GSJ: Volume 8, Issue 7, July 2020, Online: ISSN 2320-9186
www.globalscientificjournal.com

CHARACTERISTICS AND PERFORMANCE ANALYSIS OF FINITE ELEMENT OF ASPHALT PAVEMENT MIXTURE BY USING NANO ADDITIVES.

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Abstract
Asphalt cement is the major and important components of hot mix asphalt (HMA). Modifying properties of asphalt enhances mechanical properties of HMA. The practical experiences of Pakistani highway and motorways network showed that high most roads are suffering from wear out, wretch and depress in long term. These stresses are occure due to lack of mechanical quality file of asphalt or the asphalt mixtures as well as the increasing of traffic loads. Until now, the research about new suitable modifiers and new techniques to produce durable and economic HMA is essential. The aim of this research is to investigate the possibility of using different types of new additives as (Silica Fume and Nano Silica) to improve the properties of Hot Mix Asphalt (HMA) concrete mixtures. Also, evaluating the performance of wearing surface pavements (Total Stress and Vertical Displacement) analysis by using Finite Elements program is another objective. For to perform such analysis, thoroughly experimental program is designed and implemented. The experimental procedure is done for four phases including preliminary works, laboratory work, Finite Element modeling and cost analysis.
From technical point of view, results indicated that NS (Nano silica) is considered the best modifier followed by SF (Silica Fume) that achieved maximum strength, minimum viscosity flow, higher tensile strength; higher direct compression strength and minimum depress out value Through Plaxis 2D analysis, pavement responses of pavements having modified mixtures achieved lower vertical displacement and total stress than that of control mix. Finally, cost analysis for the direct cost of materials for manufacturing of 1m3 of the unmodified and modified mixtures are conducted. Also, the cost analysis indicated that the cost of producing 1m3 of mixture using NS (Nano Silica) shall be very high and not applicable to be used. Excluding the NS from cost rating leaded to bring the SF as the best modifier with 15.12 % increasing in cost comparing with the control mixture.

***Keywords** -Asphalt, Hot Mix Asphalt, stresses, Additives.*

1. INTRODUCTION

In any Highway and Motorway, the performance of asphalt pavement is much necessary and essential factor. Thus, many researches were conducted to enhance the physical and mechanical properties of HMA using several additives (Polymer, Fiber, Lime and Rubber and etc...)In addition, the evaluation of pavement responses is the most concern of asphalt paving researches. The previous studies concluded that using additives in HMA improved the pavement performance. Therefore, searching about new additives are still continuous. New additives as Silica Fume (SF) and Nano silica (NS) using to enhance the HMA properties are investigated in this study. Plaxis 2D program is also investigated to determine vertical displacement and total stress.

1.1. ROBLEM STATEMENT

Due to the increase in traffic loads (especially illegal traffic loads) on Pakistani highways and Motorway, network. That leads to the shortage in long-term performance of the paving sections. Until now, mass production of hot asphalt concrete mixes modified by any acceptable type of additives are not carried out due to technical or economic problems. Modeling of asphalt pavements to predict its stresses and strains under prevailing conditions still represent problem. It will decrease the need of high cost experiment sections.

2. LITERATURE REVIEW

2.1. INTRODUCTION

This chapter presents the current state of the art about the study problem. The presentation includes the factors affecting the behavior of HMA. Firstly, the effects of asphalt material on the characteristics of the HMA arediscussed. The second subject is improving the performance of HMA. Enhancing of the performance of HMA using additives is to be discussed in the successive section. While the last subject presents the different types of additives. Many factors influence the capacity of the asphaltic mixtures to fulfill the structural requirements. The composition of the mixture, the laying mode and the properties of the composing materials. The use of additive plays an important role to improve the properties of asphalt mixtures. Therefore, there are still many studies, which search about the use of new addition to improve the properties of asphalt mixtures.

2.2. FAMILIAR PAVEMENT DISTRESS BACKGROUND

The Performance and quality of a road pavement is reducing by different type of failure that can exist in pavement during the life services. The pavement failuresare of three type; these types are rutting which can be defined as a depression under wheel path because of repeated loading of heavy traffic loads. Firstly, rutting which is induced in pavement by the huge traffic load and the deformation induced by rutting is of permanent deformation. Rutting formed inthose pavements where the temperature is highly and where there is viscosity binder occur. Secondly, fatigue cracking is also link with load. Fatigue cracking is link those area where the compressible value for road pavement is not achieved till to that value which is achieved for high load traffic, fatigue cracking can be exist in those area where stress relaxation cycle link with vehicle passage. The last type of failure isthermal cracking. The thermal cracking is related to periodic day and night temperature changesand resulted in almost constant area break [1,2].

There are two sources of asphalt, (a) those according naturally, and (b) those obtained by refining petroleum. In both cases, asphalt is the product of fractional distillation of petroleum crude oil [3]. The increase in traffic loads during the last two decades, in addition with an insufficient degree of maintenance, has caused an accelerated deterioration of road structures in many countries [4].

2.3. Flexible Pavement Deformations on Pakistani Road Networks

Increasing of traffic loading on the Pakistani roads leads to early permanent deformations especially rutting distress. Rutting phenomena have gained a widespread attention in Pakistan because of the increasing of roads that early suffered from it. Rabie along with team surveyed 96 links in Pakistan road network in 1995 to identify their distresses [5]. Rabie found that rutting was observed on 36.8 % of the surveyed roadway lengths. Also, Gab-Allah found that 19.8% on the average of the total deduct points of 15 distresses used for pavement conditions rating was caused by rutting [6]. Gab-Allah showed that about 67% to 83% of the total pavement rutting occurred in asphalt surface layer. Recent study made a transverse surface profiles analysis of Belbis- Zagazig road segment to evaluate the contribution of pavement layers rutting distress [7]. Belbis- Zagazig road is considered one of the main road feeders of the construction materials (natural and crushed aggregate, sand, cement) for many governorates in the delta area such as Sharkia, Dakhliya, and Dammeta . The study showed that 60% of the rutting failure occurred in asphalt layer whereas, 30% of rutting failure occurred on the base layer, and 10% of rutting failure occurred on the subgrade. Therefore, producing hot asphalt mixes of high rutting resistance becomes essential.

2.4. FACTOR AFFECTING OF ASPHALT PAVEMENT

2.4.1. Characteristics of Hot Mix Asphalt (HMA)

Stacy G. Williams studied the effect of binder content (AC), and voids in mineral aggregate (VMA) of hot mix asphalt (HMA) on rutting susceptibility as measured by the utilization of wheel-tracking test. It was found that by increasing the binder content; the rut depth increased. It was believed that this is expected because too much binder can actually lubricate the aggregate particles, allowing them to shift more than they should. In addition, it was concluded that as voids in mineral aggregate (VMA) increased; the rut depth increased [8].

2.4.2. Traffic Loading

Few years ago, many states in America have experienced an increase in the severity and extent of permanent deformation (depress) in HMA pavements [9]. The increased rutting has been attributed to the increase of truck tire pressures, axle loads, and traffic volumes. The increase of tire pressure and axle load lead to the exposing of pavement surface to higher stresses than that assumed at structural design phase in accordance with the 1993 AASHTO Guide for Design of Pavement Structures. It must be noted that the design criteria are based on 80-kN (18,000-lb) axle loads and tire contact pressures of 517–552 kpa (75–80 psi) [10].

2.4.3. Climate Condition

Temperature is considered one of the most important factors influencing asphalt pavement depress.As the temperature of asphalt going to increase the viscosity of asphalt binder going to decrease.TheAsphalt which had low viscosity/ flow rate value indicate that it will support the lateral movement of traffic loads. The effect of pavement temperature on rut depth is shown in Figure (2-4) [11]. The figure shows that the rut depth significantly increases with increasing temperature. The researcher anticipated that this might be due to the viscous effect of the used asphalt content. Ahmed, M.A. studied rutting phenomena on desert, coastal, and agricultural Egyptian roads. It was concluded that the rutting rate in desert links has higher values than those in the coastal links and those in both of costal and agricultural links. The researcher anticipated that this might be due to the high temperature values on the desert areas [12].

2.4.4. Suggested Additives Silica fume to be Used Improving HMA's Properties.

After concerning the environmental requirement, the collection and land filling of SF, the use of SF in various engineering application became economically and extremely desired. There are two main forms of SF, the dry and wet. Dry SF can be provided as packages in polyethylene bags or it can be stored in hoppers and silos. While, SF slurry can be blended with high or low percentages of chemical additives. In this case, it can be stored in huge tanks with high capacities reaches to 400,000 gallons (1,510 m3). The surface area of SF is about of 20,000 m2 /kg (215,280 ft2 /lb) when measured by nitrogen absorption techniques and it consists of very fine particles. The SF particles are finer than cement particles. Its color is grey as cement and it contains a high content of silica, so, it is an effective Pozzolanic material [13].

Silica Fume has been used in improvement of the bond strength, compressive strength and abrasiveresistance test of concrete to reduce the permeability of concrete. Negi et al., studied the change of properties of clayey soil using SF. It was concluded that the addition of 20% SF to the soil decreased the potential swelling from 50% to 7% while the California bearing ratio (CBR) value increased by about 72%,Table (2-1) shows the chemical composition of SF [14].

#	Specification	Result
A	**Chemical Test (Mass %)**	
1	Silica as SiO2.	90.09
2	Sulpher tri oxide, SIO3	0.60
3	Lime, CaO	7.54
4	Magnesia, MgO	3.99
B	**Physical Test**	
1	Density, g/cc	2.07
2	Particle Size Distribution (%)	59

3. MEHODOLOGY:

To achieve the study objectives, the scope of the research shall be divided in to the following stages:

a. Stage One: Preliminary Works

- Selection the types of aggregate (coarse and Fine) and mineral filler to be used in composing HMA's investigated in this study.
- Selecting the type of asphalt to be used in this study.
- Selecting different types of conventional additives to use as a comparison based with the investigated of new additives (SF and NS) with different asphalt contents (obtained from the control mixes).
- Designed twenty HMA with different conditions.

b. Stage Two: Laboratory Work

- Preparing twenty HMA mixtures as designed in stages.
- Determining the physical properties of virgin asphalt and optimum asphalt content for control mix.
- Carrying out Marshall, Indirect Tensile Strength (ITS), Direct Compression (DC), and Wheel Tracking (WT) tests. To compute Marshall stability, flow, stiffness, ITS value, DC value and rutting depth for both all designed mixes containing conventional and modified mixtures.

c. Stage Three: Finite Element Modeling

- Selection of the different typical pavement cross sections.
- Selection of the suitable and available for finite element program.
- Identify the parameters used in finite element analysis.
- Conducting 420 runs for different pavement sections under different conditions.
- Determine pavement responses (vertical displacement and total stress).
- Produce discussions and analysis between the outcomes (Results) of conventional and modified mixtures.

d. Stage Four: Cost Analysis

- Conducting a cost analysis for the control and modified mixtures. It shall include the cost analysis that estimated to provide the best pavement modified sections of all additives.

4. RESULT AND CONCLUSION:

The Conclusion of this Research paper can be summarized as

- Using 6 % SF modifier improved the bitumen properties. It decreases the penetration value by 46.15% and increases the viscosity by about 30.16%. Adding 6 % SF modifier to HMA achieves the best enhancing in HMA properties. It increases Marshall stability by about 23.61% and the flow by 3.29%; and thus, the Marshall stiffness increases by about 19.67%. Also, the DC value increases by about 26.76% which enhances the load carrying capacity. It also increases the ITS value from 9.36 to 9.99 kg/cm2 , by an improvement of 6.73% and enhances the rutting resistance by 36%.
- Using 7 % NS modifier improved the bitumen properties. It decreases the penetration value by 16.92% and increases its viscosity by 9.78%. Adding 7% NS modifier to HMA achieves the best enhancing in HMA properties. It increases Marshall stability by 25% and decreases the flow by 19%. NS increases the mixture stiffness by 54%. It also improves the DC test value by 8.50%, increases the ITS value by 9.08 % and enhances the rutting resistance by 40%.
- All tried additives decrease the rutting depth significantly, expect waste plastic bags has the best additive because it decreases the rutting depth to 4.572 mm. In addition,

rubber and SF record the equal value of the rutting depth of 5.46 mm but NS record the rutting depth is 5.08 mm.

- In Finite Elements (FE) analysis, the Vertical Displacement (VD) and Total Stress (TS) increase with an increase in load pressure. The significant reduction in VD and TS had been occurred for the modified asphalt layer by using additives (LDPE, Rubber, Lime, SF and NS).
- Using 5.00 cm of asphalt layer and base layer =20.00 cm, the VD reduction percentages are 0.72%, 0.36%, 6.86%, 15.61% and 7.13 % after enhancing the asphalt layer by the optimum values of Rubber, LDPE, Lime, SF and NS, respectively at load 700 kpa, the TS enhances by 0.59%, 0.32%, 30.44%, 50.13% and 32.90% using Rubber, LDPE, Lime, SF and NS respectively at the same load.
- In case of 15.00 cm of asphalt layer and base layer =20.00 cm, the VD reduction percentages are 2.93 %, 1.80 %, 19.28 %, 25.59 % and 19.84 % after improving the asphalt layer by the optimum values of Rubber, LDPE, Lime, SF and NS, respectively at load 700 kpa. The improvement recorded in TS are 0.01% for using Rubber and LDPE respectively, while the increase percentages of TS are 21.35 %, 42.97 % and 23.60 % % using Lime, SF and NS respectively at the same load.
- - Improvement in asphalt properties (stability, flow, stiffness, Young's modulus and Poisson's ratio) leads to improve the pavement durability through decreasing of both the deflection and stress.

5. RECOMMENDATION:

Based on the outcomes of the study it is strongly recommended to

- Study the performance of the modified mix using different performance test methods such as super pave.
- Field test section using SF modifiers for traditional HMA are to be constructed to evaluate its field performance under different traffic loading, tire pressures and environmental conditions.
- The modeling carried out in this study comprises static loads. Further studies should include dynamic loads as Complex modulus.

- Future researches use SF to improve the out of code properties of bitumen as Alexandria bitumen.
- Future researches can use SF to improve the properties of asphalt and asphalt mixtures in different temperature as warm asphalt.

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