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A REVIEW ARTICLE ON MECHANICAL PROPERTIES OF POROUS ASPHALT MIXTURE

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ABSTRACT

Millions of kilometers of roads are constructed using asphalt mixtures, therefore; the environmental, safety, and economic factors are influenced by the materials and the methods used to prepare and implement such projects. The recent trend has focused on porous asphalt to search for alternative methods to the traditional method since the design and maintenance of asphalt mixtures are influential from an economic viewpoint. Moreover, the presence of water and a drainage system in the pavement is one of the elements that influences the composition of the pavement mixture and this has been evaluated through techniques adopted to design porous asphalt mixtures. This study reviews aspects of the materials, methods, and characteristics of porous pavement research articles to pinpoint the critical factors for understanding porous asphalt and its properties. This will make it possible to create techniques to optimize the performance of the mixture. This review article will conclude with ideas for new design strategies that use different materials and modifiers, as well as new methodologies for using porous asphalt in different classes of road pavements for better characteristics.

KEYWORDS: Modified Asphalt, Open-graded mixture, Porous Asphalt, Permeability, Environmental Advantage, Safety.

1. INTRODUCTION

Generally, cold and hot asphalts have smooth and impermeable surfaces. This smoothness and impermeability reduce safety in rainy weather conditions. As a consequence of weak drainage on the surface, splashing phenomena are formed even from a relatively thin layer of water which decreases the vehicle's rolling resistance, light reflection, and headlight glare. The water will also affect the mechanical properties of the mixture and as a result, causes life span reduction of the pavement layer. Porous asphalt with more than 20% of air voids creates a network of ducts in the mixed body that acts as a reservoir to absorb large amounts of water, snow, and rain and drain it to the side shoulders of the road followed by reduction of splashing and increase of safety. Also, by draining water through the pores of the pavement instead of the surface, the friction between the surface and the tire will be maintained at the desired level(Nicholls, 1998a).

Porous asphalt is one of the new asphalt types that has been widely used since the 1980s. At first, originally it was known as 'Friction Course' and later described as 'Porous Macadam' in the Britannia, and after that, it was termed "Porous Asphalt" in 1992. This term is included in the European Committee for Standardization's draft (CEN) terminology for highway materials. Flüster-asphalt' (whispering asphalt) in Germany, Drain-asphalt in France, and drainage asphalt in Sweden are utilized for naming this type of asphalt in addition to Plant-Mix seal, Popcorn Mix, and open-grade friction course in America(Nicholls, 1998b, Andrés-Valeri, 1991). In 1950, the formulation was very open-graded having about 20% air voids when termed "Airfield Friction Course" on airfield pavement surfaces and used on highways with different gradations (Nicholls, 1998b, Jacobs, 1982).

Fine aggregate has an important role in regulating the void ratio of the mixture, and porous asphalt mixture is often recommended for garages and roads with lower traffic volume. Pedestrian walkways, paths, sports complex requests, sidewalks, roads, shoulders, and bike lanes are other uses for porous asphalt. Both highway and urban porous asphalt. It may be used in its entirety or in a section with typical asphalt pavements.(Roseen et al., 2012, Hein et al., 2013, WAPA, 2015).

This review investigates the methods that are advantageous to further use of porous asphalt mixture in road construction. The aim is to conclude results so that it can brainstorm ideas for developing new approaches and techniques with the use of different materials and modifiers. The findings could lead toward further enhancements in the behavior and properties of the mixture along with further enhancements in the application of porous asphalt in highways with different load categories.

2. PERMEABLE PAVEMENT

Storm water runoff can be temporarily stored and/or infiltrated in an underlying stone reservoir by filtering through pores in permeable pavements into that reservoir. Figure 1 illustrates three major types of permeable pavement.

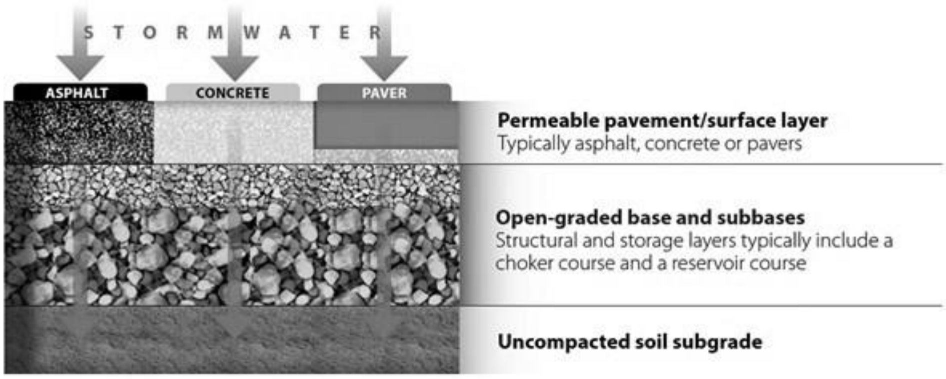

Fig.(12):- Generic permeable pavement cross-section(Eisenberg et al., 2015).

Porous asphalt pavement is commonly used for water drainage and noise abatement to improve traffic safety and comfort for both drivers and inhabitants living near roadways. It has an open texture and a porous structure because coarse aggregate makes up the majority of the material and sand and filler are only present in very small proportions(Poulikakos et al., 2006).

3. Porous Asphalt Mixture

Asphalt concrete, the road's top layer, efficiently supports vehicle weight without significant deformations. Comprising carefully blended asphalt binder and aggregate, it acts as a durable and strong driving surface when suitably designed and constructed.

While traditional flexible pavement is designed for a range of applications and boasts a superior capacity for carrying heavy traffic loads, porous asphalt is an environmentally conscious alternative that can perform comparably to other pavements intended for light to moderate traffic volumes.

In general, porous asphalt features a permeable surface that is located on open-graded aggregate subbase/base layers. This surface enables storm water runoff to movement in the pores to a stone reservoir, where it can be temporarily stored or infiltrated within the porous asphalt. These layers serve the twin purpose of retaining storm water and providing structural support to withstand the traffic volume on the pavement. If the native soil has the capacity for complete infiltration, it is possible to design the pavement without an underdrain (Eisenberg et al., 2015).

Porous asphalt consists mainly of small amounts of sand with coarse aggregate and with porosity in excess of 20 %. (Poulikakos et al., 2006). Despite its benefits, porous asphalt is inferior in service life and performance because of its structure exposing a considerable surface area leading to aging and clogging(Poulikakos et al., 2006).

Research on porous asphalt systems indicates that a porous asphalt wearing layer with a thickness of approximately 40 mm provides similar performance to a 20 mm hot rolled asphalt layer. Furthermore, the structural contribution of porous asphalt is estimated to be approximately 65% of the strength exhibited by other surface mixes (Potter and Halliday, 1981, Chu et al., 2018).

4. MERITS OF POROUS ASPHALT PAVEMENT

The porous asphalt pavement has advantages since it recharges the groundwater supply better and requires less curbing and storm sewers than other types of pavements. The advantages of porous asphalt pavement fall under the categories of safety and environment. The speed of vehicle driving on a porous asphalt pavement surface is often faster than the speed on conventional road surfaces in the rain since there is less aquaplaning, splashing, and spray but also increased skid resistance. Porous asphalt pavement offers several environmental benefits. Among these, the following are the most noteworthy advantages of porous pavement:

4.1 Aquaplaning

One of the main risks of driving through rain is aquaplaning, which occurs when a film of water forms between the tire and the road as shown in Figure 2. The tire will float on the water; the skid resistance is almost nonexistent, making steering and braking nearly impossible. The lack of aquaplaning is most definitely the major advantage of porous asphalt pavement (Lefebvre et al., 1993, Nicholls, 1998a).

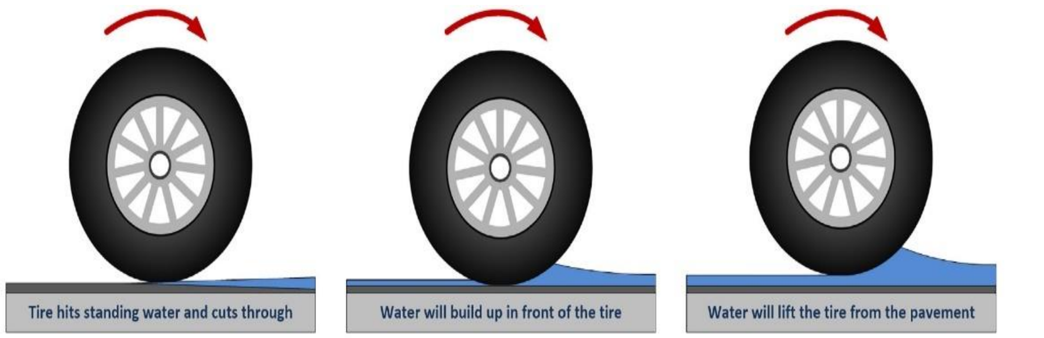

Fig.(2): -Aquaplaning through driving on roads(Lee et al., 2021).

4.2 Reduction in splash and spray

Splashing water from pools on the surface is caused by rolling wheels as in Figure 3, which will also mist the water (spray). Although the two phenomena are quite different physically, they may be addressed together in practice since they frequently coexist(Lefebvre et al., 1993). A 50 mm thick new porous asphalt pavement surface course with up to 20% air spaces can hold up to 11.5 millimeters of rain if it all fell at once. A surface course of porous asphalt pavement can therefore prevent a thick coating of surface water from accumulating for a long time and significantly minimize spray during this time(Nicholls, 1998a).

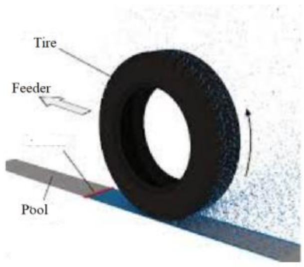

Fig.(3):- Splash and Spray on wet roads(Strohbücker et al., 2018).

4.3 Reduction in light reflection and headlight glare

Because porous asphalt serves as a drainage layer and allows rainfall to seep through the mix, headlight glare and light reflection, which are dangerous factors for drivers, especially at night, greatly decrease. The effect of these factors is especially noticeable on dark and wet roads(Poulikakos et al., 2006).

4.4 Skid Resistance

One of the primary benefits of utilizing porous asphalt is increased skid resistance in wet weather. According to the findings, porous asphalt mixtures showed considerably better friction qualities in dry situations and significantly better friction properties in wet conditions in which there was water available on the pavement(Moore et al., 2001).

4.5 Noise Reduction

The macro-texture of the road surfaces is coarse and comes into contact with the tread of the tires detailed in Figure 4. It is well known that this roughness helps the surface and tire absorb sounds. Several test sections reveal that porous asphalt has lower noise levels than normal traditional asphalt layers (Tesoriere et al., 1989, Camomilla et al., 1990).

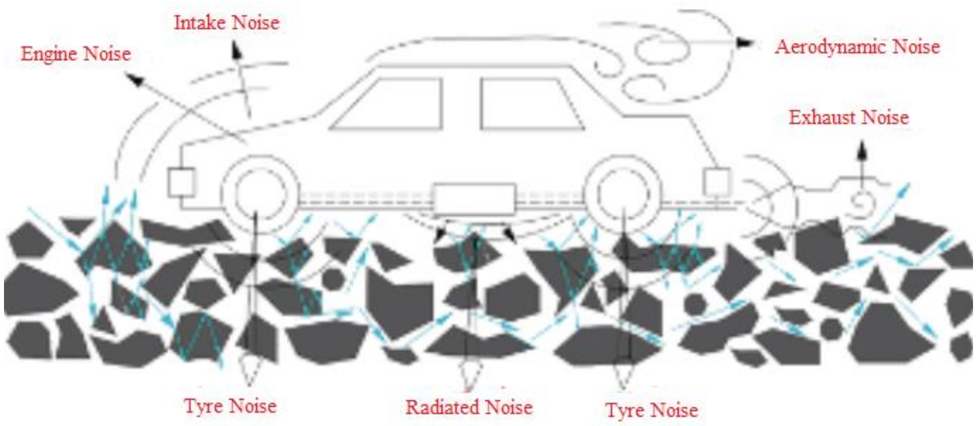

Fig.(4):- Micro-structural analysis of noise reduction mechanism of porous asphalt mature(Sun et al., 2021).

4.6 Rutting Resistance

Despite a high porosity, porous asphalt reveals less permanent deformation than other mixes. In comparison to other dense mixes, the tighter aggregate skeleton in porous asphalt may help it handle the load from vehicles(Poulikakos et al., 2006, Daines, 1992).

5. DEMERITS OF POROUS ASPHALT

Despite having many obvious benefits, porous asphalt also has important drawbacks that are connected to its production, maintenance, and lifespan and are reliant on the environmental factors the pavement is exposed to. The most significant disadvantages of porous asphalt are mentioned below.

5.1 Aging and Stripping

The tendency of the binder film on the surface of the aggregate to be continuously exposed to oxygen, sunlight, water, etc. is one of the most crucial factors in how well bituminous mixes perform. This causes the binder to harden and shorten the service life of the pavement(Poulikakos et al., 2006, Daines, 1992).

5.2 Clogging and Reduction in Porosity

Throughout its useful life, dirt, dust, and other clogging agents frequently clog the pores. Tires have a self-cleaning effect on lanes with high speeds. Clogging is therefore a bigger problem on low-speed lanes or minor roads. The benefits of drainage and noise reduction will gradually disappear with the loss of pores(Van Heystraeten and Moraux, 1990).

5.3 Winter Maintenance

Winter maintenance costs rise because porous asphalt requires more salt to be applied. When salt is used, it ends up in the shoulder and harms the environment. Additionally, compared to other dense mixes, removing ice from porous surfaces requires at least twice as much de-icing salt treatment. Snow plowing, spiked tires, and tire chains can all seriously harm open-textured pavements, necessitating additional repairs once the aggregates are removed from the surface(Lefebvre et al., 1993, Poulikakos et al., 2006). It should be noted that this surface might be colder in the winter than dense asphalt due to the lower thermal conductivity of porous asphalt. As a result, snow tends to fall and stay on the porous asphalt surface longer, and ice forms more quickly when the roads are wet(Nicholls, 1999).

5.4 Raveling

A loss of adhesion between the binder and the aggregate causes pavement distress known as raveling, which is characterized by the loss of individual aggregate particles at the pavement's surface. Comparatively to impervious asphalt mixes, the possibility of binder exposure to air is increased in porous asphalt because of the high air void content, which allows for greater access to oxygen, sunlight, and water. This exposure to the air may cause the binder to prematurely oxidize, becoming brittle and causing raveling(Lyons and Putman, 2013).

5.5 Drain Down

The absence of fine aggregate in porous asphalt mixtures, which is essential to achieve higher permeability rates compared to dense asphalt mixes, can result in drain down issues within porous asphalt mixtures. Drain Down may be brought on by an extra asphalt binder (bitumen), which is used to increase durability. The term "Drain Down" refers to the excess asphalt binder that drains from a porous asphalt mixture, especially in the summer. This excess asphalt binder can clog the last layers and reduce the permeability of the porous asphalt(Lyons and Putman, 2013, Shankar et al., 2014).

5.6 Maintenance and Construction Cost

Compared to conventional asphalt, porous asphalt is more expensive to construct. The requirement for precise processing appears to be the main factor. Another factor that could result in cost differences between porous asphalt and conventional mixes is the more expensive maintenance of this kind which it is crucial to stick more closely to the original mixture, so repairs are frequently more expensive.

6. MATERIALS

Selecting the appropriate components for porous asphalt mixtures is the first step in the mixing process. Porous asphalt is made of stone components, bitumen, modifiers such as polymers, additives like mineral fibers, cellulose, and additives such as hydrated lime. The following are the criteria for the construction of porous asphalt:

6.1 Aggregate

The difference in the maximum nominal size of granular stone materials affects the permeability properties (Nominal Maximum Aggregate Size “NMAS”) (Brown, 2004). Permeability increases when NMAS rises. This happens because the size of the independent voids in the compacted mixture grows as NMAS increases. When the independent space is larger, there is a greater opportunity for connections to be made from inside the voids. Presence of such connections, the shape of aggregates, and gradation cause pavements to be permeable.

6.2 Filler

The utilization of various kinds of fillers in the mixture follows a set of rules. Fillers have a crucial character in influencing both the chemical and mechanical characteristics of asphalt mixes, as well as their durability. The more common form is lime stone, which can be replaced with fly ash, hydrated lime, recycled materials as plastic and rubber, or even cement(Ameri and Esfahani, 2008, Al-Hdabi et al., 2019, Jalal Madhat Khowshnaw and Mustafa Salih Zebari, 2019).

6.3 Binder

Most countries that utilize porous asphalt begin their work using materials that have been coated in pure bitumen. For roads with low traffic, Belgium uses bitumen with a grade of 80/100. Bitumen from 60/70 and 80/100 was used in France, and Switzerland has proposed using modified bitumen(Watson et al., 2020). The majority of porous surfaces were simultaneously treated by Styrene Butadiene Styrene (SBS) polymer and Ethylene Vinyl Acetate (EVA). To enhance component adhesion and prolong product life, porous surfaces are sometimes treated with a polymer, which increases viscosity, reduces the surface's susceptibility to temperature and also leads to an extended product lifespan.(Watson et al., 2020).

6.4 Modified Binder

Binder modification can improve the porous asphalt's characteristics and mixture's durability. The proportion and characteristics of the binder influence the mixture's strength and structural characteristics(Verhaeghe et al., 1994). In addition to enhancing deformation and fatigue resistance, the modifiers also allow for the use of higher binder contents, which can enhance stone retention and durability without contributing to binder run-off during construction.

Modifiers are widely used in asphalt mixtures and therefore also in porous asphalt. Below are most of the widely used modifiers in porous asphalt mixtures:

6.4.1 Polymers

Many other types of polymers as Polyethylene, Polyvinyl Chloride (PVC), Polypropylene, and Fluoropolymer can be employed to enhance the features of a mixture, but the most popular ones are described here.

Styrene-Butadiene Rubber (SBR) is an elastomeric polymer that is added to a base bitumen under agitation in a latex form. Minimizing rutting in asphalt significantly increases shear rates and viscosities compared to binders that are not modified(Verhaeghe et al., 1994).

Ethylene-Vinyl Acetate (EVA): Vinyl acetate and Ethylene copolymers are well-suited to bitumen. When the content of vinyl acetate is high, it gives good compatibility, low strength properties, great tenacity, soft blends, and vice versa. Ethylene-Vinyl Acetate-copolymers are noted for improving the rutting resistance and workability of the hot mixture asphalt(Verhaeghe et al., 1994).

Styrene-Butadiene Styrene (SBS): it gives the desired characteristics of elongation, plasticity, and elasticity. When the binder modified by Styrene-Butadiene Styrene is applied in wearing courses, these binders can improve adhesion to aggregate, chip retention (initial and long term), fatigue resistance, low-temperature flexibility, resistance to bleeding, resistance against long-term distortion, and fatting up (Verhaeghe et al., 1994). In general, the adhesion between the binder and aggregate can be enhanced by incorporating polymer modifiers. The effectiveness of polymer modification may vary according to the specific type of aggregate and binder used (Chen et al., 2012, Shukry et al., 2016, Chen et al., 2013).

6.4.2 Nanoparticles

To enhance the stability of modified asphalt, nanoparticles can be used on the surface. Nanotechnology involves the making of novel systems, instruments, and materials at the level of molecular, focusing on molecular and atomic interactions that have a profound effect on the macroscopic properties of the material. Recently, asphalt mixes were modified using nanotechnology. (Zalnezhad et al., 2015, Fang et al., 2016, Li et al., 2017, Sun et al., 2017).

Nano silica is the most widespread type of nanomaterials which enhances the viscosity and shear modulus of asphalt. With a good dispersion ability and low cost, it increases the performance of fatigue cracking, resistance of rutting, anti-aging performance, and characteristics of anti-abrasion. It is usually used to enhance the moisture susceptibility and decrease the rut depth with low toxicity with a dosage between 2–6% by weight of binder(Yang and Tighe, 2013a, Ezzat et al., 2016, Zafari et al., 2014, Enieb and Diab, 2017, Shafabakhsh and Ani, 2015, Yao et al., 2013, Ghasemi et al., 2012, Hassan et al., 2014, Katman et al., 2005, Ameri and Esfahani, 2008, Pradoto et al., 2020, Tang et al., 2017, Taherkhani and Bayat, 2015, Masri et al., 2019, Baldi-Sevilla et al., 2016, Tanzadeh et al., 2019, Hamedi and Moghadas Nejad, 2015, Arshad et al., 2019).

Nanomaterials have a fundamental unit size ranging from 1 to 100 nm. These materials, including nano-fibers, nano-carbon, nano-clay, and nano-scale sphere-shaped particles (such as nano-TiO_2, nano-SiO_2, and nano-ZnO), have gained significant attention from asphalt researchers. This is primarily because of their unique chemical and physical characteristics, as well as their small size and large surface area.

6.4.3 Crumb Rubber

When this modifier is added via the dry process to the mixture, it functions as an additive rather than as a binder modifier to improve the viscosity of the binder. When temperatures are low, they make the binder less stiff and increase crack resistance. The adding of crumb rubber to binder recovers the affinity between the two, leading to several benefits. These include enhanced resistance to raveling, reduced potential for stripping (loss of adhesion), and decreased oxidation of the binder (Cheng et al., 2019, Enieb et al., 2021, Frigio and Canestrari, 2018). The act of the mix depends on the dimensions of the crumb rubber, Also, it reduces the resilient modulus, permeability, moisture susceptibility, and ITS of the porous asphalt mix(Gupta et al., 2019).

6.4.4 Fibers

Fibers are used to enhance the mechanical characteristics of mixes and they also increase the stiffness of bitumen, which may lead to brittleness (Chen and Lin, 2005). In porous asphalt, fibers facilitate a higher optimum asphalt content and are utilized to avoid binder drain down(Marchioni and Becciu, 2015).

Cellulose fibers are used to advance the stability of binder (Vale et al., 2014, Ma et al., 2018, Lyons and Putman, 2013, Afonso et al., 2017, Andrés-Valeri et al., 2018, Mansour and Putman, 2013, Chen et al., 2012, Putman and Kline, 2012). Glass fibers can be used where the temperature is low and asphalt is exposed to cracks(Wang et al., 2019). To improve characteristics as tensile strength (ITS) and elastic modulus, synthetic fibers displayed evangelist outcomes(Slebi-Acevedo et al., 2021).

Porous mixtures incorporating cellulose fibers exhibit increased Marshal stability due to the fibers' capacity to absorb a higher amount of binder. This absorption enhances the binder system and reduces drain down, resulting in increased viscosity. Consequently, the mixture demonstrates improved stability and potentially more strength to fatigue compared to similar mixes without fibers (Lyons and Putman, 2013, Eskandarsefat et al., 2019, Verhaeghe et al., 1994).

7. POROUS ASPHALT MIXTURE PREPARATION

Although, in general, the process of mixtures preparation with open-graded (porous) asphalt is the same common technique for the construction of asphalt mixes with dense granulation and with the same equipment, some considerations should be made in the work steps as below:

7.1 Aggregate Gradation and Characteristics

In typical porous asphalt mixtures, the coarse aggregate content (greater than 4.75 mm) is commonly found to be over 80% and the remaining is for fine aggregate that must be clean, hard, strong, and durable with uniform quality characteristics. Also, filler accounts for 2-4% of the mixture and has an impact on its properties. Gradation of porous asphalt should be chosen based on its performance and expected function which includes increased safety, reduced pollution, and increased permeability. The aggregate gradation in some countries and by various techniques is illustrated in Table 1.

Table(1):- Gradation of aggregate for porous asphalt mixture(Alvarez et al., 2006).

Gradation mm (inch)	United Kingdom				Spain		Denmark			Switzerland					
	PA 6/20 mm		PA 2/10 mm		PA 12		PA 0/5	*PA 0/8	PA 0/16	**PA S 16		PA S 22		PA S 32	
% Passing	Min.	Max.	Min.	Max.	Min.	Max	Medium	Medium	Medium	Min.	Max.	Min.	Max.	Min.	Max.
45(1.77)														100	
31.5(1.24)	100											100		90	100
22.4(0.88)										100		90	100		
20(0.79)	95	100			100				100						
16(0.63)									97	90	100				
14(0.55)	55	75	100												
12.5(0.49)					70	100			55						
11.2(0.44)								100	30			15	65	15	60
10(0.39)			90	100											
8(0.31)					38	62	100	94	12	15	60				
6.3(0.25)	20	30	40	55											
5.6(0.22)							99	35	9						
4(0.16)					13	27	65	11	9						
2(0.08)	5	12	19	25	9	20	10	9	8	7	20	6	20	5	20
1(0.04)							9	8	8						
0.5(0.02)					5	12	8	7	7	4	10	4	10	4	10
0.25(0.01)							7	6	7						
0.075(0.003)							6	5.5	5						
0.063(0.002)	3.5	5.5[a]	3	6[a]	3	6				3	5	3	5	3	5

[a] Hydrated lime is typically at a rate of 2% by weight of the entire aggregate,
*Pa: Porous Asphalt.
**PAS: The Swiss national standard also defines gradations for the mixtures.

Table (1):- Gradation of aggregate for porous asphalt mixture(Alvarez et al., 2006). Continued

Gradation mm (inch)	Australia				South Africa		Italy		Belgium	TxDOT			
	OG 10	OG 14	*OG 20	Tolerance	Min.	Max.	Min.	Max.		PFC-PG 76		PFC-A-R	
										Min.	Max.	Min.	Max.
26.5(1.04)			100						The Pardo Win software, developed by the Belgium Road Research Center, is utilized for the optimization of road asphalt design. Stone Friction > 2mm: 81-85%, Sand Friction (between 0.063 mm and 2 mm) : 11-13%, Filler Fraction: 4-6%				
20(0.79)							100						
19(0.75)		100	95	±6	100	0				100		100	
14(0.55)					0	0	75	100					
13.2(0.52)	100	95	55	±6	90	100							
12.5(0.49)										80	100	95	100
10(0.39)							15	40					
9.5(0.37)	90	50	30	±6	25	65				35	60	50	80
6.7(0.26)	40	27	20	±6									
5(0.20)							5	20					
4.75(0.19)	20	11	10	±5	10	15				1	20	0	8
2.36(0.09)	12	9	8	±5	5	10				1	10	0	4
2(0.08)							0	12					
1.18(0.05)	8	8	6	±5									
0.6(0.024)	6	6.5	4	±5									
0.25(0.01)	5	5.5	3	±3									
0.15(0.006)	4	4.5	3	±3									
0.075(0.003)	3.5	3.5	2	±1	2	4	0	7		1	4	0	4

*OG: Open Grade
PFC and PFC-A-R: cellulose or mineral fibers and asphalt rubber.

Table 2 outlines the prevalent aggregate gradation found in porous asphalt mixtures. Research conducted in the United States, as well as laboratory tests, are behind these different levels.

Table(2):- The prevalent Gradation of Aggregate in Porous Asphalt(Kandhal, 2002, WAPA, 2015, Kandhal).

Gradation mm (inch)	NCAT		FHWA		NAPA		WAPA	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
19(0.75)	100				100		100	
12.5(0.49)	80	100	100		85	100	85	100
9.5(0.37)	35	60	95	100	55	75	55	75
4.75(0.19)	10	25	30	50	10	25	10	25
2.36(0.09)	5	10	5	15	5	10	3	15
0.075(0.003)	2	4	2	5	2	4	1	4

The properties of aggregate, such as the ratio of Los Angeles abrasion, sand equivalent, flakiness index, fine aggregate angularity, and percent of crushed faces, are not given much importance in the design of this type of asphalt mixes in countries like the Netherlands, Switzerland, Belgium, Denmark, and Australia. However, it is crucial to note certain key points during the design process of asphalt mixture, which are highlighted in Table 3 using various methods.

Table(3):- Aggregate properties-based design method(Kandhal, Alvarez et al., 2006, WAPA, 2015, Kandhal, 2002).

Aggregate Properties	Italy	South Africa	United Kingdom	Spain	NCAT	TxDOT	NAPA	WAPA	FHWA
Los Angeles Abrasion, %	<16	<21	12 max.	<25: T3, ≤20: T1, T2, ≤15: T00, T0	<30	<30	≤30	13 max, 100 rpm, 45 max. 500	40 max.
Flakiness Index, %	-	<25	25 max.	≤25: T3, T2, T1, T0, ≤20: T00	<5(5:1) ;<20% (3:1)	<10 (5:1)	≤5(5:1); ≤20% (2:1)	≤5(5:1)	-
Sand Equivalent, %	-	>45	-	>50	-	-	-	-	-
Fine Aggregate Angularity	-	-	-	-	>45	-	-	-	-
Crushed Faces (2 Faces), %	-	90-100 Based on traffic	100	100	>90, one face:100	>95	≥90, one 100	≥90, one 100	>75 one face:90

7.2 Selection of Bitumen in Porous Asphalt

The thin coating of bitumen covering aggregate will be exposed to oxidation more frequently and more quickly because of the porous asphalt's open texture, which leads to brittleness and degradation. Because it gets to the critical hard-point faster, using bitumen with higher viscosity is not recommended for this reason. When selecting the type of bitumen, other elements like the weather and traffic volume should be taken into account.

According to the study by Schaus, L.K., the binders usually used in pavements are performance-graded asphalt cement by considering the percentage of recycled materials, traffic loading, and temperature (Schaus, 2007).

In the National Centre for Asphalt Technology (NCAT) the traffic criterion for selecting the type of bitumen in porous asphalt is considered, therefore, a suitable type of fiber or additive is selected based on traffic parameters. (Kandhal, 2002).

Table 4 displays the properties of an appropriate asphalt binder, binder modifiers, and recommended percent of bitumen for porous asphalt mixtures, which vary based on various design approaches. It is important to note that the selection of these components have an important character in the complete performance of this type of mix. Therefore, careful consideration and analysis of the design methods are necessary to ensure optimal results.

Table(4):- Binder properties and modifiers in porous asphalt mixtures(Kandhal, 2002, Kandhal, WAPA, 2015, Alvarez et al., 2006).

Binder Characteristics	Binder Grade	Binder Modifiers	Binder Content, %
Italy	-	80/100+SBS	4-6
South Africa	-	Asphalt rubber-polymer modified	4.5 min.
United Kingdom	100/150 or 160/220	SBR, fibers, natural rubber	3.7-5.2
Spain	60/70, 80/100	SBS, EVA	4.5-5.5
NCAT	-	PMB, cellulose (0.3%) or mineral fiber (0.4%)	-
TXDOT	PG76 XX (PMB),	lime (1-2%), cellulose or mineral fiber (0.2-0.5 %)	6-10
NAPA	Stiffer than normal+2	Polymer, fiber	-
WAPA	PG64-28 or PG70-28	-	5.2-6.0
FHWA	AC-20	-	-
Australia		SBS, SBR, EVA, crumb rubber, fiber (0.3-0.5%), hydrated lime	3.5-6.5
Netherland	-	-	4.5
Belgium	50/70	polymer	4.3-5.3

7.3 Evaluation of Optimum Binder Content

To evaluate binder content in porous asphalt mixture, the process requires evaluation in three consequent steps as below:

Step 1: This step evaluates the optimum binder content using the drain down test obtained by the Schellenberger Drainage test and the Basket Drainage test. (Decoene, 1990, Kandhal and Mallick, 1999).

Step 2: This optional step uses the Cantabro Abrasion Test for conditioned and unconditioned mixtures (Lefebvre, 1993).

Step 3: Porous asphalt, having a higher air void ratio compared to traditional asphalts, exhibits lower stability characteristics. It is recommended to maintain air voids at approximately 20% or less. (Krezem, 2019, Woldekidan, 2011).

In their study, Watson, D.E., et al (2004) state that the mixture must be tested for susceptibility of moisture by using the modified Lottman method (AASHTO T-283) or the boil test method (ASTM D3625) with the retained tensile strength being less than 80% that means better resistance to moisture damage in the porous asphalt pavement. James T.M. demonstrates an alternative approach for determining moisture susceptibility utilizing the wheel-tracking test (AASHTO T324) or the Hamburg Wheel Tracking Test to evaluate binder content (Watson et al., 2004, James, 2016).

8. LITERATURE REVIEW OF POROUS ASPHALT MIXTURE DESIGN METHODS AND CHARACTERISTICS

Researchers have paid deep attention to developing new methods of asphalt pavement construction that meet environmental, safety, and economic conditions. Porous asphalt mixture is currently trending as one of the prominent developments in the field of asphalt technology construction that can be aimed at achieving the stated goals. In this regard, several projects and researches that have been conducted in this field are reviewed and briefly presented in the following sections. This could guide researchers and asphalt pavement and materials engineers towards a better understanding of porous asphalt pavement and its construction technology.

In a study by Hashim et al. (2021) indirect tensile strength, stability, flow, and air void tests were used to compare the variations between the conventional and porous asphalt mixtures. The study was depending on the performance values of Cantabro abrasion, binder drain down, coefficient of Permeability, and Air voids tests. The results showed that porous asphalt had less stability and flow than normal asphalt, but it had an air void that was nearly five times larger.

In porous asphalt, aggregate gradation directly affects the air voids, hence a lack of some sizes will reduce stability. In addition, less filler will have a consequence on how the binder is absorbed and will change the flow rate in porous asphalt.

The study conducted by Mansour and Putman (2013) explores the impact of ten different gradations of aggregate on the acting of porous mix. Their findings highlight the significance of optimizing the aggregate gradation based on specific performance requirements such as permeability on strength. These findings align with the research conducted by Hamzah et al. (2004), as well as other academic researches like Liu and Cao (2009) and Ranieri et al. (2010), who also support the notion that gradation of aggregate has an important role in influencing the efficiency of porous asphalt mixes

In their research conducted in 2021 Majeed and Sarsam (2021) focused on the volumetric and physical properties of porous mixes, as well as the utilization of carbon fibers as an additive in the mixture. The results of their study indicated an improvement in stability, a flow reduction, and a decrease in the drain down rate when carbon fibers were incorporated into the mixture. These outcomes recommend that the addition of carbon fibers as an additive can positively impact the efficiency of porous mixes.

The goal of Al-Busaltan et al. (2020) investigation was to determine polyethylene material with low density and when recycled effects on porous asphalt characteristics. Compared to asphalt samples that had not been modified, the mixture's air void, porosity, and permeability were all enhanced. Additionally, it dramatically reduced drain down, moisture damage, abrasion loss, and depth of rutting. Chen and Wong (2013) and Chen and Wong (2015)goes on to say that porous asphalt made completely of recycled material can meet all functional requirements as well as the strength requirement for a low-strength pathway.

It is worth mentioning that modifiers like polymers, fibers, and anti-stripping agents typically attempt to reduce costs and maximize lifespan while considering sustainability, especially when these modifiers are made of recycled resources that will also contribute to a cleaner environment.

Al-Kaissi and Mashkoor (2016) observed that fiber modifiers provide a significant reduction in porous asphalt permeability while improving strength characteristics. Although it is evident that fibers improve a mixture's strength, more research may be necessary to confirm that they also increase air voids and permeability as Decoene (1990) and other researchers claim fibers can be added to porous asphalt to prevent drain-down with better durability(Verhaeghe et al., 1994, Kandhal, 2002, Alderson, 1996, Allen Cooley Jr et al., 2000, Santha, 1997, Kandhal and Mallick, 1998, Huber, 2000, Pasetto, 2000, Faghri et al., 2002, Iwata et al., 2002, Watson et al., 2003). It is important to be conscious that fibers cause moisture damage in mixtures and they perform better in cold locations with frequent freeze/thaw cycles, therefore the weather condition should constantly be considered.

Styrene-butadiene-styrene gives better performance and volumetric properties to enhance the adhesion which reduces the stripping as denoted by Ahmed et al. (2020), and depending on the percentage of polymers, the study indicates an additional 13 to 20 percent TSR. Similar studies show that generally polymer influences porous asphalt's moisture susceptibility and improves the rutting and abrasion resistance in porous mixture (Ahmed et al., 2019, Ali and Khoshnaw, 2020, Al-Jumaili, 2016, Mohammed, 2021, Sinha Ray and Okamoto, 2003, Fang et al., 2016, Ahmed et al., 2020).

Jalal Madhat Khowshnaw and Mustafa Salih Zebari (2019) studied the replacement of fly ash with limestone in the mixes. Performance improvement in durability and stability was noted at 6% replacing fly ash instead of limestone. This substitution of another filler type for limestone creates an opportunity to test new materials and recycled resources to enhance the properties of the mixture while removing hazardous materials from the environment.

Mansour and Putman (2013) have demonstrated how the aggregate gradation in porous mixture affects the material's performance. Depending on the ratio of air void in the defined gradation, the gradation of aggregate in the mixture can be modified to meet the strength and permeability as the performance criteria.

Chu et al. (2018) created a framework of enhanced mix design that takes into account functional characteristics assessment and is related to the mix's skid resistance, drainage capacity, and performance of tire-pavement noise to include functional characteristics evaluation. The study concentrated on the micro and macro textural characteristics, followed by a performance evaluation for porous asphalt in the field. Researcher explains that if the results of the test don't fall within the allowed range, it could be essential to repeat the gradation and asphalt content.

According to Chen et al. (2012) different types of binder can have an important effect on the efficiency of porous mix. It demonstrates that when the mixture has a high-viscosity binder, the bond between aggregate and binder is stronger, causing enhanced performance.

The percentage of air void is the most significant aspect in determining the optimum binder content. Based on research conducted by Ruiz et al. (1990) it has been determined that porous asphalt mixtures with more than 20% air voids exhibit superior performance compared to mixtures with 15 to 18% air voids. The study suggests that mixes with more air void content are more durable and less prone to clogging.

Khalid and Walsh (2000)'s research showed increased aging resistance when EVA and SBS polymer-modified binders were added to porous asphalt utilizing an indirect resilient modulus while aging was performed using a machine that circulated 60-degree air through the samples and at the same time smaller nominal size mixes have a great potential for giving good performance.

The study done by Punith et al. (2004) highlighted the advantages of utilizing polymers in mixes. The study aimed to calculate the laboratory efficiency of various porous mixtures. The findings of the study indicate that the inclusion of polymers in the mixture results in improved performance in terms of abrasion resistance, protection against damage caused by moisture, endurance against fatigue, resilience against plastic deformation, and friction coefficient.

Taherkhani and Tajdini (2019)explored the effects of Nano-silica (NS) and Hydrated Lime (HL). Both additives, hydrated lime and NS, have shown to enhance the resilience modulus and resistance to fatigue cracking of the mix. However, NS demonstrates a slightly greater development in these aspects compared to lime. Furthermore, the resilience modulus of the lime and NS mixtures exhibited lower temperature sensitivity associated to the control mix. Among the two additives, the NS mixtures displayed a higher sensitivity to temperature changes.

Furthermore, as the modifier content and temperature were increased, the sensitivity dropped as supported by Tanzadeh et al. (2019) and other investigators (Tanzadeh and Shahrezagamasaei, 2017, Arshad et al., 2019, Nazari et al., 2018, Yao et al., 2012, Yao et al., 2013, Pradoto et al., 2020, Shafabakhsh and Ani, 2015, Simon et al., 2008, Sinha Ray and Okamoto, 2003, Enieb and Diab, 2017, Yang and Tighe, 2013b).

In general, adding nanoparticles to a binder as an additive will enhance the properties of asphalt binder and the mixture. To evaluate these enhancements, performance tests must be used to determine the appropriate percentage of these elements to avoid negative effects on the mixture. Also, cost is an important consideration when deciding whether to use these materials as filler, which may need a simpler technique but a greater quantity.

In an investigation by Katman et al. (2005), the rubber as an additive was blended with bitumen. The results show that the rubber increases the porous mixture's aging resistance. This study demonstrates that the rubber absorbs the bitumen that is for covering the aggregate. As a result, the addition of rubber has no effect on raveling or stripping resistance.

According to research by Ameri and Esfahani (2008), it is established that the utilization of hydrated lime in porous asphalt mixture is widely adopted by highway agencies to enhance mixture strength and the longevity of asphalt mixture. The research aims to assess the mechanical characteristics of lime-treated Open-Graded Friction Course (OGFC) both before and after undergoing some freeze-thaw moisture conditioning cycles. Furthermore, the research demonstrates that hydrated lime offers greater improvements in durability and stability of the mix compared to limestone powder.

The durability and strength of porous asphalt could be evaluated using laboratory techniques. In his investigation, Ma et al. (2018) conducted performance tests using several binders and polymers. The outcomes reveal that the durability and strength of the mixture depend on the category of polymer and viscosity of the binders in relation to the field temperature. These findings are supported by further researchers Chen et al. (2013).

A laboratory investigation was carried out in a study by Andrés-Valeri et al. (2018). This investigation was undertaken to evaluate the feasibility of utilizing recycled Tetra Brick Aseptic (TBA) containers as a sustainable alternative to virgin cellulose fibers in porous asphalt mixtures. The research revealed that incorporating recycled TBA material into porous asphalt mixtures provided similar, if not more, benefits compared to commercial cellulose fibers. This suggests that recycled TBA containers can be a suitable addition for porous asphalt mixtures, offering environmental advantages.

Shukry et al. (2016) assessed the chemical structure and microstructure of the anti-stripping additives to show that the resilience modulus of the samples made using diatomite is larger than that of the samples made with hydrated lime and regular Portland cement.

The porous asphalt mix's open structure affects its strength and durability. These conditions result in adhesion loss at the interfaces of binder-aggregate as well as cohesion loss inside the film of binder, confirming the necessity of anti-stripping additives.

9. OPTIMUM BINDER CONTENT AND POROUS ASPHALT MIXTURE DESIGN

IN the literature, a standard method for evaluating the bitumen content of a porous asphalt mixture has not been defined. Centrifuge kerosene equivalent is employed in some places, whereas drain down is the primary criterion in others. Besides, the most common methods for designing porous asphalt are those used by the Federal Highway Administration (FHWA), National Center for Asphalt Technology (NCAT), National Asphalt Pavement Association (NAPA) and European methods, which vary depending on the nation Huber (2000), Alvarez et al. (2006). These methods are different in the selection of materials, gradation, optimum asphalt content evaluation and efficiency.

In the realm of designing hot mix porous asphalts, Roffe (1989) have proposed a theoretical approach to calculate the optimum binder content. This calculation could be achieved through an empirical equation that depends on previously determined properties of aggregate. The equation is as follows:

$$OBC = 3.25\,(\alpha)\,\Sigma^{0.2}$$

$$\alpha = 2.65 SG_{agg} \qquad \text{Equation 1}$$

$$\Sigma = 0.21C + 54S + 7.2s + 135f$$

Where OBC represents the optimum binder content, SG_{agg} represents the apparent specific gravity of the mixed aggregate, and ∑ represents the specific surface area. Additionally, C represents the percent of aggregate retained on a 4.75mm sieve, S represents the ratio of material passed a 4.75mm sieve and retained on a 600µm sieve, s represents the percentage of passing materials from 600µm sieve and retained on a 75µm sieve, and f represents the ratio of material passing a 75µm sieve.

By utilizing these equations, designers can determine the optimal bitumen content for their hot mix pervious asphalt projects.

The determination of the optimal asphalt content is achieved through some tests in laboratory that utilize both compacted and un-compacted samples with varying bitumen contents. These tests are carefully designed to ensure accurate results and inform the selection of the ideal asphalt content for a given application.

Drain down, percent of air void, Contabro abrasion (conditioned and unconditioned), and Marshall tests are the fundamental tests employed to evaluate the optimal binder content in porous asphalt. It is essential to recognize that permeability magnitudes exceeding 100 m/day (328.08 feet/day) are highly desirable. It is important to remember that ASTM PS 129 does not require that permeability in compacted specimens be determined.

10.RECYCLED MATERIALS IN ASPHALT MIXTURES

The use of eco-friendly materials is crucial in reducing the undesirable effect of human actions on the environment, particularly in construction. These materials can either be recycled to conserve energy or designed to minimize the consumption of natural resources.

Numerous studies have confirmed that incorporating waste materials in porous asphalt mixtures can significantly enhance the characteristics of the mixture. Table 5 provides a comprehensive summary of these studies, which focus on the utilization of eco-friendly materials in porous asphalt mixtures. By utilizing these materials, not only can the performance of porous asphalt mixtures be enhanced, but also a more sustainable and environmentally conscious approach to road construction can be contributed to.

Table(1):- Eco-friendly materials in porous asphalt mixtures. Adopted from (Gupta et al., 2019).

Material	Waste Glass	Recycled Concrete Aggregate	Recycled Concrete Aggregate	Bleaching Clay	Red Mud	Activated Carbon	Reclaimed Tetra Pak	Activated Carbon
Reference	(Chen and Wong, 2013)	(Chen and Wong, 2013)	(Chen and Wong, 2015)	(Sangiorgi et al., 2016)	(Zhang et al., 2018)	(Huang and Liang, 2018)	(Andrés-Valeri et al., 2018)	(Hu et al., 2019)
Type of Additive	Aggregates	Aggregates	Aggregates	Filler	Filler	Additive	Fiber	Additive
Content %	94(Agg.)	100(Agg.)	16(Agg.)	5(Agg.)	1.5(mix)	8(mix)	0.25-0.75 (mix)	1-4(Agg.)
Air voids	16.5	19.4	19.5	-	≈18	20	≈20	21
Binder	Pen 60/70	Pen 60/70	Pen 60/71	PMB 45/80	SBS	-	VB 50/70	SBS
Binder Content %	6	5.5	6	5.1	4.8	5.95	4.5	6.03
Contabro (Dry)	X	XX	XX	XX	O	X	O	O
Drain down	O	X	O	-	-	O	O	O
ITS	O	-	O	O	-	X	O	XX
Moisture susceptibility	O	O	O	X	O	-	-	O
Stiffness	-	-	-	O	-	-	-	-
Permeability	X	O	X	XX	-	-	XX	-
Porosity	-	-	-	-	-	X	-	-
Rutting	X	-	X	-	-	-	-	O

Note: O means upgrading, X refers to no important differences, VB is virgin binder, XX refers to adverse effect by the mass of aggregate, -: The test was not conducted in the study.

Ground Granulated Blast Furnace Slag (GGBS) results from the production of iron and steel as a by-product. It is a finely ground material that has cementitious properties and can be used as an alternative to Portland cement in concrete and asphalt mixtures. PET powder, on the other hand, is a waste product from plastic bottles that can be recycled and used in different applications such as construction materials. Both GGBS and PET powder are environmentally friendly alternatives to traditional fillers, as they reduce waste and conserve natural resources.

Utilizing GGBS and PET as filler alternatives in porous asphalt is a straightforward process that requires evaluation to determine their impact on the mixture. It is important to evaluate how these components affect the overall functionality of the porous asphalt mixture. This evaluation will give important information about the possible advantages of adding GGBS and PET to the mixture. Through this action, the durability, strength, and sustainability of the porous asphalt mixture can be improved, rendering it a more feasible choice for road construction.

Polyethylene Terephthalate, or PET for short, is a type of plastic that is commonly used in everyday products, such as water bottles and food containers. It is a strong and lightweight material that can withstand high temperatures, making it perfect for storing hot liquids or foods. Despite its convenient properties, it is essential to remember that PET can have negative impacts on the environment if not disposed of properly. It takes hundreds of years for PET to decompose naturally, leading to excessive waste in landfills and oceans. By including recycled PET in asphalt mixtures as a supplement, filler, or aggregate, it may aid in mitigating the negative impact of this material.

Kamada and Yamada (2002) conducted research on the use of plastic waste in asphalt mixes. The study involved mixing plastic waste with asphalt as an alternative for the aggregates, and examining the effects of the mixed plastics on the characteristics of the asphalt mixtures. The study utilized various plastic waste, including recycled polyethylene pellets derived from PET bottle labels, crushed polyethylene from industrial waste, and mixed plastics from household waste. Overall, this study highlights the potential benefits of incorporating plastic waste into asphalt mixtures, which could lead to more sustainable and environmentally-friendly road construction practices.

A group of research enthusiasts conducted an experiment using plastic waste derived from PET bottles to prepare asphalt samples. Their research was a resounding success, as they were able to demonstrate that plastic waste bottles can be effectively recycled as aggregates in mixtures. The results of their experiment, as measured by Marshall stability and flow, were highly promising and described that the utilization of plastic in asphalt concrete has excellent prospects Ahmadinia et al. (2011).

An overview of investigations concerning the effect of PET addition to asphalt mixture can be seen in Table 6.

Table(2):- Investigation outcomes on PET utilization in asphalt mixtures.

Author	Asphalt Mixture	Using of PET as	% Of PET	Improvement
(Kamada and Yamada, 2002)	Dense and porous	Aggregate	Replacing with some gradations	Fluidity (rutting), stripping,
(Ahmadinia et al., 2011)	Stone mastic	Additive in binder	0-10%	Mechanical properties
(Zakaria et al., 2018)	Dense	aggregate	1-5% and glass aggregate	Stability and Flow
(Singh, 2019)	Porous	Additive in binder	3-10%	Contabro, Permeability, Drain down
(Tjaronge et al., 2020)	Porous	Additive	0-1.5% weight of mix	Adhesion (no negative effect)
(Mashaan et al., 2021)	dense	Additive	6-8 % of binder	Stiffness and elasticity
(Mashaan et al., 2021)	dense	Modified binder in mix.	8%	Stability, rutting resistance
(Mungathia et al., 2021)	Open graded	Shredded	0-7 %	Stability and Drain down

Ground Granulated Blast Furnace (GGBF) slag is a consequence of the iron industry that has been increasingly used in construction as a result of its cost-effectiveness and environmental benefits. One application in particular is using GGBF as a substitute for part of the sand or fine aggregates in asphalt mixes. Overall, using GGBF slag in asphalt provides not only performance advantages but also contributes towards sustainable development through recycling industrial waste materials into valuable resources for construction purposes.

Nazarinasab et al. (2018) conducted research on the characteristics of porous asphalt, utilizing a bitumen that was modified with steel slag powder and crumb rubber. The results of the research indicated a decrease in the viscosity of the binder, while simultaneously increasing its stability, ITS, permeability, and porosity.

An overview of investigations concerning the effect of ground granulated blast furnace slag (GGBS) addition to asphalt mixture is shown in Table 7.

Table(3):- Investigation outcomes on GGBS utilization in asphalt mixtures.

Author	Asphalt Mixture	Using of GGBS as	% Of GGBS	Improvement
(Nassar et al., 2016)	Cold asphalt emulsion mixture	Replaced limestone	incorporated by Silica fume and fly ash	Creep stiffness, durability for moisture and frost damage.
(Lekhaz et al., 2016)	Dense mixture	Replaced filler	100%	Almost same Marshall a bit of improve
(Marandi et al., 2017)	Porous mixture	Partial sub with SBS	2.5% SBS+2.5% GGBS to binder	Decrease pen. And ductility, increase softening point, Marshall, ITS,
(Xiao et al., 2019)	Dense mixture	Replaced filler	0-100%	Adhesion, Marshall, moisture damage
(Al-Hdabi et al., 2019)	Dense mixture	Replaced with cement filler	100%	Rapprochement with control mix, Marshall, ITS
(Adiba et al., 2020)	Dense mixture	Additive to binder with bones	5-15%	Stability and flow

11.SUMMARY

Asphalt binders have a very complex chemical composition. Moreover, hot asphalts mixtures have sensitive properties against different conditions affecting the mixture. Therefore, for better performance, mixture preparation requires accurate investigation and deep understanding of the properties of the mixture itself and of the materials that make up the mixture. Nowadays, since porous asphalt mixtures are open graded mixtures, more susceptible to oxidation, faster aging process and more likely to fail under heavy loads, therefore understanding their properties is crucial for the wiser use of such mixtures in real practice.

Researchers are currently exploring ways to improve the performance of porous asphalt, which could have significant implications for road construction projects that involve medium and heavy traffic loads. To achieve this, they are experimenting with a range of materials, including chemical additives, aggregate gradation, Nanomaterials, and different types of fillers.

To determine the most suitable mixture, a variety of tests should be conducted, such as Cantabro, drain down, Marshall stability and flow, ITS, TSR, and air voids analysis. These tests have shown that the current mixture is best suited for lower traffic volumes, and further improvements are necessary to make it more appropriate for medium or heavy traffic loads.

This research introduces the methods for enhancing the mechanical properties of porous asphalt by exploring the impact of different types of fillers in the mixture. Specifically, the traditional limestone filler is replaced entirely by recycled waste fillers, such as GGBFS and PET to improve the mixture's performance beside its environmental benefits.

Recycled fillers create a more sustainable and eco-friendly solution for road construction projects that would be suitable for medium and/or heavy traffic loads. The findings of this researches could have a significant impact on the industry, leading to the widespread use of porous asphalt in high-traffic areas.

12. CONCLUSIONS

Asphalt binders are chemically complex, and hot mixtures are sensitive to various conditions. Accurate understanding of their properties is important, especially for porous asphalt, exposed to oxidation and faster aging. This knowledge is vital for its effective use in road construction under medium to heavy traffic loads.

This review paper provides a comprehensive overview of the literature on porous asphalt mixtures, highlighting their significance as a crucial element in permeable pavement systems.

From the research, the following results can be drawn:

- Stability is an important issue with porous asphalt mixtures
- Gradation of aggregate affects the efficiency characteristics of PA
- Porous asphalt improves safety; however, it has a shorter service life but offers long-term benefits.
- Close to 4% of crumb rubber can be utilized in different weather situations. It enhances crack resistance, improves the stiffness of the bitumen and reduces abrasion resistance in the mixes.
- Fibers as additives prevent drain down in mixtures since they absorb the binder but do not increase raveling. In some cases, fiber modifiers could help increase strength but on the account of reducing permeability.
- It was found that additives like Polyethylene could enhance durability of the PA while maintaining the permeability at the desired level.
- Different filler types and content have different consequences on the durability and performance characteristics of PA.
- Nanomaterials (Nano Particles) can improve the mixture characteristics when used as additive to either the binder by 2-6% of binder’s weight or the mixture provided that the optimum Nano percent is controlled. It was observed that Nanomaterial when used as filler in the mixture is more expensive.
- Different binder types with higher viscosity showed significant improvements of the mixture’s performance.
- In the evaluation of moisture susceptibility, a modified binder using polymers demonstrates an improvement in mixture properties.
- Air voids of 20% and higher enhances durability of PA mixture and provides less clogging mixture.
- Any replacement for filler is possible for porous asphalt mixture in range of 2-4 % of total mixture weight as 3.0% for limestone, PET and GGBFS fillers.
- Different percent of recycled materials based on aggregate, binder or mixture’s wight may be used to improve the properties of the mixture.

13. RECOMMENDATIONS

- The incorporation of fibers and polymers into porous asphalt to improve the mixture's mechanical characteristics and air voids.
- Modifying the porous asphalt mixtures by substituting various types of fillers for limestone.
- Modifications to porous asphalt's stability to support medium or heavy traffic volumes.

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