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Effect of Ceramic Waste Powder on Rutting and Dynamic Modulus of Asphalt Mixture

Zarak Khan[1], Abbas Khan[2]
[1]Research Scholar, Department of Civil Engineering, Abasyn University Peshawar, Pakistan
[2]Research Scholar, Department of Civil Engineering, Comsats University Islamabad Abbottabad Campus, Pakistan

Abstract: Aggregates, asphalt binder, and mineral filler are blended in appropriate proportions to guarantee the desired characteristics of asphalt. Besides from aggregates and bitumen, the role of filler material in HMA is critical since it affects the mechanical characteristics and serviceability particularly when subjected to wheel load. The current research investigated the effect of Ceramic Waste Powder (CWP) used as filler in terms of rutting, and dynamic modulus of asphalt mixtures when used in different proportions 20%, 40%, 60%, 80% and 100% by weight of Marshall Specimen, and the results were compared to conventional mixture employing stone dust as a filler. The performance testing revealed that the rut resistance increases with the increase in CWP content from 40 % to 60 % in asphalt mixtures and showed 21 %, and 58 % decrease in rut depth value to that of conventional asphalt mixture at 55 °C respectively. While dynamic modulus increases as the frequency of the applied load increases from 0.1 Hz to 25 Hz and it decreases when the temperature of the dynamic modulus test increases from 4.4 °C to 54 °C. Higher values of Dynamic Modulus are observed at 21.1°C and 37.8 °C temperature for all frequencies. Therefore, using CWP as filler in asphalt not only increases the mechanical properties of HMA but also be a suitable approach towards reducing ceramic waste pollution.

Keywords: Asphalt Mixtures, Ceramic Waste Powder, Dynamic Modulus, Rutting Resistance, Stone Dust

I. INTRODUCTION

Due to the rapid increase in world population, an increase in the volume of solid waste is occurring day by day. For sustainable environment, waste management is very necessary. One of the most important types of this solid waste is ceramic waste. Local ceramic industries that produce ceramic utensils, bricks, floors, tiles, pipes, bathroom sets and many other things, about 2 % to 3 % of their products are rejected during manufacturing processes. These rejected and refused materials (pellets, substantial particles, powder) cannot be reused and recycled in same industry, so these materials are thrown out and disposed into solid waste landfills which are an environment concern. More than 12 billion m^2 ceramic tiles are produced globally that generate ceramic waste powder (CWP) at the rate of 19 kg/m^2 due to which the generation of CWP exceeds 22 billion tons globally [1].Premature cracking, rutting and shoving are the main problems in asphalt pavement that develops quickly after the operation of pavement [2] which reduce the service life , safety and comfort of asphalt pavement [3]. Most common problem of roads in Pakistan is rutting which is the depression or groove by the wheels and fatigue. Construction and maintenance of these road distresses are very costly [4].Filler is one of the most common modifies that can be used in an asphalt pavement to increase the cohesion and adhesion between the particles of asphalt mixture and reinforce the pavement [5].

The main aim of this study is to use this ceramic waste powder obtained from different ceramic materials manufacturing industries of Hayatabad industrial zone as a filler material in 20,40,60,80 and 100 percentages in asphalt mixture and check the effect of this waste ceramic powder on asphalt mixture. Filler material plays a very important role in different characteristics of asphalt mixture because it has significant effect on the workability, moisture susceptibility, stiffness and aging characteristics of asphalt mixture [6]. The use of ceramic wastes in asphalt pavement significantly reduces the consumption of natural aggregates and fillers [7] which is a good step towards sustainable environment and its use also reduce the problem of landfill. The design method that we are going to use in our research is Marshall Mix design, but the compaction equipment is gyratory compactor. The main reason behind gyratory compactor is that compaction also plays a very important role in improving the pavement performance under heavy traffic [8][9].The point of matter is to make such steps that can make asphalt mix design effectively strengthen, economical, environment friendly and durable, simply to increase the mechanical properties of hot mix asphalt. Research shows that using CWP as a filler material in hot mix asphalt gives high stiffness, better bitumen interaction with filler, good aging properties and high resistance to rutting in HMA as compared to controlled samples [10].

II. LITERATURE REVIEW

It has been concluded by [11] that the use of ceramic dust and butyl rubber improve the temperature susceptibility and rheological properties of bitumen due to which asphalt mixture shows high resistance to rutting, and have high stiffness and flexibility as compared to controlled sample. Asphalt mix prepared with ceramic dust shows high fatigue life and has greater water resistance than mixes prepared with stone dust and marble dust. When waste materials of industries are used in asphalt mix it leads to increase in tensile strength and resilient modulus of the asphalt mixture [12]. It has been observed that the addition of ceramic waste power increase rutting resistance, furthermore it also increases the tendency of temperature cracking and fatigue cracking in pavement. CWP modified asphalt shows that the permanent strain and total strain of asphalt mixture during loading unloading can be significantly reduced which causes improvement in resistance to permanent deformation [13]. CWP is likely to be use significantly and effectively as a mineral filler in asphalt mix as it provides high stiffness, good aging properties, good interaction with bitumen, and high resistance to rutting and same fatigue performance to conventional limestone filler [8]. It has been evaluated that asphalt mixture prepared with CWP shows better performance in high and low temperature properties [14]. Ceramic dust satisfies all minimum required limits specified in MORTH bituminous concrete mix for filler material and the use of ceramic waste in asphalt mixture in place of conventional filler like stone dust and lime dust is highly sustainable and durable [15]. It has been obtained that asphalt mixtures prepared with National Highway Authority (NHA) class B has less rutting as compared to both conventional and NHA class A mixtures [16]. Physical, chemical and morphological properties of ceramic waste powder prove it to be the best waste for binder modification in an asphalt pavement. On increasing the proportion of replacement of ceramic waste with natural aggregates decreases the Marshall Stability value, increases the Marshall Flow value and it also changes the optimum binder content of asphalt mixture. 34 concluded that the presence of nano ceramic powder used for modification of bitumen in asphalt pavement shows better adhesion between bitumen and aggregates and its presence also strengthen the structural integrity of asphalt pavement [17]. It has been indicated that from gradation of CWP it is confirmed that CWP falls in the gradation range specified in AASHTO M17 specification requirement. Mineral composition showed that the sum of SiO_2, Al_2O_3, Fe was above the minimum requirement of ASTM C618, Class N, (Natural Pozzolan). [18]. Asphalt mix having ceramic tiles wastes as filler material shows high Marshall Stability which means an increased resistance to horizontal deformation for HMA. Furthermore, a slight reduction in Marshall Flow which shows that no such effect in vertical deformation occurs after changing the type of filler. Specific gravity, bulk specific gravity, theoretical maximum density, flow and the void ratio are under the range which shows high potential of using pulverized ceramic tile waste in hot mix asphalt as a filler material [19].

III. OBJECTIVES OF RESEARCH STUDY

Primary objectives of this research are as follow:

1) Using Ceramic waste powder as a supplementary filler material in asphalt mixture at different proportions (20%, 40%, 60%, 80% and 100 %).
2) To evaluate and assess the CWP for suitability to be used in asphalt mixture as a filler material.
3) To assess and compare the asphalt mixtures in terms of rut resistance and dynamic modulus, using stone dust and ceramic waste powder as filler material in HMA.

IV. RESEARCH METHODOLOGY

Different preliminary tests are performed on aggregates, asphalt binder and filler material to check its suitability to be used in asphalt mix design. Marshall Mix design procedure is employed for finding optimum binder content (OBC) which gives us the optimum quantity of bitumen used in final mix design of asphalt mixture. 2 samples of each bitumen content percentage, a total of 10 samples are made according to Marshall Mix design and evaluated based on Marshall Stability, Marshall Flow, Va, VMA and VFB. OBC is calculated as the average value of the bitumen content which corresponds to the peak values of Marshall Stability, Unit weight and bitumen content at 4 % air voids which is found to be 4.32 %. This OBC is further used in samples preparation for performance tests. Samples having 7000 g weight are prepared for performance test which are cut, cored and sliced according to their desire dimensions for performing wheel tracker and dynamic modulus performance test. Using OBC weight of aggregates, bitumen and filler material is calculated which are used in preparing 7000 g sample. As this study focused on evaluating the effect of ceramic waste powder used as a filler material on the mechanical properties such as rutting and dynamic modulus of asphalt mixture, so the filler content of stone dust which is 334.88 g calculated using OBC is replaced with 20 %, 40 %, 60 %, 80 % and 100 % CWP. The remaining portion of 7000 g sample consists of 302.4 g asphalt binder and 6697.6 g of aggregates.

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Aggregates and asphalt binder are mixed at a temperature of 152 ° C and compacted at 139 ° C using Gyratory compactor instead of Marshall Impact hammer. The main reason behind using gyratory compactor is that it is a fully automatic machine which stimulates and produces the actual compaction conditions within the actual road paving operations. Both rotary action and vertical resultant force are applied on the sample by Gyratory compactor due to which the samples prepared through Gyratory compactor shows high strength as compared to the Marshall Impact hammer.

A. Wheel tracker test

Wheel tracker performance test is performed on asphalt mixture to evaluate the rutting susceptibility of asphalt mixture in the form of rut depth (mm). Rutting is the permanent deformation that occurs in the wheel path due to heavy traffic. It is one of the most important type of failure that can occur in an asphalt pavement which has a great impact on the service life of asphalt pavement 10. A sample having 50 mm thickness is tested using wheel tracker test apparatus at a temperature of 55 ℃ by applying 700 ± 10 N load at 26.50 ± 1 RPM or 53 passes per minute using tread less tyre with solid rubber on it having diameter of 200 mm and width of 50 mm. The track width for the sample is 50 ± 5 mm. The specimen used for testing is condition for 4 hours in environmental chamber before starting the test. A total of 10,000 cycles are passed on each sample having different proportion of CWP (20 %, 40 %, 60 %, 80 % and 100 %).

B. Dynamic Modulus Test

Dynamic modulus is defined as the ratio of peak stress over peak strain. It shows us the stiffness of asphalt mixture when a repeated compressive load is applied on it [20]. Bitumen is heated up to 165 °C and aggregates up to 170 °C. After heating both the aggregate and bitumen are mixed to make an asphalt mixture which is kept for 4 hours at 135 °C for short term aging. After short-term aging the mixture is again heated for half an hour at 152 °C for sample preparation. The mixture is poured into the gyratory compactor mould and compacted using gyratory compactor. The sample is allowed to cool for some time after which it's coring and slicing is done to bring the sample to the desire shape and size. The sample used in dynamic modulus test has diameter of 100 mm and height of 150 mm. This sample is then tested in dynamic modulus test apparatus for finding permanent deformation in asphalt pavement when a repeated compressive load (stress) is applied on it at 4 different temperatures (4.4 ℃, 21.1℃, 37.8 ℃ and 54 ℃) and 6 different frequencies (25 Hz, 10 Hz, 5 Hz, 1 Hz, 0.5 Hz and 0.1 Hz).

V. EXPERIMENTAL INVESTIGATION

Four different types of materials bitumen, aggregates, stone dust and CWP are used in this study, which are mixed according to the mix design in desire proportions in hot form to make asphalt mixture. Different physical properties of these materials are investigated through different tests which are explained below to check its suitability in asphalt mixture.

A. Aggregates

Aggregates from Margalla Hills Islamabad, Pakistan are used in this research. Different tests are performed on aggregates to evaluate its physical properties which are shown in Table I.

Table I: Properties of Aggregates

Property	Value	Limits
Impact value, (%) ASTM D587	19.09 %	< 35 %
Los Angeles abrasion, (%) ASTM C131	24.16 %	< 30 %
Specific Gravity test, ASTM C127	2.63	2.5 to 3
Water absorption test, (%) ASTM C127	1.09 %	0.1 to 2 %
Flakiness index, (%) BS 933-3	7.60 %	10 (Max)
Elongation index, (%) ASTM D4791	6.93 %	10 (Max)

After sieve analysis the final proportion of each aggregate particle size is obtained which is used in mix design. The percent passing and NHA specification lower and upper limits are plotted against each other to check whether the aggregates satisfy the criteria for the mix design and are suitable for use in asphalt mixture. The proposed gradation curve is found to be satisfying NHA Class B gradation which is shown in Fig I below.

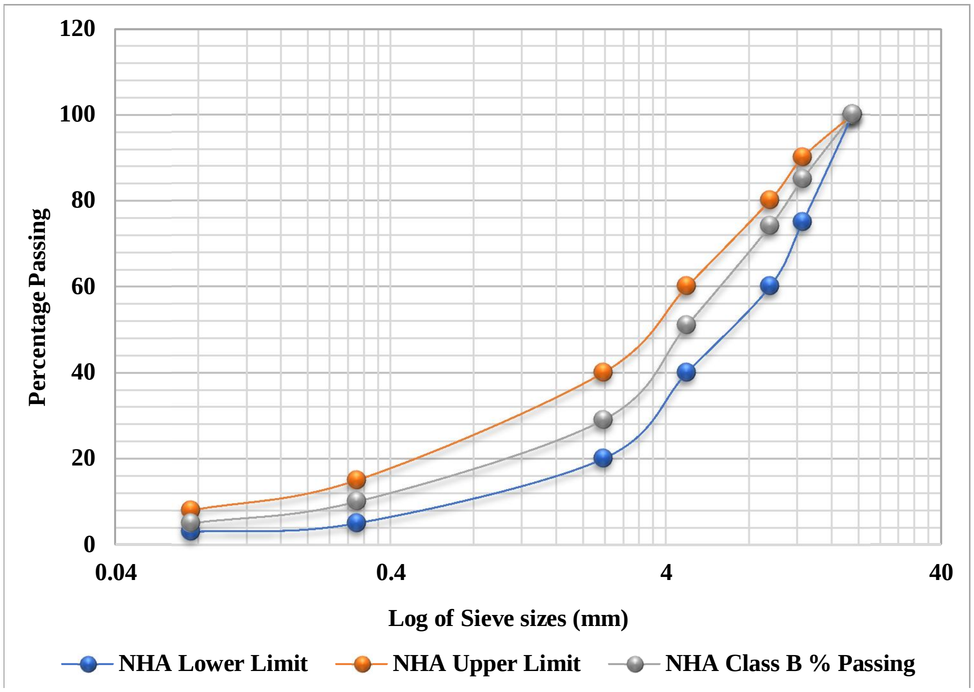

Fig 1: Gradation Curve of Aggregates

B. Asphalt Binder

Bitumen of 60/70 grade is used in this study which is collected from Attock oil refinery Punjab, Pakistan used for preparing different specimens. Different tests are performed on this bitumen to evaluate its different properties. The physical properties of asphalt binder are shown in Table II.

Table II: Properties of Bitumen

Property	Value
Penetration at 25 °C, (1/10 of mm) ASTM D5	66.16
Ductility, (cm) ASTM D113	102.16
Softening point, (°C) ASTM D36	50
Flash point, (°C) ASTM D92	234
Fire Point, (°C) ASTM D92	256
Viscosity at 135°C, (Pa.s) ASTM D4402	0.467
Viscosity at 165°C, (Pa.s) ASTM D4402	0.19

C. Filler Material

Ceramic waste is collected from ceramic industries located in Hayatabad industrial zone KPK, Pakistan. This ceramic waste is grounded into fine powder such that it easily passes sieve #200 which is further used as a filler material in asphalt mixture. The specific gravity of stone dust was found to be 2.52 while that of ceramic waste powder is 2.36.

D. Material Content for Performance Tests Samples

Optimum binder content of 4.32 % is calculated using Marshall Mix design method and is utilized in finding the aggregate content of different particle size. This aggregate content is used in preparation of 7000 g of sample using gyratory compactor for performance tests. Out of 7000 g a total of 302.4 g is the bitumen content while the remaining 6697.6 g comprised of both fine and coarse aggregates. The weight of different particle size of aggregates is shown in Table III below.

Table III. Aggregate Content for Samples of Performance Tests

Total weight of sample = 7000 g		
Weight of bitumen according to OBC (4.32 %) = 302.4 g		
Total weight of aggregates = 6697.6 g		
Sieve sizes (mm)	Percentage of aggregates Retained (%)	Weight of aggregates retained (g)
19	0	0
12.5	16	1071.616
9.5	13	870.688
4.75	20	1339.52
2.36	18	1205.568
0.3	23	1540.448
0.075	5	334.88
Pan	5	334.88

As this study focused on evaluation of effect of ceramic waste powder used as a filler material on the mechanical properties such as rutting and fatigue behaviour of asphalt mixture, so the filler content of stone dust which is 334.88 g in the pan is replaced with 20 %, 40 % , 60 % , 80 % and 100 % with CWP. The weight of different content of filler percentages is shown in Table.IV below.

Table IV. CWP and Stone Dust Content Used in Samples

Total Filler Content (g)	% of Ceramic Waste Powder	Ceramic Waste Powder Content (g)	Stone Dust Content (g)
334.88	20	66.976	267.904
334.88	40	133.952	200.928
334.88	60	200.928	133.952
334.88	80	267.904	66.976
334.88	100	334.88	0

VI. RESULTS AND DISCUSSION

The prepared samples are tested for rut resistance using Wheel tracker test machine in term of rut depth (mm) and dynamic modulus using dynamic modulus test apparatus for flexible pavement. The following results were evaluated after performing these tests.

A. *Wheel Tracker Test Results*

6 samples 1 conventional and 5 modified having different proportions of ceramic waste powder are evaluated using wheel tracker test machine. Rut depth against number of cycles is plotted to evaluate how samples behaves under loading. Different samples have different rut depth depending on their strength and stiffness. Table V shows the results of rut depth at different proportion of CWP on different number of cycles. The results of CWP samples are compared with the rut depth of conventional sample

Table V: Rut Depth (mm) at Different Number of Cycles

Number of cycles	Rut depth (mm) according to different percentages of CWP Content					
	0%	20%	40%	60%	80%	100%
0	0	0	0	0	0	0
1000	1.76	1.94	1.12	0.73	1.95	2.99
2000	1.94	2.35	1.25	0.89	3.26	3.91
3000	2.38	2.66	1.8	0.97	3.39	4.97
4000	2.47	2.94	1.82	1.2	3.56	5.31
5000	2.72	3.17	2.12	1.29	3.68	5.77
6000	2.99	3.35	2.47	1.49	3.78	5.8
7000	3.28	3.64	2.27	1.56	3.83	6.18
8000	3.41	3.81	2.61	1.57	3.87	4.25
9000	3.53	3.74	2.82	1.82	3.96	6.09
10000	3.76	4.01	2.97	1.58	4.02	6.3

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Result shows that when we replace stone dust with CWP in 40 % and 60 % proportion it gives rut depth of 3 mm and 1.6 mm which is 21 % and 58 % lower than that of conventional sample which is 3.79 mm. The reduction is rut depth is caused due to the increase in strength to permanent deformation after using CWP as filler. The lowest rut depth is measured at 60 % CWP. All the 5 specimens containing CWP as a filler material either partially or fully satisfy the minimum criteria which is that rut depth should not be more than 12 mm. As from the results 40 % and 60 % CWP shows better results than conventional stone dust while the results of 20 % and 80 % CWP content is almost like conventional sample except 100 % CWP content which is quite high as compared to conventional sample which shows that CWP can be used as a filler material is asphalt mixture and this will a good step towards a sustainable environment by using ceramic wastes in asphalt pavement design. Final rut depth at 10,000 cycles is shown in Fig 2.

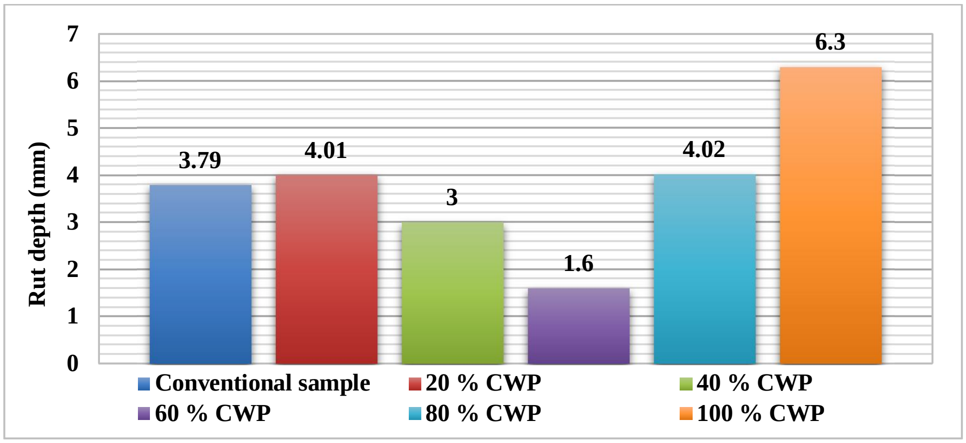

Fig 2: Comparison of Rut Depth at 10,000 cycle

B. *Dynamic Modulus test*

Dynamic modulus test is performed on 4 different temperatures (4.4 °C, 21.1 °C, 37.8 °C and 54 °C) at 6 different frequencies (25 Hz, 10 Hz, 5 Hz, 1 Hz, 0.5 Hz and 0.1 Hz). A graph between dynamic modulus against frequencies on different temperatures is plotted to evaluate that how the asphalt mixture behaves under repeated compressive load against permanent deformation. Different samples have different dynamic modulus depending on their stiffness and strength which are explained below.

A graph of dynamic modulus at 4.4 °C against 6 different frequencies is plotted and the results of conventional sample having 0 % CWP is compared with the samples having different proportion of CWP as shown is Fig. 3 below which shows that the Dynamic Modulus of conventional sample having SD as a filler is higher than that of sample containing CWP as a filler having different proportions of CWP. Dynamic modulus of sample containing 20 % CWP is recorded as the highest of all sample containing different proportions of CWP as filler. The dynamic modulus start decreasing from 25 Hz frequency up to 0.1 Hz frequency for all samples having CWP while the lowest dynamic modulus for all samples is recorded at 0.1 Hz frequency..

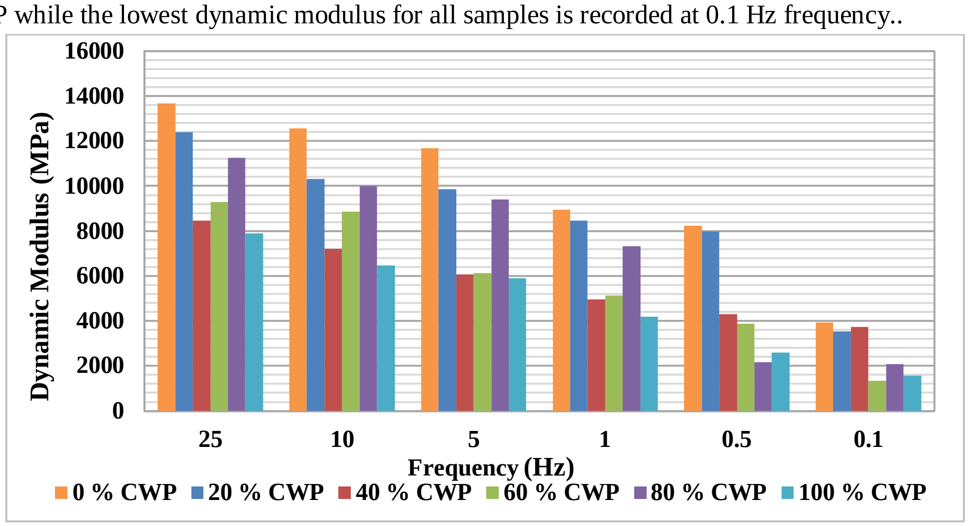

Fig 3: Dynamic Modulus at 4.4°C

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Dynamic modulus (MPa) is plotted against frequency (Hz) to compare the results of conventional sample with modified sample having CWP. It is clear from the figure that highest dynamic modulus is recorded on all 6 frequencies for 40 % CWP sample. Fig 4 also shows that DM for all samples is higher than that of conventional samples which suggest that CWP samples shows better results that conventional sample at 21.1 °C. The highest DM is recorded at 25 Hz for all samples as we move from the 25 Hz towards the lowest frequencies DM for all samples start on decreasing till the lowest frequency which is 0.1 Hz.

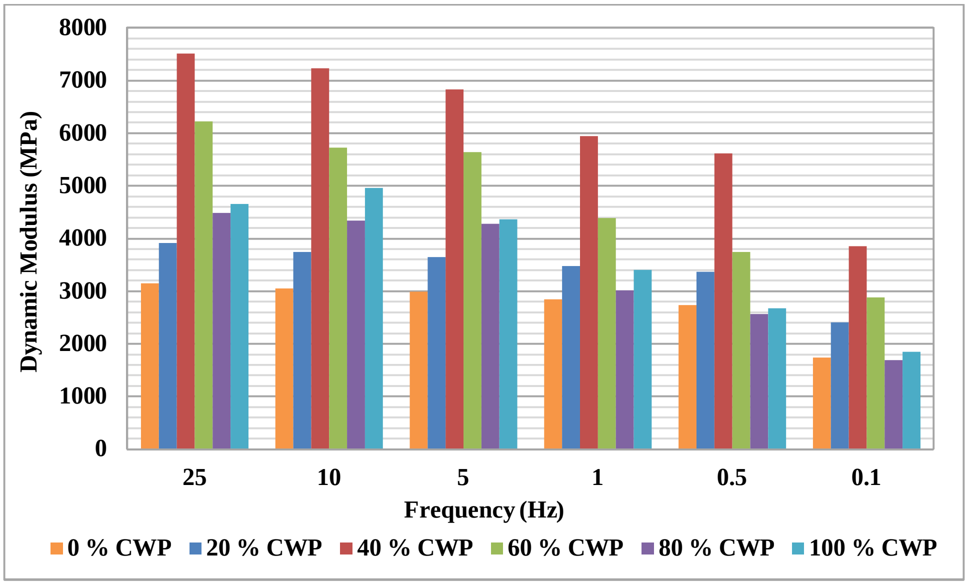

Fig 4: Dynamic Modulus at 21℃

Fig 5 shows the relationship between Dynamic modulus (MPa) and frequency at 37.8 ℃. Dynamic Modulus of conventional sample having SD as filler is lower than that of all the samples containing CWP. Highest dynamic modulus was recorded at 25 Hz by 60 % CWP sample. The value of 60 % CWP sample is higher at all frequencies followed by 40 % CWP sample. Figure also shows that the DM for both conventional and CWP samples starts on decreasing as the frequency decreases from 25 Hz to 0.1 Hz. At 37.8 ℃ the lowest Dynamic Modulus of all samples is recorded by samples having 0 % of ceramic waste powder followed by samples having 20 % CWP and 80 % SD as a filler material .

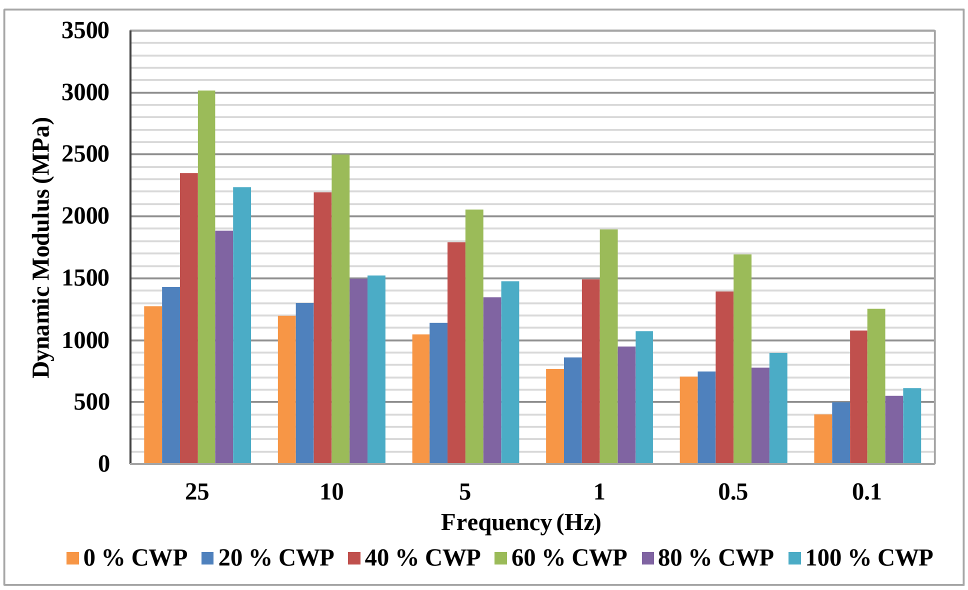

Fig 5: Dynamic Modulus at 37.8℃

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Dynamic Modulus (MPa) is plotted against frequency (Hz) at 54 °C for all the samples which shows that highest DM is observed on all frequencies by 60 % CWP sample followed by sample having 40 % CWP as a filler material. On the hand lowest Dynamic Modulus is observed at 100 % CWP sample. Fig 6 also shows that DM of conventional sample is higher than 20 %, 80 % and 100 % CWP samples and the DM of both conventional and CWP sample starts on decreasing as the frequency of the applied load decreases.

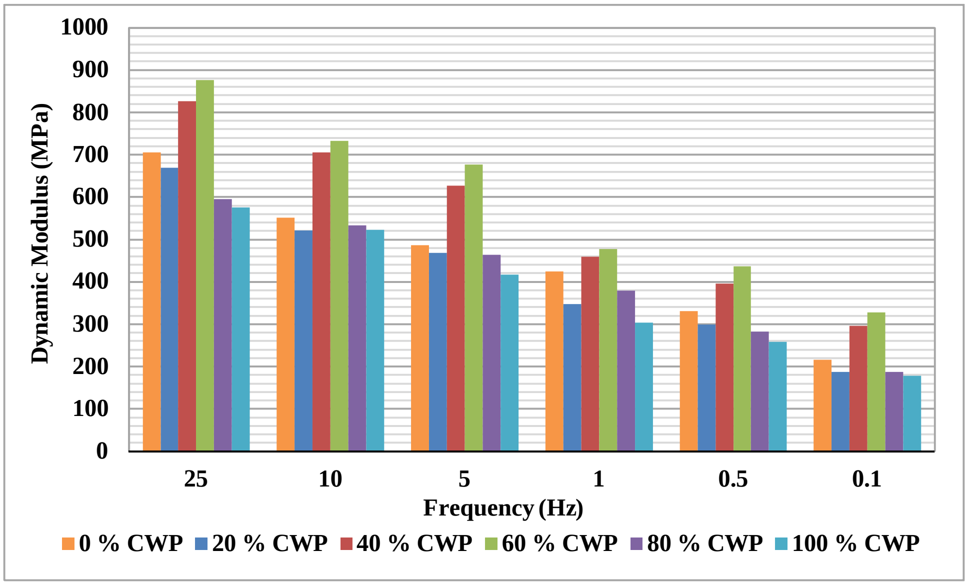

Fig 6: Dynamic Modulus at 54 °C

VII. CONCLUSION

The following conclusions are obtained from the results of different tests performed in this research study.

A. *Wheel Tracker Test*

1) Rut depth of samples containing 40 % CWP and 60 % CWP shows high resistance to rutting as compared to that of conventional and all other samples.
2) The rut depth value of conventional sample is lower than that of samples containing 20 %, 80 % and 100 % CWP.
3) Stiffness of mixture starts increasing as the proportion of CWP increased from 20 % to 60 % due to which strength increases as a result of which resistance to permanent deformation increases but after 60 % CWP to 100 % content rutting value starts on increasing.
4) On comparison between the ruts depth of CWP and conventional specimens it is clearly evaluated that samples containing 40 % CWP and 60 % CWP shows 21 % and 58 % decrease in rut depth.
5) The rutting susceptibility of modified samples having CWP in different proportions are satisfactory which shows that CWP can be used in HMA as a filler either as a partial or full replace of filler material.

B. *Dynamic Modulus test*

1) Dynamic modulus of both conventional and modified samples increases as the loading frequency increases. On the other hand, it decreases as the temperature of the test increases.
2) The optimum dynamic modulus of investigated CWP asphalt mixture is obtained at 60 % CWP content at 37.8 °C and 54 °C temperature and 40 % CWP content at 21.1 °C temperature while conventional sample has best results than all modified samples at 4.4 °C.
3) Dynamic modulus value of all samples having CWP as filler in different proportions (20, 40, 60, 80 and 100 percent) are higher than conventional sample at 21.1°C and 37.8 °C.
4) Conventional sample having 0 % CWP has higher dynamic modulus value than all CWP modified samples at 4.4 °C.

5) At 54 °C dynamic modulus of samples having 40 % and 60 % CWP is higher than that of conventional sample while 20%, 80 % and 100 % has lower dynamic value than conventional samples.
6) The use of CWP in asphalt mixture at higher temperature can increase the fatigue life of asphalt pavement as fatigue life of asphalt mixture decreases when dynamic modulus increases and from the results all samples have lower dynamic modulus value at higher temperature than that of lower temperature.

VIII. RECOMMENDATION

This study summarized some recommendation based on the finding of this research for using CWP as filler in asphalt mixture.
1) After analysing the results of using CWP in asphalt mixture as a filler material through wheel tracker and dynamic modulus test it is concluded that CWP has high potential of improving the mechanical properties of HMA by decreasing the rutting susceptibility and showing good results in dynamic modulus which shows it can be used as filler material in asphalt mixture.
2) The use of ceramic wastes in HMA is a good step towards sustainable environment by utilizing waste like CWP in asphalt pavements instead of natural fillers.
3) As excellent results are obtained from samples having 40 % and 60 % CWP as filler so more specimens are tested having different content of CWP in between 40 % and 60 % to have a broader perspective.
4) Use super pave gyratory compactor for compaction of samples instead of Marshall Compactor to achieve the density that meet field conditions.

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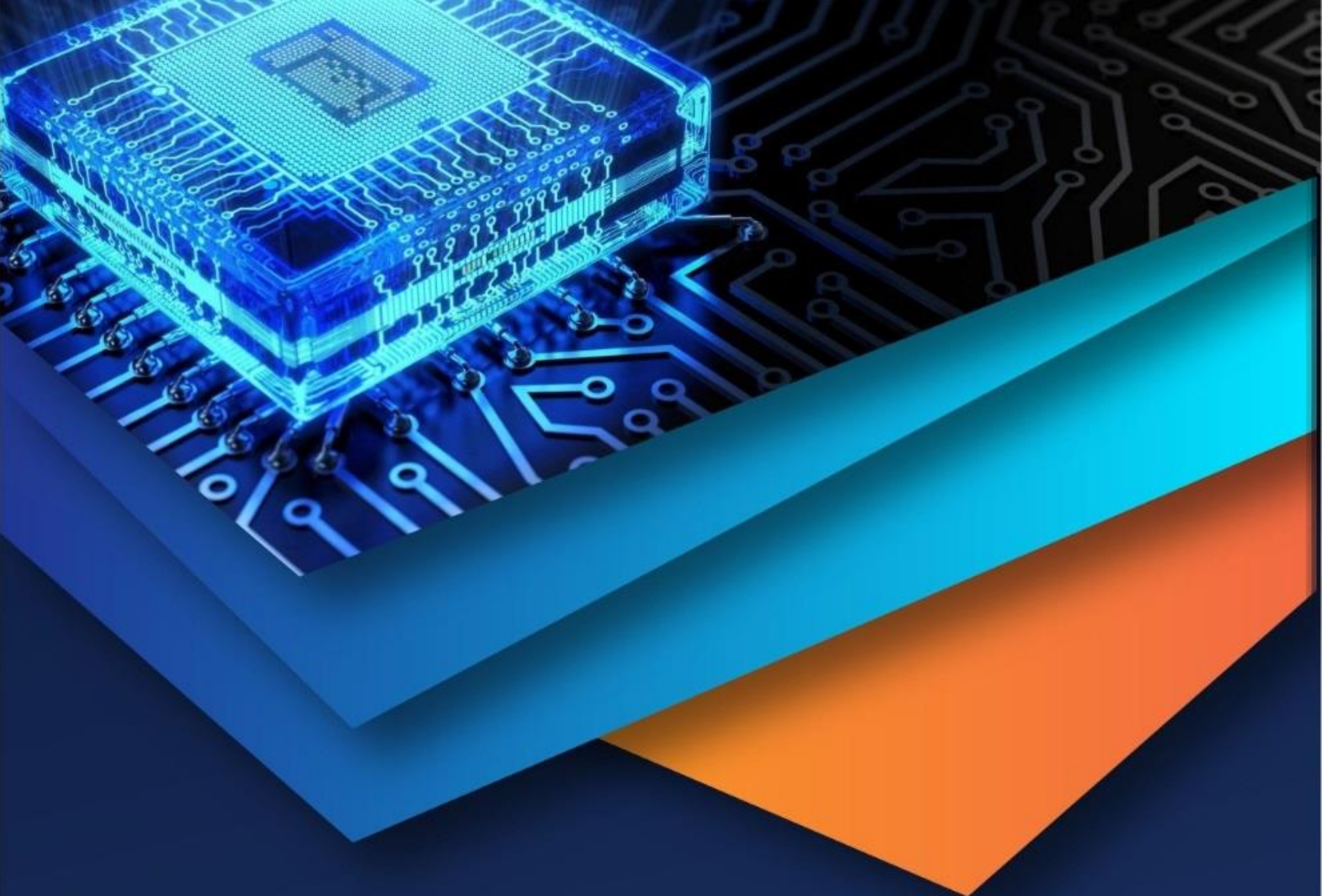

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