EFFECT OF NANO- MATERIALS ON ASPHALT CONCRETE MIXES; A CASE STUDY

Arpita Saha[1*], Bhupendra Singh[2], Subhadip Biswas[3]

[1, 2, 3]Research Scholar, Department of Civil Engineering, Indian Institute of Technology Roorkee, India-247667.

Abstract

Primary constituents of bituminous concrete are coarse aggregate, fine aggregate, binder and additive (optional). The basic properties of these constituents govern the characteristics of the bituminous mix (viz. stability, durability, temperature, stress and rutting resistance). When the basic properties of the core material are below-graded, the bituminous concrete mix fail to meet the required standard. One of the feasible solution to overcome this problem is the use of additives in order to improve the properties of bituminous mix. In this study, locally available poor quality stone aggregate and asphalt were treated with liquid Nano-material, zycosoil. The bituminous concrete prepared using Zycosoil treated stone aggregate and bitumen, yield better results compared to mix prepared with locally available conventional materials. Moreover, when zycosoil was added with bitumen as 0.5% of the weight of bitumen, the bituminous mixture gave superior results in terms of stability, rutting and temperature resistance. Apart from the improved performance, bituminous macadam prepared using zycosoil modified stone and asphalt was found to be economical.

Keywords:*Asphalt concrete mix; Nano- material; Zycosoil; Stability.*

1. Introduction

India is a developing country with rapidly expanding road network. With this expansion of road network, demand of the raw materials for pavement construction is also increasing proportionately. Availability of good quality raw material is also decreasing over time. This forces to use poor quality aggregates to meet the requirement. Increase in the traffic loads, coupled with the rising cost of asphalt, have alsodirect towards an urgency to improve the durability, the safety and also the efficiency of asphalt pavements by means of asphalt modification. So the present study examines the usage of additive material to overcome the problem of shortage, by making use of poor quality materials as well as improving the properties of good quality materials. Most of the Indian roads are flexible pavements consisting of bituminous top. Bituminous mixture is upper most (single or double, depending upon the utility of road) layer of flexible pavement structure. A bituminous concrete mainly consists of coarse aggregate, fine

* Corresponding author: Arpita Saha (arpitasaha2904@gmail.com)

aggregate, filler, binder and additive (if needed) as a constituent material. Pavement thickness is directly related to the material properties. Better quality of aggregate results lesser pavement thickness for the same performance.
Treating aggregate by additives improves its properties which will eventually improve the properties of bituminous concrete. Although a number of studies have revealed that the use of some nano- materials can improvethe properties of pavement materials so as, the performance of the pavement, the application of nano-science and technology to serve this purpose is still in its infant stages. Nano science and nanotechnology have the ability to take control of matters at nanometer scale (molecular) and to utilize the properties of this dimension in materials, tools and modern systems. So it is necessary to stimulate the application and development of Nano-scientific and technological concepts for bituminous materials and asphalt pavements for evaluating the mechanical and the physical properties and as well as the durability of important composite construction materials.

The present study is an attempt to use of the locally available poor quality stone aggregates (as few basic properties are not in the permissible limit) in preparation of bituminous macadam. For that purpose, a liquid Nano-material named zycosoil is usedto treat the stone aggregates. In this context, the basic properties of aggregates (specific gravity, water absorption, impact, abrasion, crushing and stripping) were evaluated and compared with the properties of aggregates modified with zycosoil.Marshall Stability test was performed by adding different dosages of zycosoil with both of stone aggregates and bitumen. Improvement in the quality of stone aggregates and bituminous concrete were noticed. The feasibility of zycosoil application in road construction was also evaluated and found to be positive.

2. Background literature

Pavement design for any country is influenced by the environmental conditions, the economic status and the user requirement of the country. Depending upon all those factors, countries have their own guidelines. Moreover, those guidelines also specify the variety in the way of observation of different properties of material. In most of the cases, conventional and locally available materials are preferred while it sometimes fails to maintain the standard recommended in those guidelines. Hence, in order to achieve the required standard, additives are added to the mix. In recent times, a number of Nano- materials have emerged as effective additives. In this regard, the entire field of Nano-science and Technology is gaining popularity and it may lead to significant contributions towards the development in asphalt pavement technology.Gandhi *et al.*(2002) evaluated the moisture susceptibility of the mixes by testing the mixtures which was made with fresh binder as well as the conditioned mixed samples prepared with binder stored for 3 days at 163°C and 0.5% of liquid anti stripping agents. Hydrated lime and the liquid anti-stripping agents were equally effective for the mixes when conditioned beyond 1 day.Khodaii *et al.*(2014)also observed that the coating of the aggregate surface with zycosoil reduces the moisture susceptibility of the asphalt concrete mix. According to Moghadas Nejad *et al.*(2012), zycosoil is a water soluble reactive organo-silicon component that is specially designed to improve the adhesion between bitumen and aggregates in hot mix asphalt. Behbahani *et al.*(2015) revealed that apart from the case of asphalt mixture, zycosoil (4.5%) act as an anti-stripping for

glasphalt mixture also and improves the moisture susceptibility. Similarly, Ziari *et al.*(2015) also observed that use of zycosoil modified glasphalt gives better rutting resistance and stiffness modulus as compared to the conventional asphalts. According to Teppala *et al.*(2014) zycosoil can improve the performance of DBM crumb rubber modified bituminous mix of 55 grade. Moreover, Dam *et al.*(2014) indicated that application of zycosoil can reduce the stripping of aggregate and improve the properties of asphalt which eventually, leads to the enhancement of the quality flexible pavement. To evaluate the performance of bitumen and aggregate, past researchers have applied zycosoil in various percentages according to their requirement. For instance, Dam et al. (2015) applied 0.02, 0.03 and 0.04% of zycosoil with 5.1% of bitumen content. Sarkar *et al.*(2014) improved the performance of stone and brick aggregate by soaking them into a solution of 1kg zycosoil: 400 liters water and then spraying the mix of 5% by weight of aggregate on oven dried aggregates. Ibrahim *et al.*(2015)applied zycotherm both on asphalt and asphalt concrete mixes, it was observed that zycotherm provide resistance to asphalt concrete mixture against rutting, moisture damage, fatigue and temperature cracking. Therefore, outcomes of the past researches suggest that, zycosoil can be used for treating stone aggregate as well as mixing with hot asphalt while preparing the mix.

3. Objectives of the Study

Based on these past research, the present study focuses on the evaluation of the improvement in the properties of aggregates as well as asphalt concrete mix. The main objective of this study is to use low quality of stone aggregate (in place of bricks) for flexible pavementconstruction in the places where stone is not locally available. For this purpose, materials like low quality of stone aggregate, locally available bitumen and liquid Nano-material zycosoil was used.

4. Materials and Experimental Procedure

Required materials were collected from the available sources and the basic properties of aggregate and bitumen were checked. In the study, the used aggregates were obtained from local sources in Tripura. Binder used was conventional binder VG-30. Zycosil a pale colored Nano-material was utilized for the treatment of aggregates and modification of binder. Zycosoil is a water soluble compound that forms odorless water clear solution. Interaction of Zycosoil with the aggregates leads to the permanent Nano siliconization of the surfaces which converts water loving silanol groups to water repellent siloxane bonds. The Si-O-Si siloxane bond which is known to be one of the strongest and durable bonds, increases the durability of the aggregates.Zycosoil's reactive bonding ability with the aggregates and asphalt results in considerable decrease in stripping of aggregates and thus increases the durability of the pavement.

First of all, basic properties of stone aggregates i.e. impact value, abrasion value, crushing strength, specific gravity and water absorption were found out. Asphalt binder was characterized by performing basic tests like penetration, ductility, softening point. High temperature performance grade (PG) and kinematic viscosity at 135 °C were also calculated using dynamic shear remoter (DSR) and rotational viscometer respectively. In order to check the temperature susceptibility of the binder, penetration index (PI) was

calculated by using the equation (1). The value of PI ranges from around -3 for high temperature susceptible bitumen to +7 for highly blown low temperature susceptible bitumen. Basic properties of aggregate and asphalt binder are given in table 1 and 2.

$$PI = \frac{1952 - 500\log(\text{Pentration}) - 20\ (\text{Softening Point})}{50\log(\text{Penetration}) - (\text{Softening Point}) - 120} \quad (1)$$

Table 1: Basic Properties of Stone Aggregate

Tests	*MORTH* Specified Values*	*Obtained Values*
Specific Gravity	-	2.50
Water Absorption (IS:2386, Part 3)	Maximum 2%	2.60%
Impact Value (IS:2386, Part-4)	Maximum 30%	29.53%
Los Angeles Abrasion (IS:2386, Part-4)	Maximum 40%	40.06%
Crushing Strength (IS:2386, Part-4)	-	26.55%
Soundness (IS:2386, Part-5)	Maximum 12%	9%
Stripping Value (AASHTO T182)	Maximum 5%	4%

*Ministry of Road Transport and Highways, India.

Table 2: Basic Properties of Bitumen

Properties	*IS: 73* Specified Values*	*Obtained Values*
Softening Point (ºC) (IS:1205)	Minimum 47	52
Penetration Values (mm) (IS:1203)	Minimum 45	75
Penetration Index	-	-0.0071
Ductility Value (mm) (IS:1208)	-	98.5
Specific Gravity	-	1.02
High Temperature PG (ASTM-D7175)	-	PG 70-XX
Kinematic Viscosity (cSt) @135 °C (ASTM-D4402)	Minimum 350	415

*IS: 73 (2013) Indian Standard PAVING BITUMEN — SPECIFICATION (Fourth Revision)

From the obtained values, it is clear that some of the key aggregate properties (water absorption, specific gravity and Los Angeles abrasion) do not fulfil the required criteria, on the other hand bitumen was found to be fulfilling all the criteria well. It implies that the quality of bitumen is good to be used in bituminous macadam but aggregates are of poor quality. In an attempt to improve the properties, aggregates were treated with zycosoil. Zycosoil was mixed with water at a proportion of 1kg Zycosoil: 400 liters of water and the stone aggregate by soaking them for 24 hours in the zycosoil and water mix. After surface drying, basic properties of the aggregates were again evaluated. Aggregate properties after zycosoil treatment are given in table 3.

Table 3. Basic Properties of Zycosoil treated Stone Aggregate

Tests	*MORTH* Specified Values*	*Obtained Values*
Specific Gravity	-	2.65
Water Absorption (IS:2386, Part 3)	Maximum 2%	1.823%
Impact Value (IS:2386, Part-4)	Maximum 30%	21.89%
Los Angeles Abrasion (IS:2386, Part-4)	Maximum 40%	32.40%
Crushing Strength (IS:2386, Part-4)	-	21.30%
Soundness (IS:2386, Part-5)	Maximum 12%	7%
Stripping Value (AASHTO T182)	Maximum 5%	1%

*Ministry of Road Transport and Highways, India.

From the obtained values, it is clear that zycosoil treatment improved the properties of the aggregates significantly. Attained values were in limit as specified by MORTH and hence the aggregates could be used in bituminous mix. These improvements in the aggregate properties can be attributed to the strong Si-O-Si bonds which transform hydrophilic aggregate surface to hydrophobic one. So the zycosoil has given satisfactory results and has fulfilled the purpose of using it for treating the aggregates.

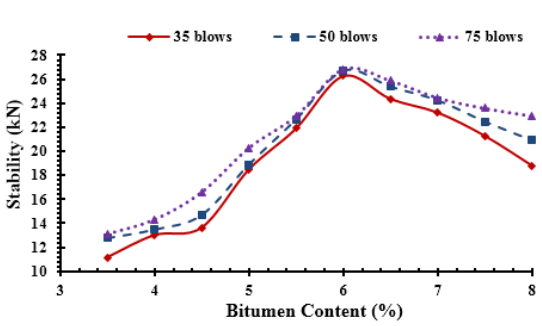
In order to examine the effect of zycosoil on the asphalt mixture properties, zycosoil was also added in the mixture at the rate of 0.1%, 0.2%, 0.3%, 0.4% & 0.5% by weight of the binder, at the time of preparing mixture and the comparisons were made.

5. Marshall Stability Test

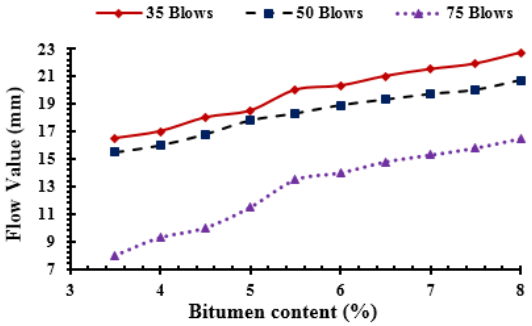
Marshall Stability test was performed to evaluate the stability of the bituminous concrete. Gradation of the aggregates used in the study is given in table 4. Binder contentwas varied from 3.5% to 8% by weight of aggregatewith an increment of 0.5%. In order to simulate for low, medium and high traffic volume roads, 35, 50 and 75 number of blows had been given separately while compacting the samples. Results showed that the stability value increases with the increase of bitumen content for different number of blows up to certain level exceeding which the stability starts decreasing (Fig.1 (a)). Subsequently the flow value also increases with the increase in bitumen content and number of blows (Fig.1 (b)). The voids were found to be decreasing with the increase in bitumen content. In case of higher compaction, the voids reduce to the minimum. It indicates that the binder fills the voids and make proper binding of bituminous mix however, under heavy compaction the voids get reduced and the unit weight increases. For low volume of roads at optimum bitumen content of 6% maximum stability of 19kN was achieved. Similarly, for medium and high volume of roads at optimum bitumen content of 5.9% and 5.8% the maximum stability of 21 and 23kN were achieved (Fig.1 (a)).

Table 4: Grading of aggregate used in Marshall Stability Test

Sieve Size (mm)	*Cumulative % by weight of total aggregate passing*	
	MORTH Specified limits	*Obtained Values*
26.5	*100*	*100*
19	*90-100*	*92*
13.2	*56-88*	*78*
4.75	*16-36*	*28*
2.36	*4-19*	*12*
0.3	*2-10*	*6*
0.075	*0-8*	*2*



(a)



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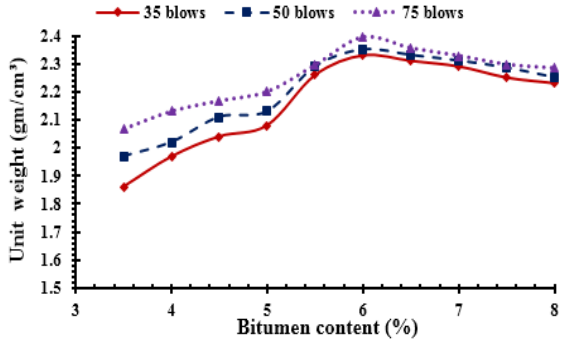

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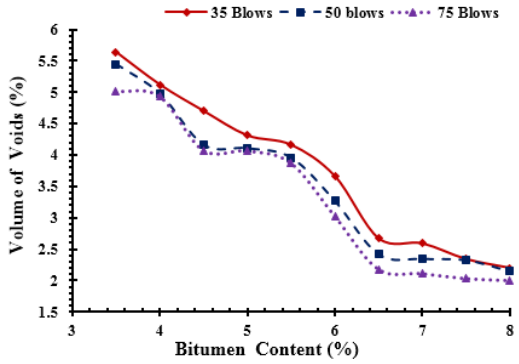

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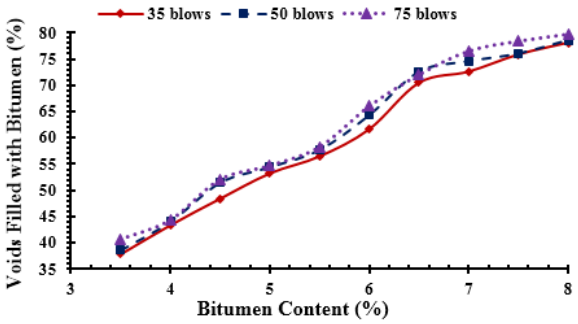


(e)

Figure1: Marshall Test Results Exhibiting the Variations in (a) Stability, (b) Flow Value, (c) Unit Weight, (d) Volume of Voids and (e) Voids Filled with Bitumen with % of Bitumen for Plane Stone Aggregate

The basic properties of the plane aggregate were found to be unsatisfactory as mentioned in table 2. But the Marshall Stability test (Fig.1 (a)) shows that the maximum stability for the optimum bitumen content is 23kN which is more than the minimum stability value required for bituminous macadam. It highlights the gap in the Marshall's method of mix design as it does not include the individual properties of components of the bituminous mix. Many of the previous researches have also stated that only stability value of the mixcannot justify the suitability and durability of the pavement in service. Hence the aggregates were first treated with zycosoil which resulted in improvement in the aggregate properties and were find to be fulfilling required criteria. Marshall Test was again performed on the mixes containing zycosoil treated aggregates. Figure 2(a-e) shows the results of Marshall test with the treated aggregates.

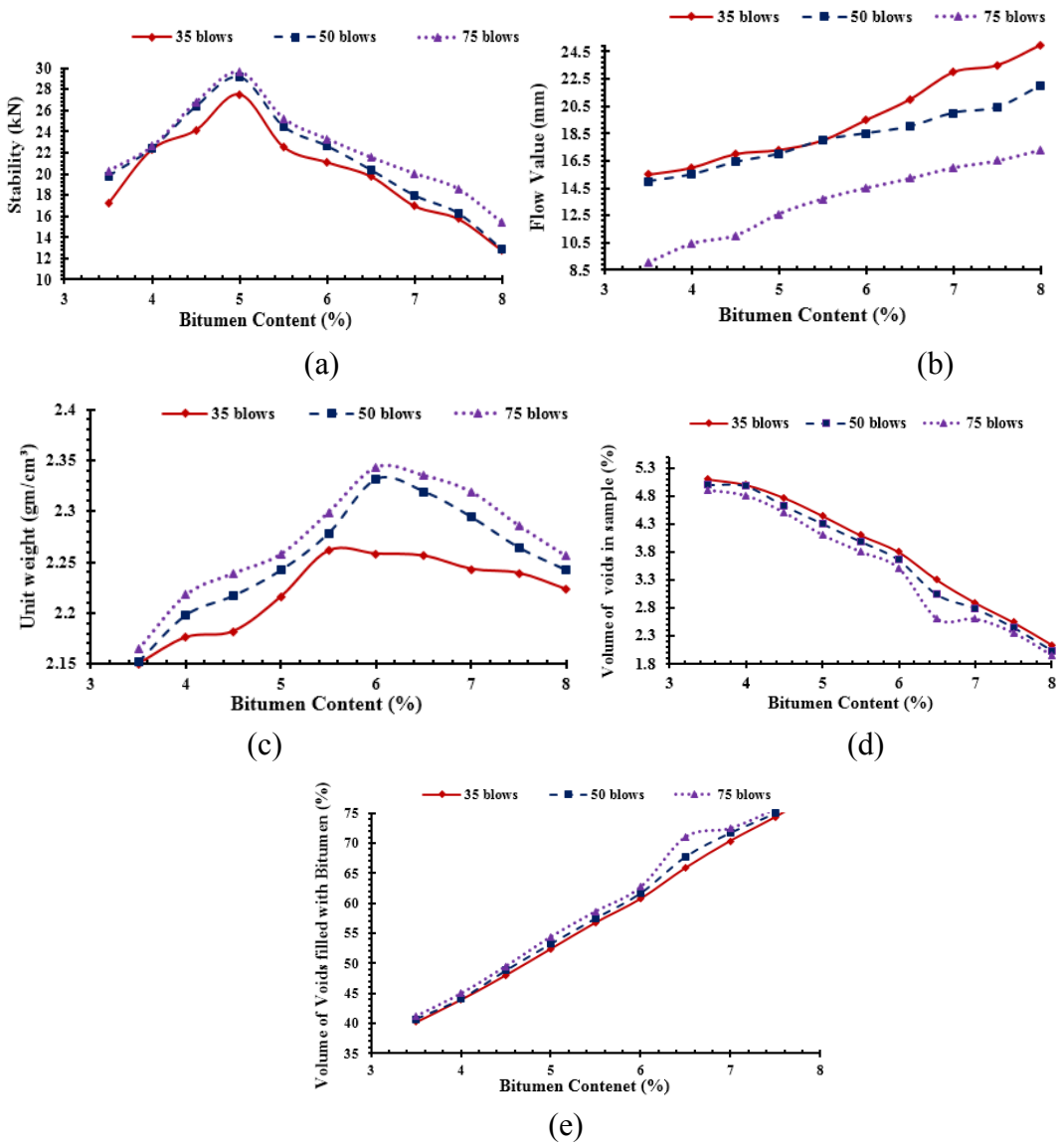
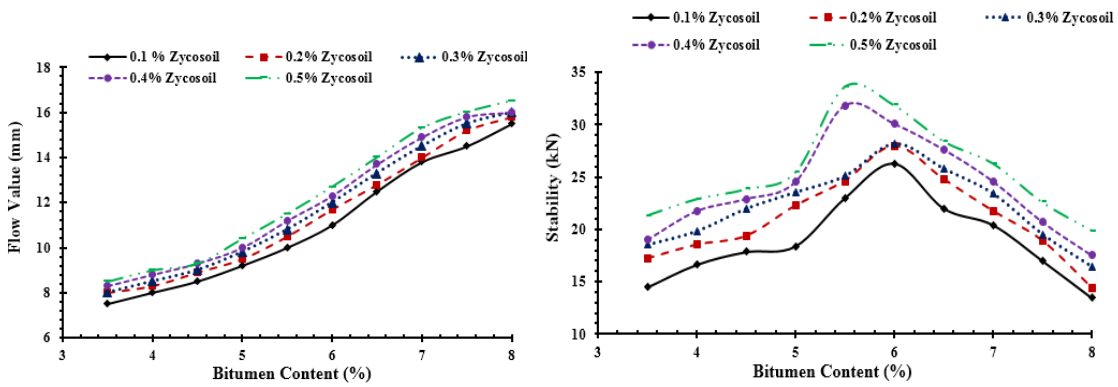


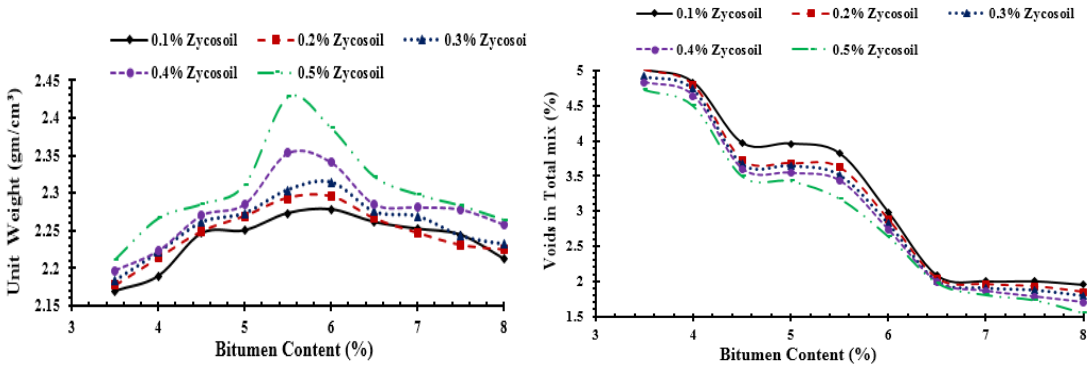
Figure 2: Marshall Test Results Exhibiting the Variations in (a) Stability, (b) Flow Value,(c) Unit Weight, (d) Volume of Voids and (e) Voids Filled with Bitumen with % of Bitumen for Modified Asphalt Concrete Mix

The test results indicate that after using zycosoil treated stones, stability of the bituminous mix increased with increasing bitumen content for different traffic volume.At optimum bitumen content of 5.2% and 5.5% for low and medium volume traffic maximum stability of 23.8 kN and 25 kN are obtained. Similarly, for high volume traffic maximum stability of and 26 KN is obtained at optimum bitumen content of 5.5% with increased flow value of 3.23 mm. It indicates the superiority of the zycosoil treated stones over the conventional ones. Moreover, 80% of voids are filled with bitumen and provides better binding of aggregates with bitumen. Therefore, improvements in all the results signify the suitability of zycosoilapplication on locally available low quality plane stone aggregate by enhancing the stability of bituminous mix and thereby fulfils the objective of treating plane aggregates (stone) to enhance their properties.

Zycosil has an estimated molecule size of 3-6 ηm. These nano molecules containalkoxy groups of silane.It chemically react with hydroxyl (OH) groups present in the pavement materials and forms siloxane bonds (Si-O-Si) which are known to be one of the strongest natural bonds. This chemical reaction makes pavement water repellent by modifying surface characteristics from hydrophilic to hydrophobic.In order to examine the effect of zycosoil on the properties of bituminous mix, zycosoil was alsoadded in the mix while preparing it apart from using it for treating aggregate. Zycosoil dosage varied in the mixture at the rate of 0.1%, 0.2%, 0.3%, 0.4% & 0.5% by weight of the binder. Fig. 3 (a-e) shows the test results with varies percentages of zycosoil in the bituminous mix.



(a) (b)



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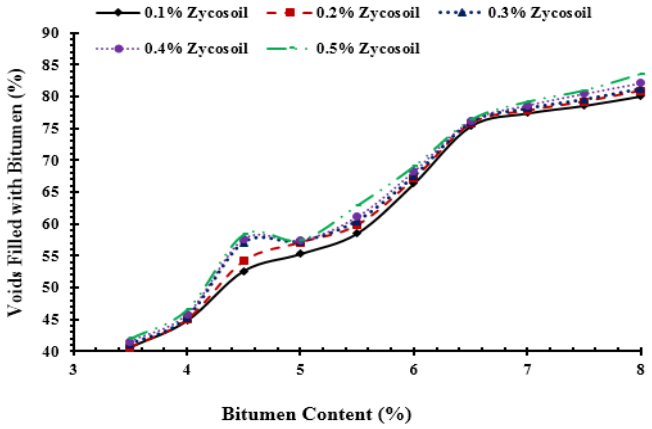

(e)

Figure 3: Marshall Test Results Exhibiting the Variations in (a) Stability, (b) Flow Value,(c) Unit Weight, (d) Volume of Voids and (e) Voids Filled with Bitumen with % of Bitumen for Zycosoil Treated Asphalt Concrete Mix

From the figure 3 (a) it is clear that the addition of zycosoil with bitumen improved the stability of the mix.This improvement was found to be directly proportional to the amount of zycosoil added in the mixture. Moreover, at optimum bitumen content of 5.12%, stability of 29.94 KN and flow value of 3 mm was observed when 0.5% zycosoil was added with bitumen. The volume of voids decreases as the bitumen content increases due to the liquefying ability of zycosoil and reduced to 1.55%. Adding to this, 83.5% voids of aggregates filled with bitumen produce a greater binding of aggregate with bituminous material and provide satisfactory result. Therefore it can be concluded that addition of 0.5% zycosoil in the bituminous mix helps in achievinggood stability and resistance against deflection.

5.1 Marshall Quotient

Marshall Quotient is used as a measure of the permanent deformation; shear stress and rutting of the mix to be used in the road service. Marshall Quotient can be estimated as the ratio of stability of the asphalt concrete mix to the flow value. A comparison of Marshall Quotient was done for asphalt concrete mix using plane stone, zycosoil treated stone and zycosoil added asphalt. It is observed in figure 4 that Marshall Quotient is

maximum when 0.5% of zycosoil is added with bitumen while preparation of hot bituminous mix and it is 1.25 times higher than the Quotient of the bituminous mix prepared by using plane stone.

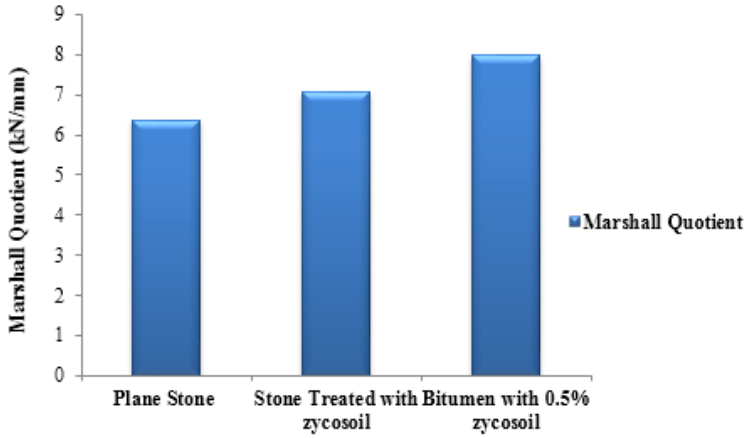

Figure 4: Marshall Quotient for Different Types of Bituminous Mix

5.2 Tensile Strength Ratio

The resistance of asphalt concrete mix to the moisture effect is expressed as Tensile Strength Ratio (TSR). The TSR is defined as the ratio of tensile strength between dry and wet specimens. Higher TSR value indicates more resistant to moisture damage of asphalt concrete mixture. The minimum permissible value of TSR is 80% Hadiwardoyo and Fikri (2013). Figure 5 shows that, the TSR values obtained from all mixes are greater than 80% that satisfies the mix design specification. s of mix containing plane and zycosoil treated aggregate did not show much difference. However, TSR value of zycosoil added asphalt mixture is greater than the normal asphalt mix which can be attributed to the formation of hydrophobic strong siloxane bonds (Si-O-Si).

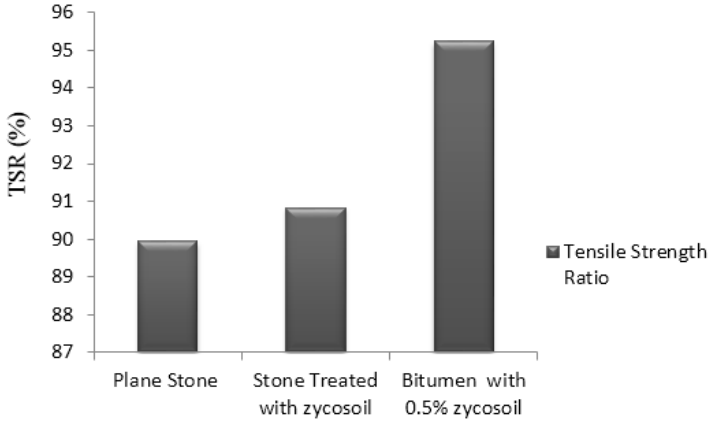

Figure 5: Tensile Strength Ratio for Different Asphalt Concrete Mixes

6. Cost Analysis of Bituminous Macadam Construction

Zycosoil has the property of liquefying the bitumen after mixing with it and helps in enhancing the stability. Moreover,when bitumen is liquefied, its viscosity gets reduced and in consequence, less quantity of bitumen is required to coat and bind all the aggregates together. This can be seen in the optimum bitumen content before and after

the use of Zycosoil was 5.8% and 5.12% respectively. As a result, the cost of construction reduces since less amount of bitumen is required with this proposed approach.

In order to compare the cost of construction with and without the use of zycosoil, a segment of bituminous Macadam (BM) (1 km length, 100 mm thickness and 3.75 meters width) was considered. For preparation of BM using plane stone and zycosoil treated stone, different quantities of bitumen and zycosoil are required. Hence the cost of mix prepared with different types of aggregate also varies. The rates of items are taken from SOR 2008 (Public Works Department Tripura 2008). Total cost of BM prepared with plane stone is Rs 31,33,891.84, zycosoil treated stone is Rs 30,50,870.80 and with plane stone and zycosoil mixed bitumen is Rs 30,49,999.80.

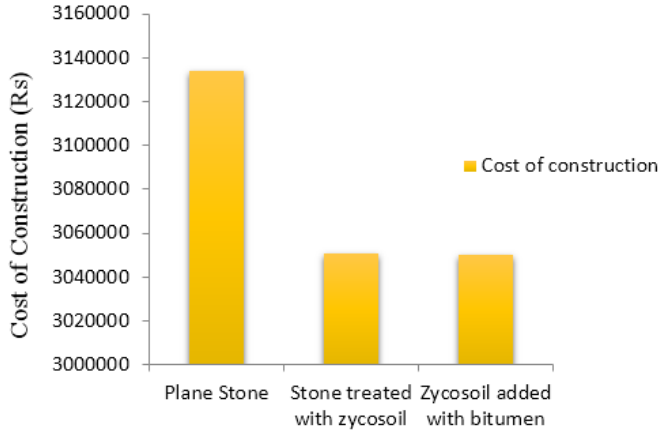

Figure 6**:** Cost Analysis of 1Km Long Bituminous Macadam

Fig.6 indicates that that the use of zycosoil treated stone in construction of BM can reduce the cost of construction to Rs 30 ,50,870.80 which is is less than the cost (Rs 31,33,891.84) for the other case. Moreover, if zycosoil is added to the mixture at a rate of 0.5% by weight of bitumen while preparing the mix,the cost of construction of BM will be less than the cost of BM prepared using normal stone (without treatment) and zycosoil treated stone which is reduced to Rs 30,49,999.80. Therefore, use of 0.5% of zycosoil with bitumen and zycosoil treated stone can provide better stability of the mix along with less bitumen content and less construction cost.

7. Conclusion

Aggregate, binder and filler are the core components of bituminous macadam. If locally available core components are not of satisfactory quality then there is a need of using some additives which can improve the quality of materials and can increase the stability of macadam as well. The present study used a liquid Nano-material, zycosoil to treat the locally available stone aggregate and obtained desired stability of the mix. It was observed that when zycosoil treated stone aggregates were used in the preparation of bituminous mix, it came up with better stability than the mix prepared with locally available stone. Moreover, in case of high volume traffic stability of 26kN was achieved at optimum bitumen content of 5.5%. In addition, when zycosoil was added as 0.5% by weight of the bitumen in preparing the hot bituminous mix, at optimum bitumen content of 5.12%, a stability of 29.94 KN was achieved. Therefore, the use of

zycosoil with both aggregate and binder can improve the stability of mix by 30% as well as remarkably reduces the construction cost of the bituminous macadam by 3%.

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