in AC60/70 Asphalt samples

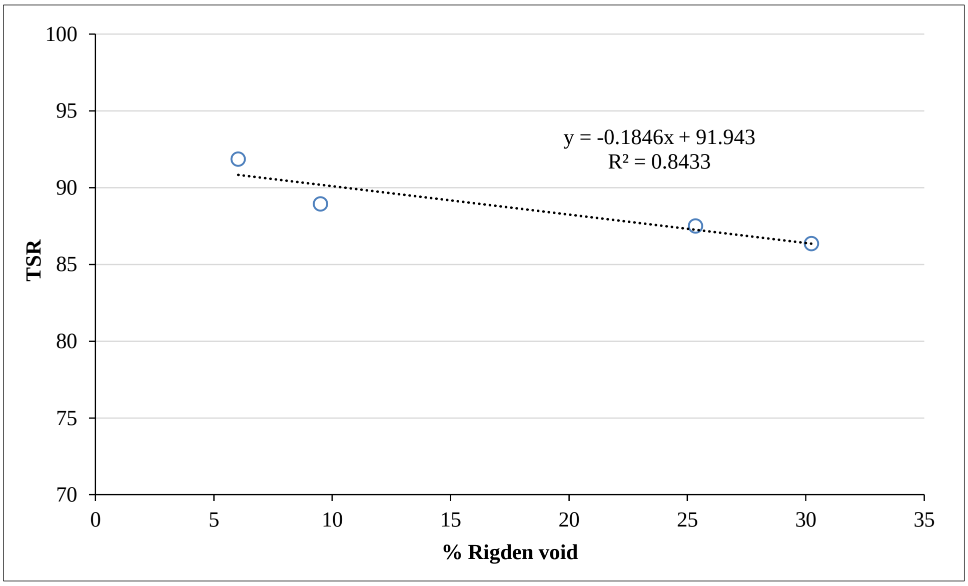


Figure 8. The correlation between TSR (Tensile Strength Ratio) and the percentage of void in Carbon black Asphalt (CB) samples

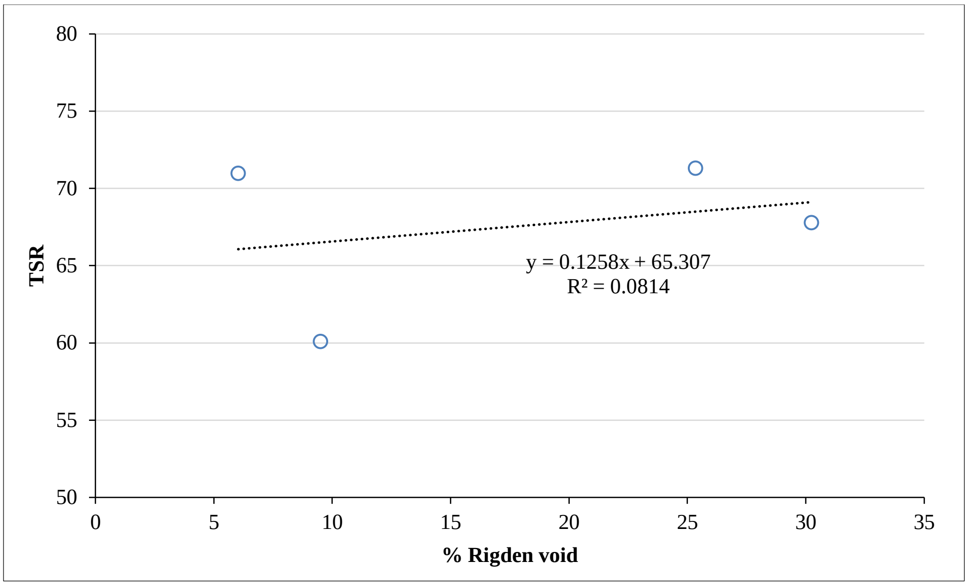


Figure 9. The correlation between TSR (Tensile Strength Ratio) and the percentage of void in Polymer-Modified Asphalt (PMA) samples

The findings provided valuable insights into the influence of aggregate gradation on the relationship between TSR and Rigden Void. The moderate correlation observed in the AC60/70 dense gradation suggests that changes in Rigden Void within this gradation have a discernible impact on TSR. Similarly, the stronger correlation in CB dense gradation indicates that variations in Rigden Void have a more pronounced influence on TSR within this gradation. On the other hand, the weak correlation in PMA open gradation suggests that changes in Rigden Void have minimal impact on TSR within this gradation.

The variations in correlation between TSR and Rigden Void among different grades can be attributed to differences in aggregate packing characteristics, asphalt binder distribution, and the presence of air voids. Dense gradation mixtures typically exhibit higher aggregate packing and a more interconnected structure, which may contribute to the moderate correlation observed. Open-gradation mixtures, on the other hand, have a more permeable structure with larger void spaces, resulting in a reduced interaction between Rigden Void and TSR, explaining the weak correlation.

The results indicate that Rigden Voids play a significant role in the development of moisture damage in both dense and porous mixtures. These findings align with the prior research conducted by Das in 2020, which employed Grey relational analysis to investigate the relationship between filler properties, bond strength, and the potential for moisture damage in asphalt mastics, highlighting the strong correlation of Rigden Voids as the most influential factor [33].

4. Conclusions and Recommendations

This study investigated the influence of fillers on the moisture damage resistance of asphalt concrete by examining the Rigden Voids and their relationship with the Brunauer-Emmett-Teller (BET) surface area. The results demonstrated that the Rigden Voids percent varied significantly among different fillers, with limestone filler exhibiting the highest Rigden Voids percent, followed by granite, bagasse, and coconut fillers. The density of the fillers was found to be directly proportional to the Rigden Voids, indicating that higher filler density resulted in increased void volume in the compacted filler.

The findings highlight the importance of considering the properties of fillers when designing asphalt mixtures to ensure adequate moisture resistance and pavement durability. The Rigden Voids test proved to be a useful method for evaluating the influence of fillers on asphalt performance. By assessing the Rigden Voids, engineers and contractors can make informed decisions regarding filler selection and optimize the asphalt mixture design. Furthermore, the study explored the relationship between the Rigden Voids and BET surface area. The BET analysis provided insights into the surface properties of the fillers and their potential impact on asphalt performance. The results indicated that fillers with larger Rigden Voids exhibited higher BET surface areas, suggesting enhanced asphalt-filler interactions and improved frictional effects. This information can be valuable for selecting fillers that promote better asphalt binder-aggregate adhesion and overall pavement performance.

The correlation analysis between Rigden Void and contact parameters (contact number and contact length) in different types of asphalt (AC60/70, CB, and PMA) revealed varying relationships. AC60/70 asphalt showed weak positive correlations, while CB asphalt exhibited strong positive correlations between Rigden Void and both contact number and contact length. PMA asphalt demonstrated a moderately positive correlation with contact number and a weak correlation with contact length. These findings emphasized the importance of considering microstructural characteristics when analyzing asphalt mixture performance. Furthermore, the study explored the relationship between Rigden Void and moisture damage resistance. The correlation between Rigden Void and resistance to moisture-induced damage, as measured by the Tensile Strength Ratio (TSR), varied with asphalt grade. Dense gradation mixtures showed a moderate correlation, while open gradation mixtures exhibited a weak correlation. These results highlighted the significance of aggregate packing characteristics and the presence of air voids in influencing the relationship between TSR and Rigden Void.

This research contributed to the understanding of the role of fillers in asphalt mixtures and their influence on moisture resistance. The findings emphasized the importance of considering the Rigden Voids and surface characteristics of fillers when designing asphalt pavements. By incorporating appropriate fillers with desirable properties, engineers and contractors could enhance the performance, durability, and moisture resistance of asphalt pavements, particularly in regions with volatile climates and increased rainfall.

Future studies could focus on evaluating the long-term performance of asphalt mixtures incorporating different fillers and their resistance to moisture damage under various environmental conditions. Additionally, investigating the impact of fillers on other asphalt properties, such as rutting resistance and fatigue life, would provide a more comprehensive understanding of their overall influence on pavement performance. By expanding our knowledge in these areas, we can continue to improve asphalt mixture design and construction practices, leading to more sustainable and resilient road infrastructure.

5. Declarations

5.1. Author Contributions

Conceptualization, P.C.; methodology, J.W. and P.C.; software, J.W. and N.H.; formal analysis, J.W.; investigation, P.C.; resources, J.W. and N.H.; data curation, J.W.; writing—original draft preparation, J.W.; writing—review and editing, P.C.; visualization, J.W. and N.H.; supervision, P.C.; project administration, P.C.; funding acquisition, P.C. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

Data sharing is not applicable to this article.

5.3. Funding

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5.4. Conflicts of Interest

The authors declare no conflict of interest.

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