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Rock Aggregate Size Influence on Physical Degradation of Laminate Sedimentary Rocks in Flexible Pavement

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Abstract

Rock aggregates are the most fundamental material of highways, railroads, and other construction activities. Degradation of aggregate is the disintegration of aggregate due to the wheel load and moisture saturation causing loss of support in unbound granular layer and reduction of drainage in pavement materials. Sedimentary rocks from different quarries were evaluated to determine the influence of aggregate size on the degradation of materials. This study is to find out the effect of size on physical parameters of aggregate used in flexible and rigid pavement. The performance of river rock and crushed rock physical properties has been tested and compared. In order to determine the effect of aggregate size on their degradation properties, different sieve ranges were selected. The sieve sizes are graded into four categories according to Indian Standard sieve: R1 (20 mm-16 mm), R2 (16 mm-12.5 mm), R3 (12.5 mm-10 mm), and R4 (10 mm-4.75 mm) for degradation test such as, aggregate impact value (AIV), aggregate crushing value (ACV), water absorption (WA) and weathering test such as soundness and slake durability. It is observed that the larger size of aggregate has given better resistance against impact load, abrasion, weathering action and water absorption compare to smaller size over the same volume of rock. The rate at which aggregate degradation occurs is influenced by size. Along with the wheel load, environmental factors including moisture and temperature changes are the primary causes of the early degradation of aggregate. The river rock has a better resistance against degradation and weathering action as it has lesser lamination (a small scale sequence of fine rock layer). Adoption of larger size aggregate in the pavement base course is suggested to withstand the effect of environmental action and wheel load, especially on the friable and quickly disintegrated rock. A rating value, rating index and regression equation have been developed for aggregate degradation.

Keywords: Particle Size, Properties of Rock, Weathering, Slake Durability, Degradation Index

Introduction

Aggregates on road construction play significant role as it affects the overall performance based on the aggregate strength, durability, and resistance to sustained load after construction. Aggregate characteristics such as particle size, shape, and texture influence hot mix asphalt pavement performance and serviceability. Low resistance to deformation will ensue if the aggregate structure is weak. Careful grading control can yield high stability from aggregates possessing little strength.

Aggregate degradation means breakdown of particles into smaller pieces through physical or environmental processes. Degradation causes raveling and instability in pavement surfacing, loss of support in roadbases, excessive and differential settlements in pavement foundations (Balasubramanyam, 1993).The physical degradation is caused by the forces developed duringplacing, compacting and finally by the traffic while degradation due to environmental actions are caused by temperature change, moisture content variation, freeze-thaw effect and by chemical processes like hydration, hydrolysis, oxidation, leaching, chemical attack of polluted water and dissolved acids. The extent of degradation of road aggregates depends on several factors *e.g.* aggregate strength, shape, size, grading, compaction and moisture. High strength aggregates suffer less degradation. For this reason the initial specified gradation should be coarser for a weak aggregate than that for a strong aggregate (Laldintluanga *et al.*, 2021; Joji *et al.*, 2022).

Degradation increases with the increase in compactive effort. It increases either by the increase of the magnitude of the load or by the increase of the number of repetitions of the load however the effect of the former is more pronounced. No particular engineering test other than the strength property tests are specified to find the degradation susceptibility of road aggregates. Los Angeles abrasion test, Soundness test, Aggregate crushing test and Aggregate impact test with or without modifications have been done to simulate the expected service life conditions. The qualities of asphalt mixtures can be significantly enhanced by using aggregates with good physical and mechanical properties (Walubita and Martin, 2010). High-density aggregates and good crush resistance in asphalt pavements can reduce the chance of aggregates breaking under repeated vehicle loads (Cai *et al.*, 2018; Xu *et al.*, 2014; Zakaria 1986).

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The gradation is closely related to the quality and performance of the pavement. The aggregates retaining on sieve sizes of 2.36 and 4.75 mm provide more than 50% contribution to resist load and rutting, and the aggregates retaining on sieve sizes of 1.18, 0.6 and 0.3 mm provide more than 50% contribution to strength the structure. The aggregate gradation played a considerable role in resisting the permanent deformation of pavement (Hussain *et al.*, 2014; Zhang *et al.*, 2019; Martin *et al.*, 2014; Lv *et al.*, 2020). The rutting resistance increased first and then decreased with regard to the changing of the gradation from fine to coarse (Golalipour *et al.*, 2012; Yu *et al.*, 2021; Yue *et al.*, 2022).

The size-dependent performance of rock with regard to physical properties is the main focus of the study. As stipulated by Indian Road Congress, the performance of rock size gradation specification used in the construction of flexible pavements is not satisfactory in terms of durability, mainly when applied to thinly laminate sedimentary rock that has a high aggregate degradation and water absorption value (IRC37, 2018). In Mizoram, most rocks cannot withstand repeated wheel loads in the presence of moisture during the long monsoon rainy season. Hydro-geological factors have also contributed to the longevity of the asphalt pavement.

Rock size specification used in the construction of flexible pavements is supposed to have the shear transmission of stress that should be uniformly distributed throughout the flexible pavement. But, uniform shear transmission is not present in the granular layer when weak rock is present. The ability to resist load has a limit due to shear transmission of the load that is not taking place properly in weak rock, which leads to premature failure. Increased stresses, localized stress concentrations, increased rutting, and decreased drainage are the results when rock aggregate fails before the traffic load is transferred to the adjacent support rock. For this reason, modifications to pavement structure design are necessary.

The investigation results suggested, especially for the friable and easily disintegrated rock, is to use larger stone blocks in flexible pavement to withstand the impact of environmental action and wheel load as the design specification is not performing. In a hilly area with highly degraded rock and heavy rainfall, this study will alter the pavement structure design based on materials response to load and environmental action.

Study Area

The rock sample collected area is within Bhuban Formation of Miocene age and comprises of shale, siltstone and sandstone (Fig. 1). Mizoram terrain is an immature topography and geologically the arenaceous and argillaceous sequences of sedimentary rocks of tertiary age. The rock types exposed include well laminated iron stained splintery green shale, and silt / shale interlaminations with thick zone of pelagic shale and mudstone (GSI, 2011).

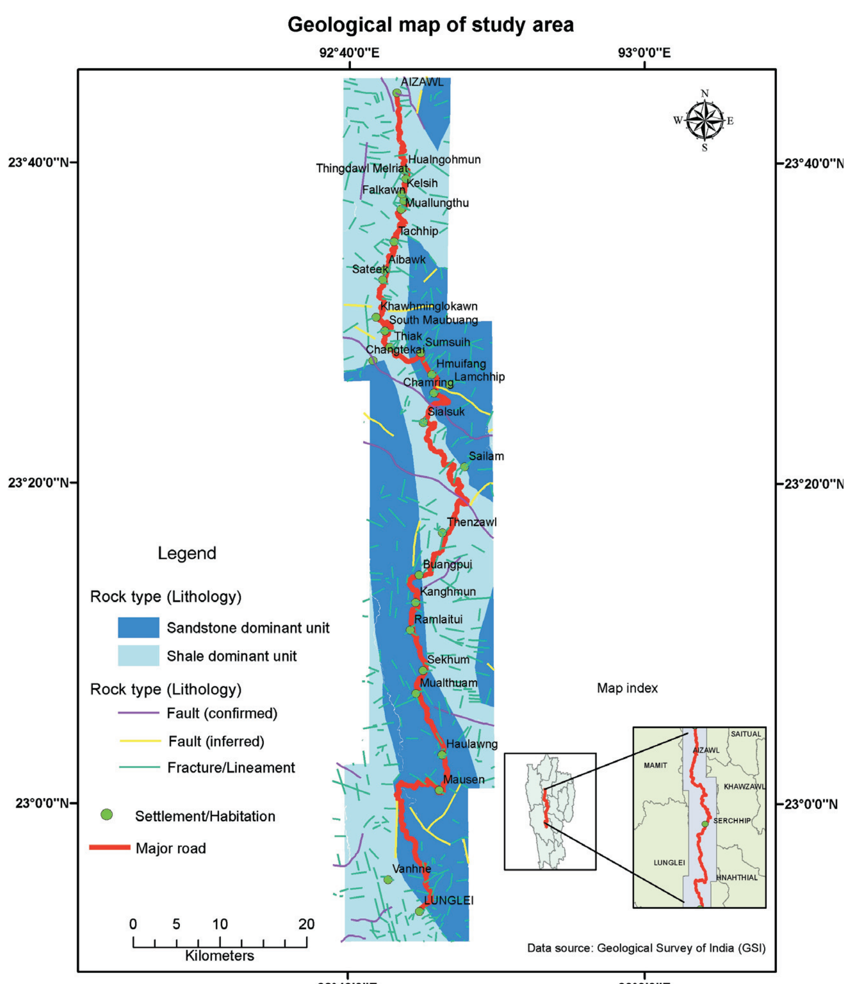

Fig.1. Geological Map of the study area

Indian Remote Sensing Satellite Quickbird, (IRS-P6) LISS III data having spatial resolution of 23.5m and Cartosat-I stereo-paired data having spatial resolution of 2.5m were used as the main data to plot the geological map of study area. Survey of India (SOI) to pographical maps and various ancillary data were also referred in the development of the map. The main road connecting Aizawl city and Lunglei (study area) *i.e.* 160 km long was buffered 500m on both sides. In a GIS environment, the geological lithology and structure were plotted.

Materials and Methods

Materials

The aggregate used in this study is obtained from river stones *i.e.* Tuipui and crushed aggregates (crushed stone) obtained from different quarries such as Hlimen, Maubuang, Mausen and Sentezel. Tuipui river stone and Hlimen quarry stone has been used for finding the degradation of aggregate physical properties. Maubuang, Mausen and Sentezel rocks are used for Soundness test which evaluate the resistance of rock against weathering action.

Flexible and rigid pavements are constructed with coarse aggregate.The load transfer capability of pavements is heavily influenced by aggregates. Various properties are tested, including strength, toughness, hardness, and ability to absorb water (Alex *et al.*, 2014; Hofer *et al.*, 2013; Afolagboye *et al.*, 2017). The aggregate size includes maximum size, size range, and gradation. Materials selections for the study are from different quarries.

Methods

Different coarse aggregates were selected and divided into four ranges of sizes. Each range of coarse aggregateswas tested using physical properties tests such as soundness, aggregate impact value, aggregate crushing value, water absorption and slake durability. To determine the physical properties of rock, tests are performed to determine the performance of coarse aggregate in constructing flexible pavement under various loads, including impact, abrasion, and water absorption.

The aggregate (rock) sizes are divided into the normally adopted size of four ranges of aggregate size as per IS sieve standards as per IS code:- R1 (20 mm-16 mm), R2 (16 mm-12.5 mm), R3 (12.5 mm-10 mm), and R4 (10 mm-4.75 mm) for aggregate impact value, aggregate crushing value, water absorption, and soundness value.The grading A to G is adopted for classification of aggregate size in the Abrasion test (Alex *et al.*, 2014; Hofer *et al.*, 2013; Afolagboye *et al.*, 2017; IS 383, 2016).

The soundness test is adopted to simulate the physical effects of weathering into the aggregates. It is a chemical test to determine the resistance to disintegration of aggregate by soaking aggregate specimen in saturated solutions of sodium sulphate to accelerate the effect of weathering into the aggregates (IS 2386, 1997). Slake durability test is used to assess their resistance to weakening and disintegrating. In this test, rock samples are subjected to two cycles of alternate drying and wetting in a slake fluid, usually water (IS 10050, 2001).

Results and Discussions

This study examines how aggregate size affects rock's physical properties, as well as the possibility of using a bigger stone in flexible pavements to reduce degradation. The size of the aggregate plays a significant role in its durability, permeability and strength. The response of unbound material (granular layer of pavement) depends on the moisture content. In high moisture content in the pavement structure, weak aggregate (thinly laminated rock) cannot withstand repeated traffic loads (Said and Wahlstorm, 2000; Lekarp, *et al.*, 2000). Material behaviour depends on the magnitude, time, nature of load to which the material is subjected and moisture levels (Wei Tu, 2007). Some laminated sedimentary rocks have a high water absorption capacity but little weathering resistance mainly due to the presence of clay and silt in the lamination layer. The main cause of failure on weak aggregate pavement is a degradation of rock caused by the presence of groundwater, which saturates the rock and causes it to crumble when wheel load is applied as well as the presence of clay and silt in the small scale sequence of fine rock layer (lamination). Larger aggregate of stone block size can be introduced into the base layer of the pavement to counteract traffic load-induced rock degradation and moisture-induced damage as bigger rock size has more thickness to resist loadand equivalent depth of water penetration through the rock lamination regardless of the size.

Influence of Aggregate Size in Aggregate Impact Value (AIV)

AIV is the test that measures toughness. This test simulate the wheel load pounding/dropping action occurs in the undulation or potholes. The larger sizes of aggregates have given better result over smaller size of aggregate (Fig. 2). It means that a larger size of aggregate has a higher capability to withstand repetitive impact load as the larger aggregates are capable of absorbing more impact load due to more thickness. At pavement undulations, impact loads frequently lead to the degradation of soft rock.

Influence of Aggregate Size in Water Absorption Value (WAV):

Water Absorption Values (WAV) measures the ratio between difference of dry weight aggregate and saturated surface dry weight of aggregate to dry weight of aggregate. High rainfall during the wet seasons causes moisture ingress through the pavement surfaces. Absence of proper drainage facility lead massive moisture related damage to the pavement structure and consequent premature failure depending upon the water susceptibility of the pavement material.

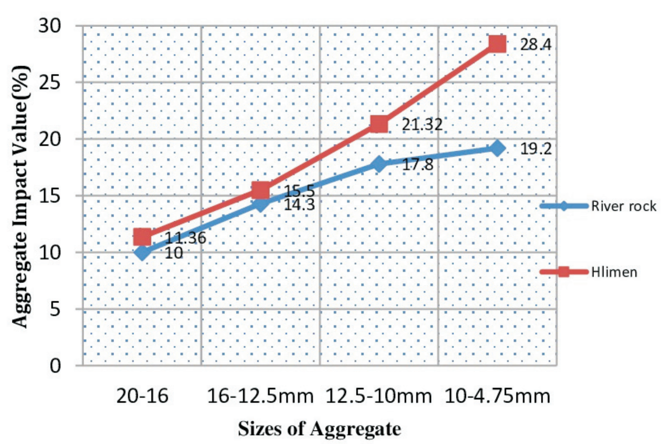

Fig.2. AIV of River rock & Hlimen with different size of rock

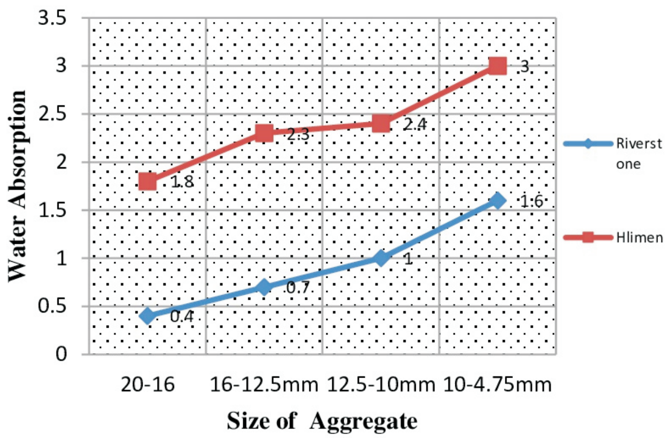

Fig.3. WAV of River stone & Hlimen with different size of rock

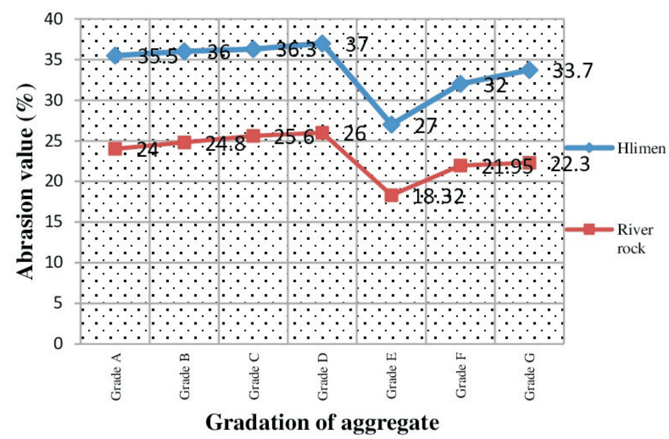

Fig.4. LAAV of Riverstone & Hlimen with different gradation of aggregate

The locally available material, stone aggregate used in the pavement, degrades highly in presence of moisture due to high of water absorbability.

Larger sizes of aggregates have given lower absorption values compared to smaller sizes (Fig. 3). This may be due to the depth of water penetration to the rock remain the same regardless of the size within a specific period of time.

Influence of Aggregate Size On Los Angeles Abrasion Value (LAAV)

The percentage degradation (wear) of the sample aggregates due to rubbing with steel balls and the falling impact of balls are determined as a percentage in the observation value. LAAV test involves two kinds of action *i.e.* impact (pounding force) and abrasion (frictional force). In flexible pavement, these two action forces reflect the actual conditions of the site at some extent. It has been observed that gradations with a higher sieve size (coarser aggregates) have a lower level of abrasion (Fig.5). The time required to wear away a larger size of the rock is more compared to the time required to disintegrate the smaller size of aggregate. LAAV test involves the combination of different gradation sizes of aggregate (Table 1). At a larger particle size, the desired value of abrasion is obtained.

The lower abrasion value indicates less degradation. The largest particle size mixture, grade E, has less degradation, while the smallest particle size mixture, grade D, has more degradation (Fig. 4). As the particle size increases, the abrasion value decreases.

Influence of Aggregate Size On Aggregate Crushing Value (ACV)

Aggregate Crushing Value is used to measure the strength of aggregate. As the size of aggregate gets larger, the strength of aggregate increases. The larger size has the ability to resist more loads (traffic load) due to individual thickness of aggregate that imparts more strength (Fig. 5).

Influence of Aggregate Size On Degradation Due to Weathering

The weathering resistance of the rock is measured using soundness and slake durability test.Soundness tests simulate the physical effects of weathering on aggregates. Aggregates may degrade and disintegrate due to weathering, leading to early pavement distress. Aggregates from the Mausen, Maubuang, and Sentezelrock used in the construction of State Highway were collected for conducting soundness. Sodium sulphate was used to test the soundness of the coarse aggregate taken. The weight loss caused by weathering has been checked after five cycles of repetition. It is found that larger particle size has a lower weight loss value, whereas a smaller aggregate tends to exceed the permitted limit of soundness. The value for soundness for various aggregate sizes is displayed in Table 2.

Table 1: Gradation of aggregates for LAAV

Sieve Size		Weight in gm of test sample for grade						
Passing (mm)	Retained (mm)	A	B	C	D	E	F	G
80	63					2500		
63	50					2500		
50	40					5000	5000	
40	25	1250					5000	5000
25	20	1250						5000
20	12.5	1250	2500					
12.5	10	1250	2500					
10	6.3			2500				
6.3	4.75			2500				
4.75	2.36				5000			
No of Spheres		12	11	8	6	12	12	12
No.of Revolution		500	500	500	500	1000	1000	1000

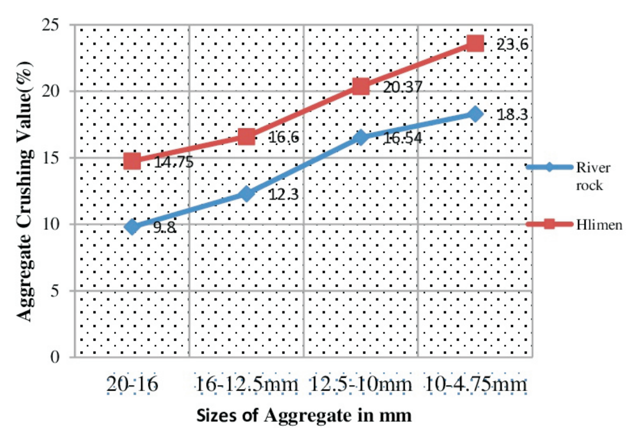

Fig.5. ACV of Riverstone & Hlimen with different size of rock

Table 2: Soundness value for various aggregate sizes

Sample	Particle Size (mm)	Percentage (%) loss of weight after 5 cycle	Permissible limit as per IS 2386 Part V, &MoRT&H 4th revision
Maubuang	40-20	17.33	<12% with sodium sulphate, <18% with magnesium sulphate after [Sodium sulphate is used in this test.]
	20-10	21.00	
	10-4.75	26.67	
Mausen	40-20	7.8	
	20-10	8.5	
	10-4.75	16.67	
Sentezel	40-20	12.27	
	20-10	14.60	
	10-4.75	19.67	

Slake durability Index (SDI) test measures the influence of weathering on the durability of rock.The Hlimen and Tuipui river rock has been tested as per IS 10050-1981 for slake durability. The durability value increases with rock size (Table 3).

Soundness and Slake durability values decrease with increasing particle size primarily because of the lesser surface area, where weathering action has less of an impact than it would on a smaller-sized rock, which has larger surface area per unit volume.

Aggregate Degradation Rating and Index

Aggregate Degradation Index is the indicator for the magnitude of disintegration. In addition to reducing particle angularity, surface texture, and size, aggregate degradation also reduces aggregate materials grade and shear strength. The disintegration of rock caused by repeated impact loads, and abrasive force, has changed the gradation. Gradation as per design is lost shortly after the application of load on the pavement because of aggregate degradation. In this situation, the larger particle size of the rock will slow down the disintegration process, especially for brittle and soft rock.

A rating value is assigned to each parameter ranging from 1, 1.1 to 2.0 and 2.1 to 3.0, which correspond to Low, Medium, High, and Very High levels of aggregate degradation index, respectively. After giving each parameter a rating number, the rating value of each individual parameter is given a suitable weightage (fixed) to calculate the weighted rating value of each individual parameter.

The weighted rating values of all degradation test parameters, such as AIV, ACV, LAAV and WA are averaged to obtain the final rating value. The following fixed weightages and rating value have been assigned for the computation of the Weighted Rating Value of each individual parameter as stated inTable 4. The weighted rating value is calculated with the value obtained from aggregate degradation tests (Table 5) as well as the rating value and aggregate degradation index (IRC-82, 2015).

The aggregate degradation rating value increases with the enhancement of rock size. This shows that rocks with larger particle sizes have a greater ability to withstand degradations caused by abrasion, repeated impact, crushing, and the presence of moisture. Aggregate Degradation Index is the indicator for the magnitude of disintegration.

Table 3: Durability value and weathering grade for various aggregate sizes

Name of the Source	Rock Size	Id2 (%)	Durability classification as per IS 10050-1981	Weathering Grade (ISRM)
Tuipui river sandstone	20-16 mm	96.4	Extremely High	Un-weathered
	16-12.5mm	95.8	Extremely High	Un-weathered
	12.5-10mm	95.4	Extremely High	Un-weathered
	10-4.75mm	93.8	Very High	Partially weathered
Hlimen Sandstone	20-16 mm	95.8	Extremely High	Un-weathered
	16-12.5mm	93.12	Very High	Partially weathered
	12.5-10mm	92.6	Very High	Partially weathered
	10-4.75mm	91.2	Very High	Partially weathered

Table 4: Aggregate Degradation based Rating for pavement

Parameters	Ranges(%)				Weightage value
AIV	0-10	10-20	20-30	>30	1
ACV	0-10	10-20	20-30	>30	0.8
LAAV	0-20	20-30	30-40	>40	1.1
WA	0-2	2-3	3-5	>5	1.1
Rating	3-4	2.1-3	1.1-2	0.5	
Degradation Index	Low	Medium	High	Very High	

Regression equation was developed to predict the Aggregate degradation rating value with respect to aggregate degradation test such as impact, crushing, abrasion and water absorption.

Aggregate Degradation Rating value:

$$AD = 4-0.023*AIV-0.029*ACV-0.011*LAA-0.23*WA (R^2 = 0.99)$$

where,

AD = *Aggregate degradation rating value*
AIV = *Aggregate Impact Value*
ACV = *Aggregate Crushing Value*
LAA = *Los Angeles Abrasion*
WA = *Water Absorption*

Conclusions

The larger size of aggregate has been found to have higher toughness (impact), strength (crushing), abrasion and weathering resistance than the smaller size of aggregate. Larger aggregate size has higher capability of absorbing more repetitive impact load, higher strength due to individual thickness of aggregate and less water absorption due to less surface area compared to smaller size over the same volume of rock. The early degradation of aggregate is mostly caused by environmental factors such as moisture and

Table 5: Aggregate Degradation Index and Rating value for Tuipui and Hlimen rock

Source of Rock Gradation	Tuipui				Hlimen			
	20-16 mm	16-12.5mm	12.5-10mm	10-4.75mm	20-16 mm	16-12.5mm	12.5-10mm	10-4.75mm
AIV	10	14.3	17.8	19.2	11.36	15.5	21.32	28.4
ACV	9.8	12.3	16.54	18.3	14.75	16.6	20.37	23.6
LAAV (Grade-B)	14	14.8	15.6	16	35.5	36	36.3	37
WA	0.4	0.7	1	1.6	1.8	2.3	2.4	3
Weighted Rating Value	3.3	2.93	2.69	2.49	2.47	2.21	1.99	1.55
Aggregate Degradation Index	Low	Medium	Medium	Medium	Medium	Medium	High	High

temperature variations, in addition to wheel load. The rate at which aggregate degradation occurs is influenced by size. Abrasive and weathering effect on aggregate is slowed down by larger particles because they degrade away more slowly in the same volume of rock compare to smaller rock. The aggregate degradation rating value is increasing with increase in rock size. This shows that rocks with larger particle sizes have a greater ability to withstand degradations caused by abrasion, repeated impact, crushing, and the presence of moisture. The river rock has a better resistance against degradation and weathering action as it is the remaining pieces in the river which endure the extreme environmental condition. The nature of the rocks, being sedimentary and having high water absorption of Hlimen rock, has shown a lower value of physical properties of rock under the application of load compared to Tuipui river rock.

Authors' Contributions

HL: Investigation, Conceptualization, Methodology, Writing – Original Draft. **RR:** Visualization, Supervision, Editing. **ZR:** Investigation, Formal Analysis

Conflict of Interest

Authors confirmed that there are no conflicts of interest or competing interest from any party.

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