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A Comprehensive Review on the Effect of Filler Materials on Engineering Properties of Asphalt Concrete Mixes

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ABSTRACT

The effect of filler materials on the properties of bituminous concrete was reviewed in this paper. Flexible pavement layer is made up of asphalt concrete. It is the commonest type of pavement in the world. Asphalt concrete contains aggregates, bitumen binder and fillers. The Asphalt concrete has voids which needs to be filled for better performance of its functions. Fillers help to fill voids and change the physical and chemical properties of asphalt concrete and bitumen combines with filler to forms mastic that holds the aggregates together. Asphalt Institute recommended 4-8% fillers for use. The recent developments in technology is geared towards the use waste materials as fillers in concrete production. It was revealed in this review that Marble dust and Calcium Carbide Residue (CCR) can be used in bituminous mix as alternative to conventional fillers in asphalt mixes. The waste bagasse and coconut peat fillers give mastic viscosity similar to limestone filler but higher than granite filler. Concrete dust and brick dust as fillers in bituminous mix improve flow value, Marshall stability and physical characteristic of bitumen.The conclusion of this review analysis shows that fillers in bituminous mix reduces the problem associated with waste disposal and high concentration of calcium carbonate in waste ash can help to reduce rutting and moisture damage potentials.

KEYWORDS: Pavement, Filler, Marshal Stability, Marshal Flow, Mineral filler, Optimum Bitumen Content (OBC)

1. INTRODUCTION

Pavement is a durable coating laid on a targeted area of land to support vehicular and pedestrian movement. Flexible or (Asphalt) pavement is mostly used in highway construction because it is economical to construct and maintain. Flexible pavements are made of asphalt mix. Asphalt mixture consists of Aggregates, Bitumen and fillers in different proportions. The aggregates are coarse and fine aggregates. Coarse aggregates are made up of particle sizes that are more than 4.75 mm while fine aggregates have particle size less than 4.75 mm. The properties of aggregate used for flexible pavements are hard, durable, crushed rock and free from impurities. Hot Mix Asphalt (HMA) are manufactured by hot-mixing of appropriate proportion of Bitumen, fine aggregate, Coarse aggregate and filler material in an asphalt plant. Coarse aggregates contribute to large voids in Asphalt mix which are filled up by fine aggregates. All voids are not filled by fine aggregates; some still remain which can only be filled by fillers. Fillers play important role in filling voids. It also improves the physical and chemical properties of mix

Fillers increase the densification of aggregates and also determine the Optimum Bitumen Content (OBC) of mix. The major filler used in Hot Mix Asphalt is cement. Adetoye and Oladejo (2022) stated that cement production leads to release of large amount of CO_2 to the atmosphere and also pollutes the environment. This leads to extensive research work on waste materials with low carbon footprint as a potential substitute to cement.

Pozzolans such as rice husk ash, fly ash, limestone furnace slag, cassava peel ash, incinerator ash and siliceous materials which are agricultural and industrial wastes are used as fillers, they require less energy but are difficult to obtain because of their particle sizes which are less than 0.075mm (passing through sieve No. 200 in gradation test). In many cases, aggregates must be crushed to obtain needed fillers.

2. LITERATURE REVIEW

Highway pavement is a structure which consists of layer of materials that are superimposed above the natural soil sub-grade. Flexible pavement is the type of pavement whose surface layer is constructed with asphaltic or bituminous concrete. The function of flexible pavement is to distribute the applied vehicle loads to the sub-grade and also provide a good surface for riding, adequate skid resistance and low noise pollution.

2.1 Pozzolanicity of Agricultural Wastes

Pozzolan is a material containing siliceous or alumina-siliceous element which in finely form and in the presence of moisture will chemically combine with calcium hydroxide at room temperature to form compounds possessing cementitious properties (Canadian Standard Association, 2000). Agricultural wastes are wastes such as rice husk ash, wood ash, bagasse ash, groundnut husk ash, corn cob ash, cassava peel ash etc., are good cementing materials. Mangi et al. (2017) conducted a research to ascertain pozzolanic properties of sugarcane bagasse. The chemical combination of sum of alumina, silica and ferrous oxide was 78.2 %. Elinwa (2016) reported that Saw dust ash as a pozzolan which reacts with the hydration product of cement Ca(OH)2 to produce C-S-H which added more strength to concrete. Amu et al. (2005) conducted a research on the use of wood ash in the stabilization of lateritic soil. Fajobi and Ogunbanjo (1994) used wood ash to impact greater strength to sub-grade. Salau and Olonade (2011) confirmed cassava peel ash as a pozzolanic material. Basha et al. (2020) reported the result of the chemical properties of cassava peel ash as 79% of combined silica, alumina and ferric oxide. The chemical compositions of Saw dust ash using X-ray diffraction shows calcium pyrophosphate ($Ca_2H_2O_8P_2$) 38.00 %, Calcite ($CaCO_3$) 28.90 %, Quartz (SO_2) 24.20 %, Potassium nitrate (KNO_3) 6.40 %, Sodium Chloride (NaCl) 1.00 %, Carbon graphite 2H (C) 0.60 %, Periclase (MgO) 0.60 % and Potassium Chloride (KCl) 0.20 %.

Table 1. Chemical Composition of Brick Powder and Limestone Powder (Chen et al., 2011).

Component	Brick powder (%)	Limestone powder(%)
SiO_2	68.10	17.95
CaO	2.05	46.90
$Al_2 O_3$	16.35	0.46
Fe_2O_3	6.64	0.52
MgO	1.43	3.64
K_2O	2.38	0.10
Na_2O	1.20	0.08
TiO_2	0.85	0.03
SO_3	0.11	0.02
P_2O_5	0.26	0.04
MnO	0.06	0.14
ZrO_3	0.05	0.11
SrO	0.02	0.02
ZnO	0.03	0.01
BaO	0.07	0.02
Cl	0.00	0.00
LOI	0.80	29.95
Total	99.80	99.99

2.2 Filler materials

Fillers are fine powders with less than 75µm (No. 200) BS sieve. They occur naturally as calcium carbonate, kaolin, basalt, caliche, dolomite, limestone, volcanic ash, granite or gotten from industrial waste e.g. furnace slag, fly ash from power plant. Some agricultural wastes such as rice husk ash, bagasse ash, wood ash etc. have been successfully used as fillers in Asphalt concrete.Anzar (2018) studied the use of brick dust and concrete dust as filler material. The effect of Marshall Properties of Bituminous mixes were studied and compared. The results of the experimental study on adding of fillers revealed an improvement on the physical characteristics of bitumen, stability and flow value of bitumen mix. Asphalt institute in India recommended the use of 4-8% of filler in bituminous mixes. Filler materials are added to dense-graded asphaltic concrete mix to fill up the void spaces in between aggregates and minimize the gaps in the mix.

Table2: Physical Properties of Mineral Fillers (Noor, 2010).

Property	**Portland Cement**	**Silica fume**	**Fly Ash**
Specific Gravity	3.12	2.5	1.41
% Passing sieve No.200 ASTM C117	90	90	90

Rashad et al. (2013) in his paper "Metakaolin as cementitious material: History, source, production and composition –A comprehensive overview" revealed that Kaolin is an industrial mineral that can help satisfy the world demand for filler. They are provided to fill voids in Asphalt concrete, excess amount of fillers may lead to increase in stability, brittleness and tendency to cracking. Lack of filler material increased void content, lower stability and the mix. Fillers used in bituminous mixes are Lime, Cement, Fly ash, Pond ash, Stone waste, Saw dust ash, Rice husk ash, Sewage sludge ash. Ceramic dust, Brick dust, Marble dust, Glass powder Coal waste, Metakaolin etc.

Table 3: Physical characteristics of filler materials (Basah, 2020).

Sieve size (mm)	Test method	Standard value
0.6	AASHTO M-17	100
0.3	AASHTO M-17	95 - 100
0.075	AASHTO M-17	70 - 100
Plastic index	AASHTO M-17	≤ 4
Specific gravity	ASTM D-854	-

2.3 Asphalt Concrete.

Several researches have been carried out and published on the use wastes (Agricultural and industrial) material in Hot Mix Asphalt (HMA). Management of agricultural waste by reprocessing is one of the best, most convenient and economicalway of disposing agricultural waste materials. Afolayan et al. (2022) in review of the effect of pozzolanic properties of metakaolin revealed that the utilization of supplementary cementitious waste material in concrete can help to reduce the technical, economic and environmental issues caused by cement production. Anzar (2018) defined asphaltic concrete as bituminous concrete made from a petroleum product (Bitumen) stated that it is used for roadways, curbs, pathways, walking paths etc. Pavement is the travel surface made durable and serviceable to withstand the traffic load travelling on it. Mix design helps to determine the proportion of aggregates, bitumen and fillers so as to produce strong, economical, durable and workable mix.

Table 4: Physical characteristics of asphalt.

Property	Test method	Standard value
Penetration,100 gm, 5 sec at 25 °C	ASTM D-5	60 - 70
Ductility, 5 cm/min at 25 °C	ASTM D-113	100 +
Specific gravity at 25 °C	ASTM D-70	1.01 - 1.06
Softening °C	ASTM D-36	46 - 56
Flashpoint °C	ASTM D-92	≥ 230
Solubility %	ASTM D-2042	≥ 99
Loss on heating	ASTM D-6	≤ 0.2

Ashiru et al., (2021) accessed the performance of asphalt concrete with coal bottom ash as partial replacement of cement in the mineral filler. Marshal Mix design method of HMA samples preparation and testing was used. The Marshall Stability, volumetric properties and flow test results obtained showed that the samples prepared with 5.5 OBC and 25% CBA as filler satisfied the requirements of the NGSRB for wearing course of flexible pavement. Addition of 25% CBA by volume of cement in asphalt concrete can reduce pollution of the environment by the waste material and reduce consumption of cement thereby reducing the total cost of production of cement.

Mistry and Roy (2021) conducted an investigative research into the use of Fly ash, Rice husk ash (RHA) as alternative fillers and hydrated lime as conventional filler in bituminous mastic performance. The percentage of filler used varied from 2%, 4%, 6% and 8 % by weight of aggregate and the percentage of binder percentage varies from 4.5 % to 6.5% with an increase of 0.5% by the weight of aggregate used for Marshall mix design. Tests conducted are Marshall stability, ITS, TSR tests on bituminous mixes. The result gotten showed that at 4% and 6% filler contents the RHA mixes and FA mixes shows less OBC values of 5.95% and 7.6% less than conventional HL bituminous mixes. Rice Husk Ash mixes showed greater ITS than the control HL mix. Also fly ash and Rice Husk Ash mixes revealed higher Marshall stability and Volumetric properties when compared to control HL mixes. It was finally concluded that RHA mastics showed higher adhesion force than the control HL mastic at 0.8 f/b ratio.

Krit (2020) determined the effect of using bagasse and coconut peat as filler material on mastic viscosity. The result of the findings revealed that using coconut peat and bagasse as fillers shows similar viscosities of asphalt mastic with that of limestone filler for all temperatures at 20 percent filler content. The waste bagasse and coconut peat fillers give higher mastic viscosity to granite filler but similar to limestone filler.

Dulaimi, A. et al. (2020) conducted a research by replacing limestone filler with calcium carbide residue (CCR) at different ratios of 0%, 3%, 6% by aggregate dry weight in Hot Mix Asphalt (HMA). It was shown in the research that CCR as filler showed a good performance in stiffness modulus, permanent deformation resistance and durability (based on water sensitivity results). CCR can also be used as antistripping agent and doesn’t contribute harmful impact on the environment when used as fillers in HMA based on toxicity characteristic leaching procedure (TCLP) test. CCR were recommended to be used as filler in Hot Mix Asphalt.

Basha (2020) researched into the use of sawdust ash as filler material in asphalt concrete production. Physical and chemical properties of Saw Dust Ash (SDA) were determined. A control test of Asphalt specimen was prepared using basaltic stone dust without sawdust as filler. The result of the experiment showed that Saw Dust Ash enhanced the fatigue life and permanent deformation of asphalt concrete at variable temperature. Furthermore, an optimum value of SDA that can replaced the basaltic dust is 12 % in asphaltic concrete production.

Tarbay, et al. (2019) investigated the use marble waste as an alternative to the traditional filler limestone in hot mix concrete. The result of the research on the use of marble waste showed higher Marshall stability value than the limestone filler mixes. The result also stated mixes with marble dust produced higher indirect tensile strength ratio. The prepared mastics using marble waste had higher softening point value and RV Viscosity compared to the limestone mastic. The prediction of pavement performance of waste filler mixes using QRSS software exposed better rutting resistance when compared to limestone mix.

In the research conducted by Nwaobakata and Eme (2018), Almond leave ash (ALA) was used as partial replacement of Quick lime (QL) as fillers in Hot-Mix Asphalt (HMA). Hot mix asphalt specimens were produced in the laboratory with varying proportions from 0.5% to 4.5% of Quick lime. Marshall method was used for testing. The results of the investigation showed good performance of HMA with the addition of ALA and QL at a ratio of 4.5% almond leave ash and 2.5% Quick lime. The mix ratio satisfied the marshalcriteria for medium and light traffic.

Satish et al., (2018) presented a review paper on the use of Rice Husk Ash as mineral filler in hot mix SDBC. Many researches have been conducted on the addition of waste filler materials by different scholars. Addition of OPC and waste materials such as cement kiln dust, rice husk ash and lime as filler materials were studied and their effects analysed. The final conclusion showed that the use of different types of fillers increased the marshal stability values, lifespan of pavement and lowered pavement deformation. There was increase in fatigue resistance and provides better adhesion between asphalt and aggregates. It increases the durability of flexible pavement.

Mohammad et al., (2016) revealed the effect of concrete dust and brick dust as fillers on bitumen mixes. The properties of the bituminous mixes were studied and compared using Marshall Method of mix design. They also conducted tests on aggregates and bitumen and compares the results with specification. The final result of the study revealed that incorporating concrete dust and brick dust as fillers in bituminous mix improves flow value, Marshall stability and physical characteristic of bitumen.

Yasanthi et al (2016) revealed the performance of waste materials such as wood saw dust, PET and hot mix asphalt waste in bituminous concrete. The behaviour of Hot Mix Asphalt concrete was examined when waste materials were introduced in some suitable replacement percentages. The results showed that wood saw dust carbonized in oxygen-less condition suitable to be used in replacing the traditional filler in HMA.

Ceramic waste was investigated by Fatima et al. (2014) as a filler material in semi-dense bituminous concrete. Results of the research shows that there is an increase stability values and other parameters of samples containing ceramic wastes were improved in comparison to conventional mineral filler.

Sadeeq et al (2014) conducted a research in Reclaimed Asphalt Pavement (RAP) with Rice Husk Ash (RHA) blends as Filler. RAP was reconstituted with fresh aggregate with Rice Husk Ash (RHA) used in partial as replacement for Ordinary Portland Cement (OPC). Marshall Stability tests were conducted on various mixes to study the pavement performance indices of the blended materials. The mix constituents that is most effective and meets all design requirements is 70% RAP, 27% fresh aggregate and 3% mineral filler. An optimum value of RHA filler in partial replacement of OPC was 25%. From the indirect tensile strength test results, it clearly showed that the use of RHA as filler contributes significantly to crack resistance of recycled asphalt pavement than OPC filler.

Onyeiwu et al (2014) presented a report on the use of RHA as filler in Asphalt concrete pavement. Marshall Stability method was used to test the performance of the materials. Several trial mixes with bitumen contents of 4.5%, 5.5%, 6.5% and 7.5% were produced so as to obtain the OBC. The experimental investigation focused on the partial replacement of the cement by RHA in the following order 0 % (control), 5%, 7.5%, 10%, 12.5%, 15%, 17.5%, 20%, 22.5%, & 25%. The total 42 mix specimens were produced and used for the experiment. 12 specimens were compacted with each percentage of bitumen content to determine the Optimum Bitumen Content (OBC) and 30 specimens were used to determine asphalt concrete strength. Marshall Stability- flow test and density-void analysis were conducted on the specimens. The results obtained showed that the performance of mix containing 10% RHA have stability, flow, CDM, VIM, VMA and VFB of 7.63%, 2.19 mm, 1.78gm/cc, 28.23%, 36.77% & 23.23% respectively at an OBC of 5.5% which satisfied the provision in the standard specification requirement of Marshall criteria by Asphalt Institute (1979). 10% RHA was recommended for use in partial replacement of cement as filler in Asphalt Concrete mix.

Chandra et al. (2013) conducted a research on filler materials such as industrial wastes (marble dust, granite dust and fly ash) with hydrated lime and stone dust from quartzite in bituminous concrete. The results showed that marble dust, granite dust, and fly ash could be used as a filler material in bituminous mixes. Among all these wastes, marble dust showed the best result with the lowest optimum binder content (OBC).

Karasahin, et al. (2007) conducted a research on the use marble dust as filler in bituminous concrete. The results showed similar performance between limestone and marble dust. The marble dust in the mixes had higher values of the plastic deformation.

Noor (2010) evaluated the influence of new different fillers (portland cement, fly ash and silica fume) gotten from different local sources on the performance of asphalt mixtures. A detailed experimental Investigation was conducted on the properties and effect of filler type on asphalt concrete. Marshal Mix design was used on all types of fillers at different ratios to evaluate the performance of filler quantities in the asphalt mixture. The properties of mixes were conducted using marshal test, indirect tensile strength and creep. Indirect tensile test at three different tests temperature of 15^0 C, 30^0 C and 45^0 C were adopted to investigate the effect of change in temperature on the susceptibility of these mixes. The results of the study show that replacement of portland cement by 9.8% of silica fume worsen the resistance of the mixes to rutting and cracking. Coal fly ash is also not suitable and cannot be used as filler in HMA paving applications.

Table 5: Marshall properties with BSD and SDA (Basah, 2020).

Mix properties	**BSD**	**SDA**	**Standard values**
OBC (%)	5.2	5.6	4 - 10
Unit weight	2.31	2.15	-
Air void (%)	4.26	10.12	3 - 6
Stability KN	11.27	8.94	≥ 8
Flow mm	3.63	3.33	2 - 4
VMA (%)	20.91	25.90	≥ 14
VFB (%)	71.60	55.55	65 - 73

3. CONCLUSION

From this review, it has shown clearly that

(i) Agricultural and industrial waste materials can be advantageously utilised in pavement construction and the use of wastes as fillers in bituminous mix reduces the problem associated with waste disposal.

(ii) Agricultural and industrial wastes have potentials be used to produce asphalt concrete with improved properties.

(iii) Marble dust and CCR can be used in bituminous mix as alternative to conventional fillers in asphalt mixes.

(iv) Ceramic waste filler material in semi-dense bituminous concrete shows an increase stability values comparison to conventional mineral filler but coal fly ash is also not suitable for use as filler in HMA paving applications

(v) The bagasse and coconut peat fillers give mastic viscosity similar to limestone filler but higher than granite filler.

(vi) Concrete dust and brick dust as fillers in bituminous mix improves flow value, Marshall stability and physical characteristic of bitumen.

(vii) High concentration of calcium carbonate in waste ash can help to reduce rutting and moisture damage potentials. Asphalt concrete mixture containing fly ash has less workability and tensile strength when compared to other asphalt concrete mixes while silica fume and portland cement have more workability and higher tensile strength in asphalt concrete mixes.

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