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 materials 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 effects of moisture change, percent of fines in gradation curve, stress level and aggregate type on resilient modulus and permanent strain of a flexible pavement. Water can intervene into the unbound base-course layer and may result in premature pavement failure. Thus, it is necessary to investigate the UGM behaviour under optimum moisture content (OMC) towards wet side as well as 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 using Repeated Load Triaxial (RLT) test technique. The results demonstrated that type of aggregate, material gradation, percent of fines in gradation curve and percentage of moisture significantly affect resilient modulus M_R and permanent strain of unbound layers of flexible pavements. Moisture content has an adverse effect on unbound base-course materials. When moisture increases from OMC towards wet side, M_R decreases and permanent strain increases. On the contrary, M_R increases by reducing water content from OMC towards dry side and permanent strain also decreases. Result from RLT test demonstrates that sandstone is more sensitive to moisture as compared to limestone.

KEYWORDS: Resilient modulus, Unbound granular materials, Moisture damage, Stress level, RLT test, Proctor test, Limestone, Sandstone.

Received on 11/10/2017.
Accepted for Publication on 29/1/2018.

INTRODUCTION

In developing countries, like Pakistan, the pavement design is empirical in nature. Empirical design procedure concentrates on designing the bituminous layer, sub-grade condition, climate and 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 are 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 non-linearly under application of loading. Resilient modulus is defined as the ratio between applied repetitive axial deviator stresses (σ_d) and the recoverable axial strain ($\epsilon_{1,r}$), as shown in Eqn. (1).

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

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 a given number of load repetition at a given stress level, the permanent deformation for a laboratory test sample may be calculated as:

$$\varepsilon_p = \frac{\Delta H}{H_o} \quad \text{…………..……….……… (2)}$$

where,
ε_p is the permanent strain in percent,
ΔH is the change in specimen height,
H_o is the original specimen height.

Hveem (1950) was the first researcher who worked on resilient property of Unbound Granular Materials (UGMs). 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 sub-grade 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, aggregate shape and size, frequency and load sequence. He also 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. Other researchers (Mohammad Shafiqur Rahman et al., 2015; Omer et al., 2013; Hoff 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 moisture content towards wet condition, M_R reduced and permanent strain increased significantly. According to some researchers (Makhaly Ba, 2012; Rahman et al., 2012; Abu-Farsakh, 2012), dry density has a positive influence on M_R, as when dry density increases, M_R also increases. Alam et al. (2010), Stolle et al. (2009) and Kancherla (2004) further concluded 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.

MATERIALS AND METHODS

In this research, two different types of aggregate (limestone and sandstone) 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 showing maximum density gradation (Fuller and Thompson, 1907).

The following equation 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 that 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 curves, shown in Fig. 1 by changing Fuller constant 'n' to be 0.3, 0.4, 0.5 and 0.6. For investigating moisture effect, four different moistures were selected. First, OMC was obtained for each gradation 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 of fines was selected as the percent passing 0.075mm sieve from coarser to finer (3%, 5%, 10% and 17%).

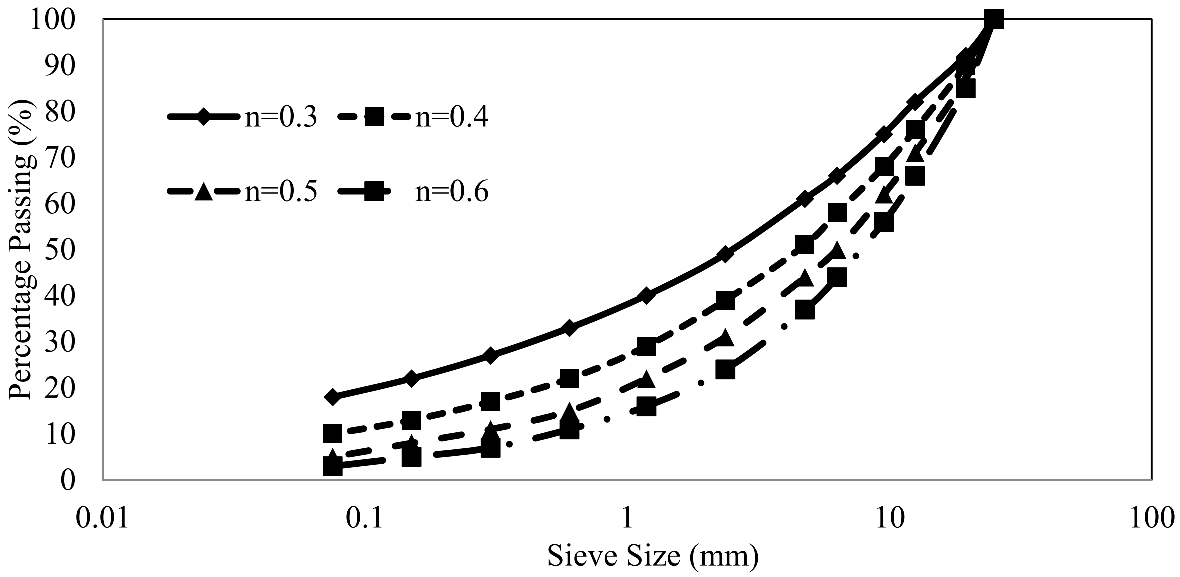

Figure (1): Gradation curves for UGMs

Research methodology was divided into two phases of testing. In the first phase, aggregate conventional test and modified proctor test were conducted, while in the second phase, (Repeated Load Triaxial) performance test was conducted. Aggregate conventional test results are shown in Table 1.

Table 1. Aggregate conventional test results

S. No.	Description	Designation	Limestone	Sandstone	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 and 4.66	4.3 and 3.66	8% max.

For aggregate gradations, optimum moisture content (OMC) and maximum dry density (MDD) were obtained by using modified proctor test. Results are shown in Table 2.

Table 2. MDD and OMC of different grading coefficient values

Grading coefficient (n)	Limestone		Sandstone	
	OMC (%)	MDD (t/m^3)	OMC (%)	MDD (t/m^3)
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, a sample size of 4-inch diameter and 8-inch height was used with a maximum particle size of 0.75 inch. Oven-dried samples were mixed by adding the required moisture, compacted with the help of a vibratory compactor in 4 layers, each layer of 2-inch thickness and a relative density of 98%.

The materials were tested according to AASHTO T-03. Samples were subjected to triaxial testing in a triaxial pressure chamber. Samples were conditioned for 500 cycles at confining stress and deviator stress of 103.7kPa and 93.1kPa. Then, samples were subjected to 15 loading sequences for repeated 100 loading cycles with different combinations 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 the 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.

RESULTS AND DISCUSSION

Effect of Moisture Content on M_R and Permanent Strain

Fig. 2 demonstrates the resilient modulus at a confining stress level of 137.9 kPa. It is observed that with 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 limestone and sandstone, respectively. By decreasing moisture by 1% from optimum to dry side; i.e. OMC-1%, the resilient modulus increases by 20% and 23%, whereas the permanent strain decreases by 20%. By further decreasing the moisture from optimum to dry side; i.e., OMC- 2%, the resilient modulus increases by 39% and 46% and the permanent strain decreases by 35% and 40% for limestone and sandstone, respectively. The results show 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 sandstone.

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

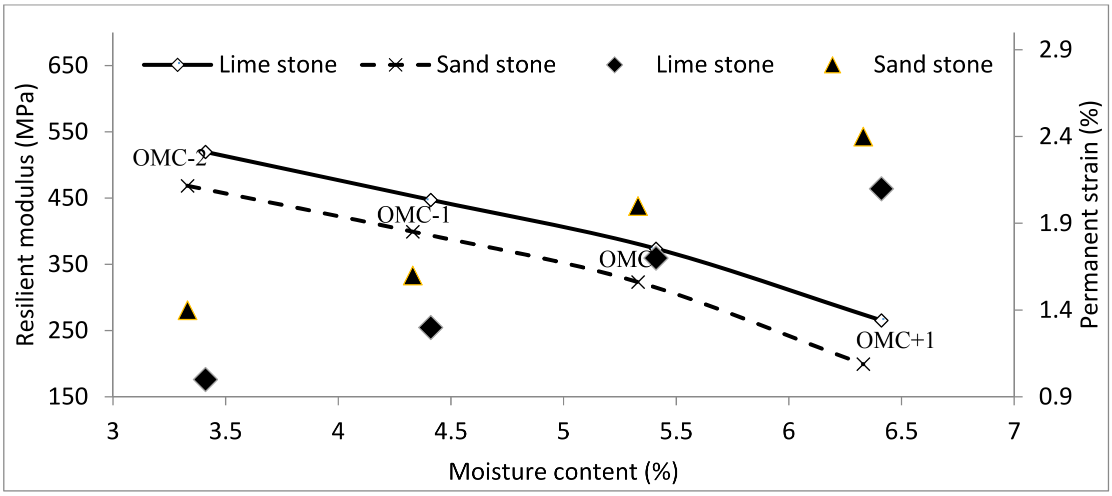

Figure (2): Effect of moisture on resilient modulus and permanent strain

Effect of Stress Level on M_R and Permanent Strain

The other factor that affects the resilient modulus values of unbound granular materials is the stress level. Samples are tested at five varying stress level combinations. Fig. 3 demonstrates that M_R is directly related to confining stress level (20.7kPa, 34.5kPa, 68.9kPa, 103.4kPa and 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 that permanent strain also increases by 70% and 80% for limestone and sandstone, 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 strain hardening can be expected due to reorientation of grains into a denser state. Therefore, compacted specimens become stiffer with increasing load repetitions and the elastic deformation decreases gradually, resulting in higher modulus.

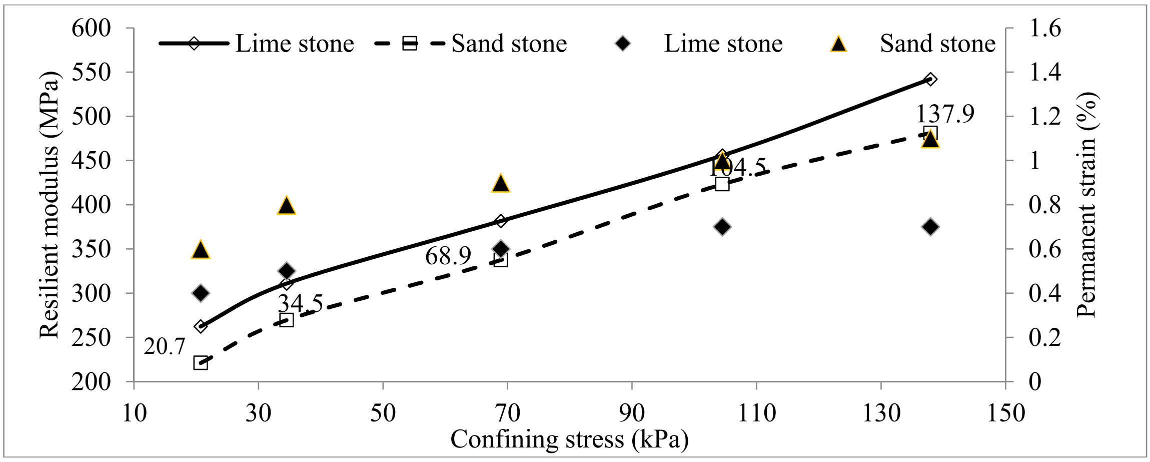

Figure (3): Effect of confining stress on resilient modulus and permanent strain

Effect of Percentage of Fines on M_R and Permanent Strain

Percentage of fines in the gradation curve of UGM has high influence on M_R and permanent strain. The specimens were tested at four different percentages of passing 0.075mm sieve (3%, 5%, 10% and 17%). Fig. 4 demonstrates the effect of percentage of fines on M_R and permanent strain behavior. It is observed from the results that by increasing percentage of fines passing 0.075mm sieve from 3% to 17% in the gradation, M_R decreases by 33% and 38% for limestone and sandstone, respectively. High percentage of fines results into high plasticity and more susceptibility to moisture. Materials do not drain well and larger particles float in a fines' particle sea, resulting in soft gradation and reduced M_R.

From Fig. 4, it is observed that with a high percentage of fines (greater than 10% by weight), M_R decreases by 18% and 22% for limestone and sandstone, respectively at OMC. High amount of fines has a severe effect on M_R and starts to destruct the aggregate load shift matrix quickly, which results in a drastic decline in the strength of UGMs.

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

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

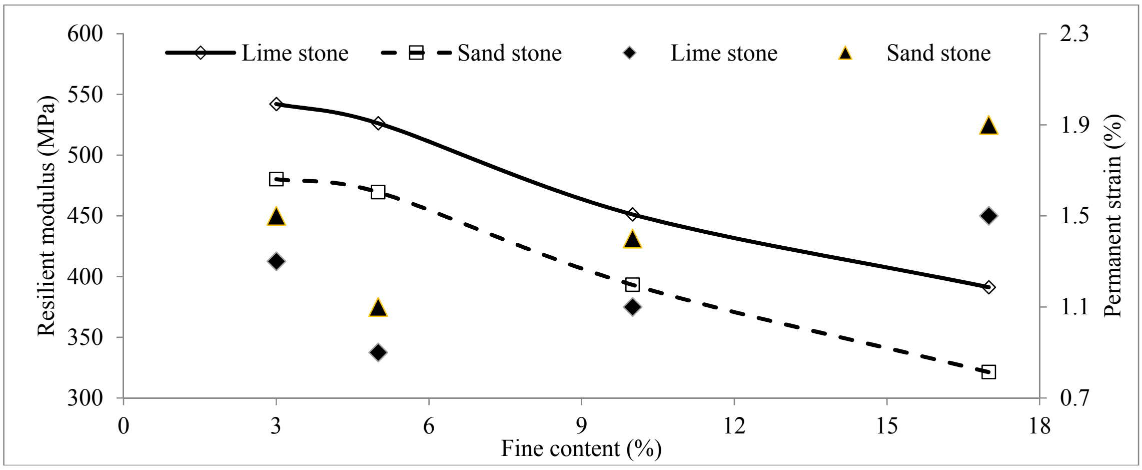

Figure (4): Effect of fines on resilient modulus and permanent strain

Effect of Aggregate Type of Fines on M_R and Permanent Strain

Lastly, from modified proctor test results, it is observed that sandstone has higher percentage of optimum moisture content and lower density (MDD) as compared to limestone. Also, from aggregate properties, it is established that specific gravity of limestone is higher than that of sandstone. Fig. 5 demonstrates that limestone has higher elastic response as compared to sandstone. Limestone shows 23% higher resilient modulus compared to sandstone. Fig. 6 demonstrates the results of permanent strain, where it is observed that limestone has better resistance against permanent deformation than sandstone. Limestone shows 21% better resistance against permanent strain than limestone.

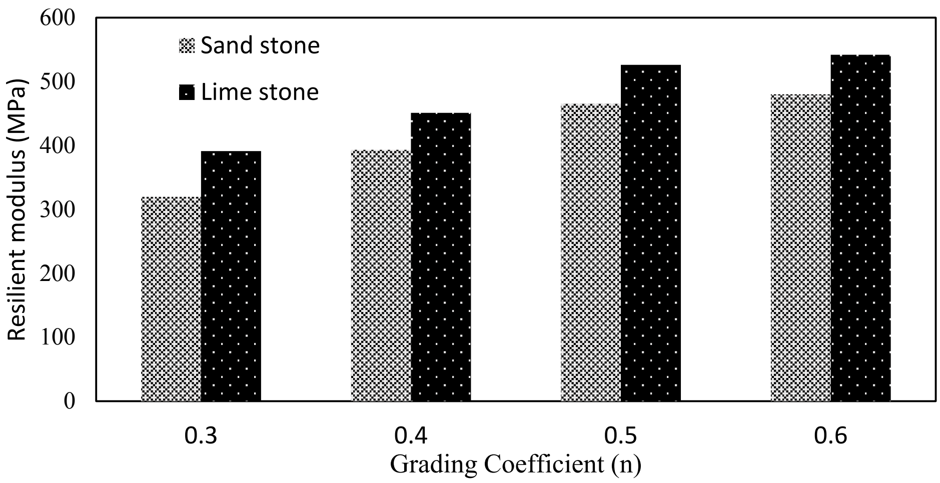

Figure (5): Effect of aggregate type on resilient modulus

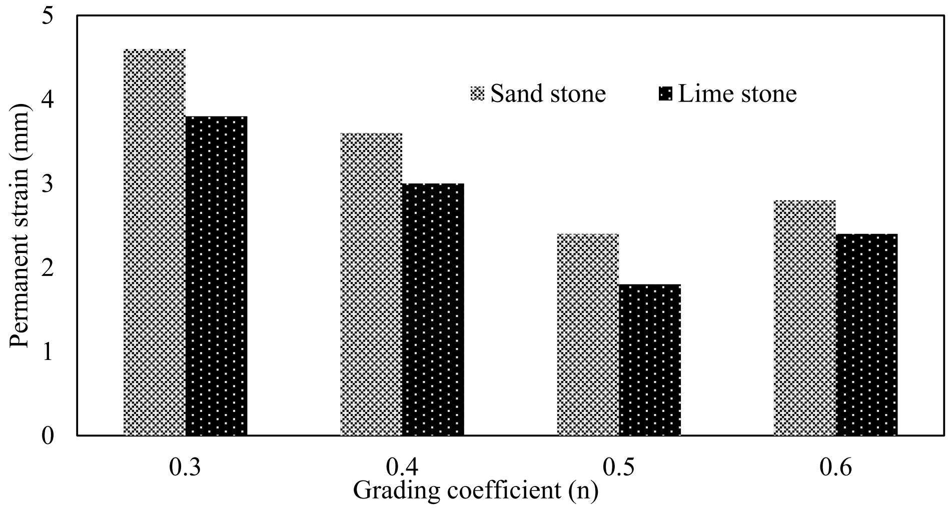

Figure (6): Effect of aggregate type on permanent strain

CONCLUSIONS

- Aggregate type affects the behavior of unbound granular materials; limestone shows higher resilience behavior than sandstone at the same loading, moisture and gradation. This shows that limestone has higher resistance to permanent deformation as compared to sandstone.
- The increment of fines in the gradation curve results in a reduction of resilient modulus and an increment in permanent strain for unbound granular materials. Fuller grading value constant 'n' of '0.3' gradation having high fines results in the lowest value of M_R. The concentration of fines affects the rigidity and stiffness of the sample. As fine content is increased, the sample begins to soften and friction between particles is 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. This is due to decreases in stiffness and rigidity and reduction in friction among particles.
- It is concluded from the test results that limestone has better performance than sandstone. The results of sandstone are also satisfactory, but limestone shows better performance than sandstone, 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 to permanent deformation when compared to all other gradations. By increasing or decreasing percentage of fines from 5% in gradation, permanent strain increases in both cases.

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