Comparison of Performance of Base-course Aggregates for Limestone and Sandstone at Varying Moisture and Gradation.

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Abstract

Unbound Granular Materials (UGMs) are widely used as base and sub base layer materials in flexible pavements all over the world as these are proficient to bear heavy vehicle loads and are inexpensive as compared to bound materials. This paper demonstrates the relationship among resilient modulus(M_R), permanent strain and physical properties of limestone and sandstone obtained from Margalla and Sargodha regions of Pakistan respectively. This research paper investigates the effect of moisture change, percent fines in gradation curve, stress level & aggregates types (M_R)and permanent strain of a flexible pavement. The water can intervene into the unbound base course layer and may result into premature pavement failures. Thus, it is necessary to investigate the UGMs behaviour under optimum moisture content; OMC towards wet side and OMC towards dry side. In order to examine the aggregate properties, basic aggregate tests (i.e. Impact value test, specific gravity, soundness and water absorption test) were performed; the basic test results of aggregate used in this research work were under allowable limits. Performance test (M_R) and permanent strain of designated materials were conducted under Repeated Load Triaxial (RLT) test technique. The results demonstrated that type of aggregates, materials gradation, percent's fine in gradation curve and percentage moisture significantly affect (M_R) and permanent strain of unbound layers of flexible pavements. Moisture content has adverse effect on unbound base course materials. When moisture increases from OMC towards wet side, (M_R) decreases and permanent strain increases. Contrary to it, (M_R) increases by reducing water content from OMC towards dry side and permanent strain also decreases. Result from RLT demonstrates that sandstone is more sensitive to moisture as compared to limestone.

Keywords: Resilient modulus; Unbound Granular Material; moisture damage; stress level; RLT test; proctor test; limestone and sandstone

1. Introduction

In developing countries like Pakistan, the pavement design is empirical in nature. Empirical design procedure concentrates on designing the bituminous layer, subgrade condition, climate & temperature, traffic loading etc. and does not take the strength of UGMs (base and sub base course) into consideration. UGMs are used in pavement construction as base and sub-base layers. It is important that the resilience and permanent deformation behavior and nature of response of granular layers under traffic loading is taken into account and thoroughly understood.

Resilient Modulus (M_R) is a key property and this term is used for unbound materials as these materials behave nonlinearly under application of loading. Resilient Modulus is defined as the ratio between applied repetitive axial deviator stresses (σ_d) to the recoverable axial strain ($\epsilon_{1,r}$).

$$\boldsymbol{M_R} = \frac{(\sigma_1 - \sigma_3)}{\varepsilon_{1,r}} = \frac{\sigma_d}{\epsilon_{1,r}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where,

M_R = Resilient Modulus**,** σ_1 = Principle stress**,** σ_3 = Confining stress**,**

σ_d = Deviator stress$(\sigma_1 - \sigma_3)$**,** $\epsilon_{1,r}$ = Recoverable Axial Strain

Permanent strain is defined as the accumulated irrecoverable (permanent) deformation throughout the pavement service life. Under given number of load repetition at a given stress level, the permanent deformation for a laboratory test sample may be calculated as

$$\boldsymbol{\varepsilon p} = \frac{\boldsymbol{\Delta H}}{\boldsymbol{Ho}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Where,

εp is the permanent strain in percent, ΔH is the change in specimen height

Ho is the original specimen height.

Hveem **1950** was the first, who worked on resilient property of Unbound Granular Materials (UGMs) and he concluded that deformation of UGMs under transient loading was elastic in nature. Later on, (Seed et al **1962)** introduced the (M_R) concept in characterizing the recoverable strain of subgrade soils and their relation to fatigue failures in asphalt pavements.

(Lekarp **2000)** found that the resilient behavior of unbound granular materials was affected by various factors such as cycle of load application, density, moisture content, stress level, fine content, aggregates shape and sizes, frequency and load sequence. He found that the parameter, which mostly influenced the resilient behavior of material, was stress level.

Several researchers (Jia Li **2013**, Leite et al. **2011**, Ghazireh et al. **2011**) concluded that the resilient modulus was directly proportional to confining stress as by increasing confining stress resilient modulus increased significantly. (Stolle et al. **2009**) suggested that the magnitude of applied deviator stresses practically did not affect (M_R) or could be neglected. Researchers (Mohammad Shafiqur Rahmanab et al. **2015,** Omer G et al. **2013,** Hoff I et al. **2012**) concluded that moisture content had a negative effect on resilient modulus M_R and permanent strain as by increasing moisture from optimum towards wet condition, the M_R reduced and the permanent strain increased significantly. According to some researchers (Makhaly Ba **2012**, Rahman et al. **2012**, Abu-Farsakh **2012**) the dry density has a positive influence on (M_R) as dry density increases, the (M_R) also increases. (Alam et al. **2010**, Stolle et al. **2009**, Kancherla **2004)** further conclude that (M_R) generally decreases and permanent strain increases in samples containing more fines and that the specimen height does not influence the test results.

2. Materials and Methodology

In this research, two different types of aggregates (lime stone and sand stone) were selected and obtained from Margalla Islamabad and Sargodha Punjab Pakistan respectively. To obtain well-graded aggregates, which have high density, an equation was developed by Fuller which shows the maximum density gradation (Fuller and Thompson in 1907).

Following is the equation that demonstrates the Fuller's curves:

$$P = (d / D)^{n}$$

Where:

P = Percent finer than the sieve, d = Sieve size being considered,

D = Sieve used of maximum size, n = Factor demonstrates curve shape

To investigate the gradation effect on (M_R) and permanent strain, four different gradations for base course materials were selected using fuller grading curve, shown in fig- 1 by changing fuller constant 'n' (0.3, 0.4, 0.5, 0.6). For moisture effect four different moistures were selected. First OMC was obtained for each gradations using modified proctor test. The consequent moisture contents were changed to optimum moisture content (omc), optimum to dry side (OMC-1%, OMC-2%) and from optimum to wet side (OMC+1%). The percentage fines were selected as the percent passing 0.075mm sieve from coarser one to finer (3%, 5%, 10%, and 17%).

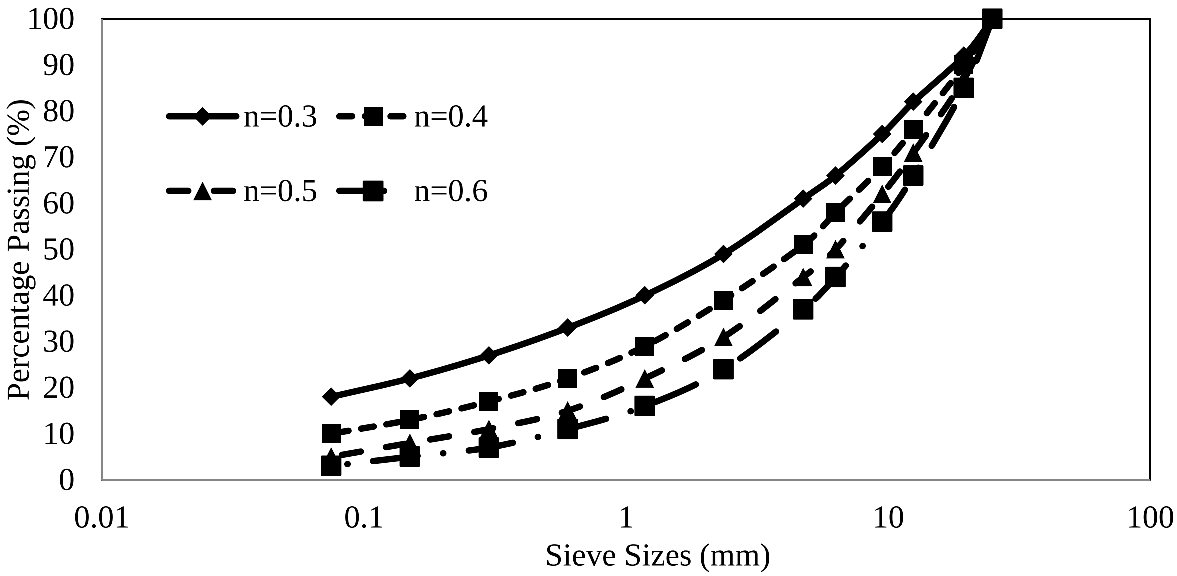

Fig.1: Gradation curves for UGMs

Research methodology was divided into two phases of testing: In the first phase aggregate Conventional test and modified proctor tests were conducted and in the second phase performance test (Repeated Load Triaxial) was conducted. Aggregates conventional test results are shown in table-1.

Table .1: Aggregates Conventional Test Results

S. No	Description	Designation	Lime stone	Sand stone	Recommended values
1	Abrasion Value %	C 131	21.5%	23%	<41%
2	Water Absorption %	C 128	1.04%	0.96%	<2.0%

3	Specific Gravity	C 127	2.74	2.66	2.5-2.9
4	Soundness coarse and fine	C 88	9.67&4.66	4.3&3.66	8% max

For aggregate gradation's optimum moisture content (OMC) and maximum dry density (MDD) was obtained by using modified proctor test. Results are shown in table-2.

Table .2: MDD and omc of Different Grading Coefficient

Grading coefficient (n)	Lime Stone		Sand Stone	
	omc (%)	MDD(t/m3)	omc (%)	MDD(t/m3)
0.3	5.41	2.478	5.33	2.461
0.4	4.87	2.493	4.79	2.478
0.5	4.38	2.513	4.32	2.496
0.6	4.05	2.529	3.96	2.509

For RLT test, sample size of 4 inch diameter and 8 inch height was used with maximum particle size 0.75 inch. Oven dried samples were mixed by adding required moisture, compacted with the help of vibratory compactor in 4 layers, each layer of thickness 2 inch and a relative density of 98%.

The materials were tested according to AASHTO T-03. Sample was subjected to triaxial testing in a triaxial pressure chamber. Samples were conditioned for 500 cycles at confining stress, deviator stress of 103.7kPa and 93.1kPa. Then samples were subjected to 15 loading sequences for repeated 100 loading cycles with different combination of confining stress (20.7, 34.5, 68.8, 103.4, and 137.9) KPa and deviator stresses. (M_R) and permanent strain were calculated using last 5 cycles. Contact stress was applied to the sample in order to ensure the contact between sample and plates throughout the cyclic process. The duration of cyclic stress pulse was 0.1s with a rest period of 0.9s.

3. Results and discussion

3.1 Effect of moisture content on M_R and permanent strain:

Fig-2 demonstrates the resilient modulus at confining stress level of 137.9 KPa. It is observed that the addition of 1% moisture from OMC to wet side i.e. OMC+1%, the resilient modulus decreases by 25% and 32% whereas the permanent strain increases by 20% and 17% for lime stone and sand stone respectively. By decreasing moisture from optimum to dryer side i.e. OMC-1%, the resilient modulus is increased by 20% and 23% whereas the permanent strain decreases by 20%. By further decreasing the moisture from optimum to dryer side i.e. OMC-2%, the resilient modulus increases by 39% and 46% and the permanent strain decreases by 35% and 40% for lime stone and sand stone respectively. The result shows that the shift from optimum to wet side moisture has drastic effect on resilience response of UGMs as base-course materials especially in case of sand stone.

This is because as by increasing water from optimum towards wet side, the workability of the material increases and moisture turns as a lubricant agent, resulting into reduction of M_R. From results it is observed that the limestone shows better performance as compared to sand stone when moisture increases from optimum to wet side and sand stone is more sensitive to water than lime stone. By decreasing moisture from optimum to dry side, the material becomes stiffer and rigid which gives higher (M_R) .

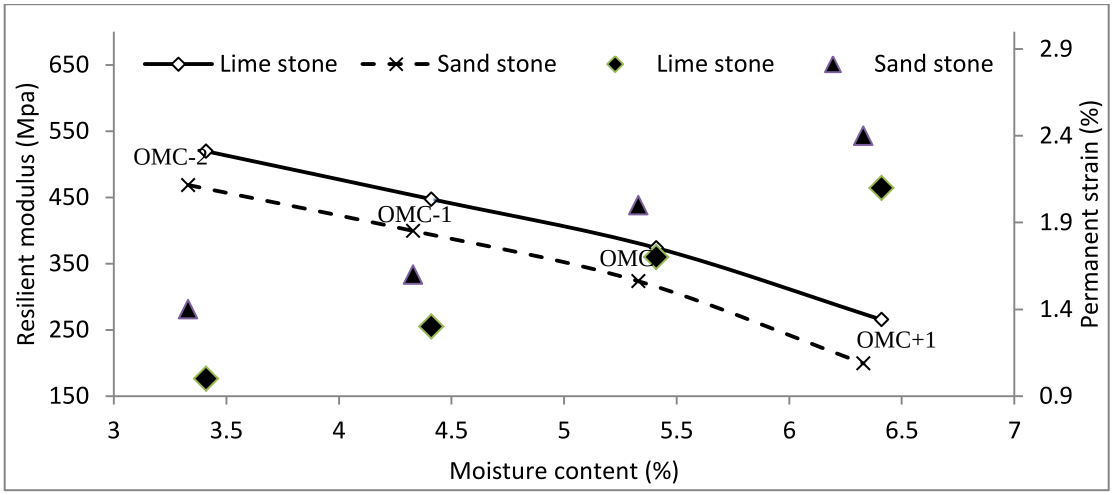

Fig.2: Effect of Moisture on Resilient Modulus and Permanent Strain

3.2 Effect of stress level on M_R and permanent strain

The other factor that affects the resilient modulus values of unbound granular value is the stress level. The sample is tested at five varying stress level combination. Fig-5 demonstrates that (M_R) is directly related to confining stress level (20.7kPa, 34.5kPa, 68.9kPa, 103.4kPa, 137.9kPa). From fig-3 it is observed that (M_R) increases by increasing confining stress from 34.5kPa to 137.9kPa by 75% and 79% and the permanent strain also increases by 70% and 80% for lime stone and sand stone respectively. This is for the reason that the sample becomes more stable by increasing confining stress and is prevented from earlier failure. This is also because the strain hardening can be expected due to reorientation of the grains into a denser state. Therefore, the compacted specimens become stiffer with increasing load repetitions and gradually decrease the elastic deformation, resulting in higher modulus.

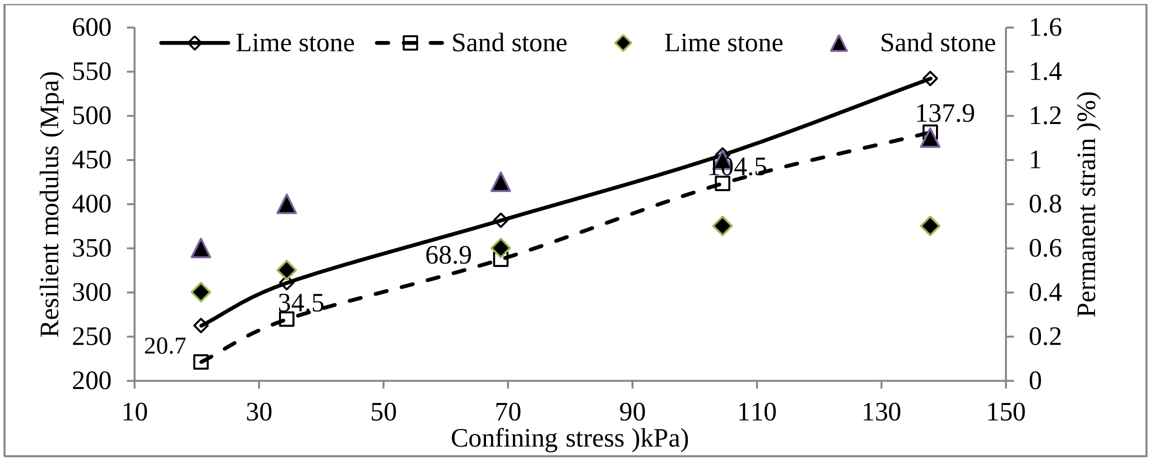

Fig.3: Effect of Confining Stress on Resilient Modulus and Permanent Strain

Effect of percentage of fines on M_R and permanent strain

Percentages fine in gradation curve of UGMs has high influence on (M_R) and permanent strain.. The specimens were tested at four different percentages passing 0.075mm sieves (3%, 5%, 10%, and 17%). Fig-4 demonstrates the effect of percentage fines on (M_R)and permanent strain behavior. It is observed from the results that by increasing percent of fines passing 0.075mm sieve from 3 to 17% in the gradation, the (M_R)decreases by 33% and 38% for lime stone and sand stone respectively. High percent fine results into high plasticity, more susceptible to moisture, material do not drain well and larger particles float in fine particles sea, resulting in soft gradation and reduced sample M_R.

From fig-4 it is observed that high quantity of fines (greater than 10% by weight), the (M_R) decreases by 18% and 22% for lime stone and sand stone respectively at OMC. The high amount of fines has severe effect on (M_R) and start to destruct the aggregate load shift matrix quickly, which results in drastic declines in strength of UGMs.

It is also seen that permanent strain is found maximum when percentage fines is 17% i.e. 1.5% and 1.9% for lime stone and sand stone respectively. As shown in fig-5, by decreasing the percentage fines the permanent strain is also decreased and when percentage fines is 5%, permanent strain is observed to be minimum. By further decreasing fines i.e. 3% the permanent strain again increases. This is because when fines percentage is 5% at gradation curve then the gradation is dense. By further decreasing fines, the gradation becomes porous due to voids left in gradation resulting in an increase in permanent strain.

Furthermore, the resilient modulus of lime stone is higher than that of sand stone and the permanent strain for sand stone is found to be greater than that of lime stone under same testing conditions. It is found that lime stone shows about 13-18 % higher elastic response as compared to sand stone.

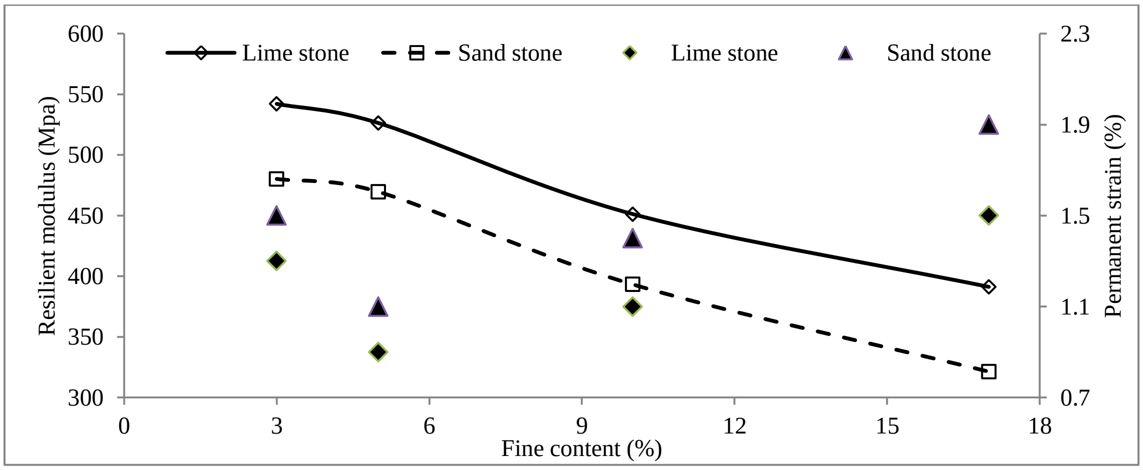

Fig.4: Effect of Fines on Resilient Modulus and Permanent Strain

3.4 Effect of aggregates type of fines on M_R and permanent strain

Lastly, from modified proctor test results, it is observed that sand stone has high percent optimum moisture content and low density (MDD) as compared to limestone. Also from aggregate properties, it is established that the specific gravity of lime stone is higher than that of sand stone. Fig-5a demonstrates that lime stone has high elastic response as compared to sand stone. Lime stone shows 23% higher resilient modulus value compared to sand stone. Fig-5b demonstrates the result of permanent strain and it is observed that lime stone has better resistance again permanent deformation than sand stone. Lime stone shows 21% better resistance against permanent strain than lime stone.

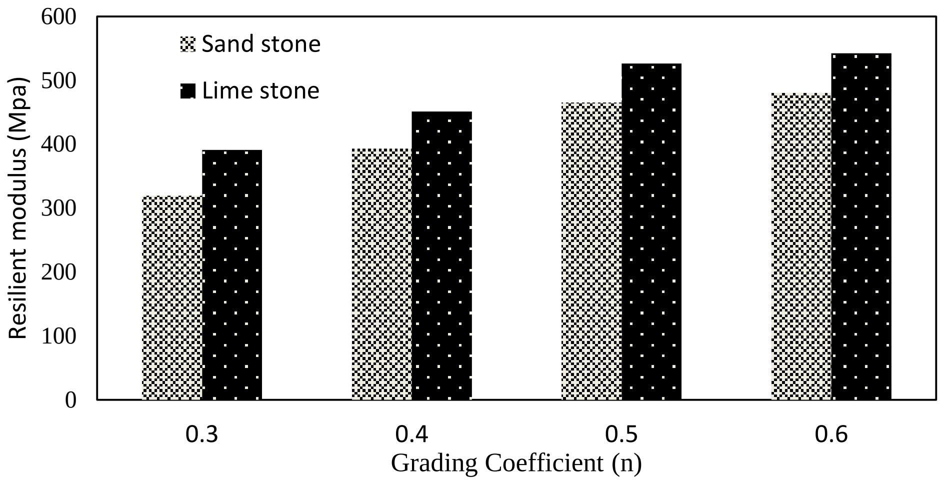

Fig.5a: Effect of Aggregate type on Resilient Modulus

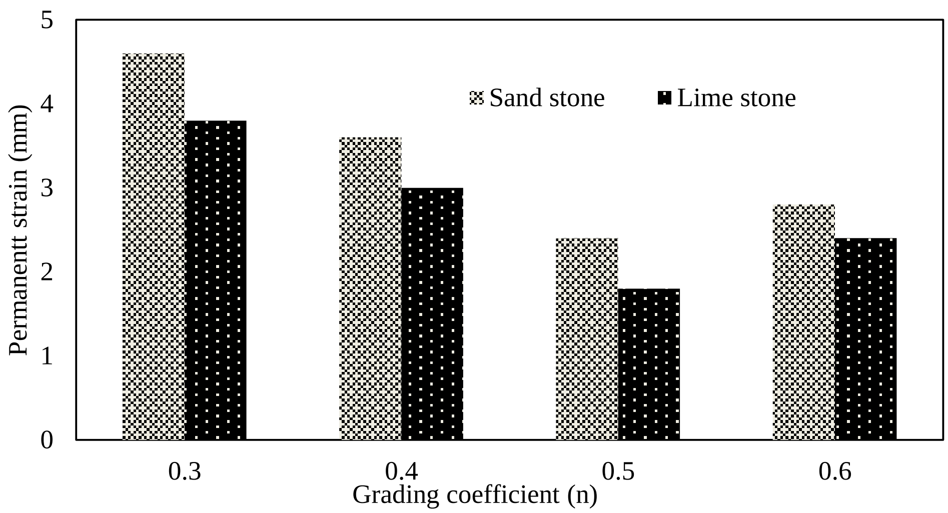

Fig.5b: Effect of Aggregate type on Permanent Strain

4. Conclusions

- The aggregate types affect the behavior of unbound granular materials; limestone shows higher resilience behavior at same loading, moisture and gradation. This shows that limestone has high resistance to permanent deformation as compared to sandstone.

- The increment of fines in gradation curve results into the reduction of the resilient modulus and increment of permanent strain for unbound granular materials as fuller grading value constant ‘n’ equal to ‘0.3’ gradation having high fines results in the lowest value of (M_R). The concentration of fines affects the rigidity and stiffness of sample, as fine contents are increased the sample begins to soften and friction between particle reduced.

- The addition of moisture content from dry to wet side in base course material results in low resilient modulus and high permanent strain especially for sandstone as compared to limestone. Due to decrease in stiffness and rigidity and reduction in the friction among the particles.

- It is also concluded from test results that limestone has better performance than sandstone. The results of sandstone are also satisfactory but limestone shows better performance than sand stone especially when moisture changes.

- Lastly, aggregate gradation containing 5% fines (passing 0.075mm sieve) when fuller constant “n” is equal to 5 shows better resistance in permanent deformation when compared to all other gradations and by increasing or decreasing percentage fines from 5% in gradations the permanent strain increases in both cases.

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