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Improving the Rutting Resistance of Flexible Pavement Reinforced with Steel Fiber

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ABSTRACT

Permanent deformation or rutting accrues as a result of repeated loading due to heavy traffic loading which cause progressive accumulation of permanent deformation under repetitive tire pressures. In order to improve the conventional asphalt concrete pavement performance, reduce road maintenance costs, extend the life of the pavement, the asphalt mixture mixed with steel fibers in conventional asphalt mixes in engineering practice.

*Two slabs with dimension (300*300*50) mm were prepared for rutting test with two percentage of steel fiber content (0.0, 0.2) % to simulate the performance of flexible pavement with life.*

The results showed that the rutting value is (27.04) mm in case of control mix while the rutting value at 0.2 % steel fiber content and 5.5 % asphalt content is (22.42) mm. The dynamic stability is increased about by 6.4 % at 0.2% steel fiber content for asphalt mixture.

Development of a three-dimensional finite element model is implemented for flexible pavements using ABAQUS (6.14-4) to simulate the laboratory tests. A statistical analysis is adopted to find the compatibility between lab models and numerical models and investigate the possibility of using the numerical approach for the prediction of other improvement in pavement body.

1. Introduction

Asphalt cement modifiers have been used in pavement technology to enhance pavement performance and reduce different types of pavement distress, of which, rutting, low temperature cracking, fatigue cracking, stripping, and hardening are the most common failure. Fiber is one of the additives used for this purpose **Thomas et al (1999)**. **[8]**

The principal functions of fiber as reinforcing materials are to provide additional tensile strength in the resulting composite; this may increase the amount of strain energy that can be absorbed during the fatigue and fracture process of the mix **Mahrez et al (2003)**. **[4]**

The addition of conductive fibers provides for multifunctional applications in asphalt concrete such as structural health self-monitoring, self-healing, and removal of snow and ice on the pavement surface.

Huang et al. (2006) evaluated electrical conductivity of conductive HMA containing micron-scale steel fiber, aluminum chips, and graphite as conductive fillers. They also investigated the applicability of relating the electrical properties to the laboratory mechanical properties of HMA mixtures. Among the conductive additives evaluated of mineral fibers, steel and carbon fibers generally retained or improved the laboratory performance of HMA mixtures, whereas graphite, due to the need for higher content, significantly altered the performance of HMA mixture and especially compromised the cracking resistance. **[3]**

Sercan Serin (2012) used different rates of steel fiber (0%, 0.25%, 0.50%, 0.75%, 1.0%, 1.5%, 2.0%, 2.5%) were prepared and the optimum value for fiber rate that results in the best stability value was determined as 0.75%. The result of study showed, steel fiber additions can be used in binder course of flexible pavement because of its positive stability impact. **[7]**

Quantao Liu et al (2009) The effect of steel fibers volume content on the indirect tensile strength (ITS) of porous asphalt concrete was increased with a steel fibers content of 11%. Adding more fibers to the mixture results in a decrease of the indirect tensile strength, because too many fibers reduce the mastic film thickness causing a bad adhesion between the asphalt components. **[5]**

Baoshan Huang (2009) The effects of three conductive additives, a micron-scale steel fiber, a carbon fiber, and graphite, on some laboratory-measured properties of HMA mixtures were investigated through mixture performance testing. The results from this study indicated that the micron-scale steel fiber was the most effective additive to produce conductive HMA. The inclusion of steel and carbon fibers improved permanent deformation properties, maintained the indirect tensile cracking resistance, and slightly reduced the dynamic modulus of the conductive HMA. The inclusion of graphite as an electrically conductive additive significantly improved the rut resistance, increased the dynamic modulus, and significantly reduced the indirect tensile cracking resistance of the conductive HMA mixtures. **[2]**

2. The Objectives Study

The objectives of the study are:

1. Experimental investigation on the performance of asphalt concrete mixture reinforced with steel fiber in term of permanent deformation (wheel track test).
2. Development of three dimensions' finite element model using ***ABAQUS ver.6.14.4*** program to compare its between with laboratory result (rutting test).

3. Material characterization

The selected materials to be used in this study are widely used in asphalt pavement in Iraq. The requirements of ***SORB specification (2003)***, was considered to be followed. Physical and chemical properties are described in the following sections.

3.1. Asphalt Cement

The binder used in this study is asphalt cement (40-50) penetration grade brought from Daurah refinery plant. The optimum asphalt content is equal to (5.5) % by weight of total mix, and this value is used in this research. The physical properties of the asphalt cement are presented in Table (1).

Table. 1 Physical Properties of Asphalt Cement*.

Test	Result	Unit	SCRB Specification (2003)
Penetration (25°C, 100g, 5sec). ASTM D 5	44	1/10 mm	40-50
Ductility (25°C, 5cm/min). ASTM D113	167	Cm	≥ 100
Softening point (ring & ball). ASTM D 36	51	°C	50-60
Flash point (cleave land open cup). ASTM D 92	252	°C	≥ 232
Kinematic Viscosity At 135°C	480	Cst	> 210
Solubility in trichloroethylene	99.5	%	> 99
Penetration of residue	37	1/10 mm	< 55
Ductility of residue	151	Cm	> 25
Loss in weight (163°C,50gm,5h) %	0.3	%	-

*Tests are carried out in cooperation with National Center for Construction and Laboratories.

3.2 Aggregate

The aggregate used in this work was obtained from Al-Nibaie quarry; it consists of crushed quartz, hard, tough, grains, free of injurious amount of clay, loam or other deleterious substances. This aggregate is widely used in Baghdad city for asphalt concrete mixes. The coarse and fine aggregates used in this work were sieved, and recombined in the proper proportions to meet the wearing course gradation as required by specification (**SCRB, R/9 2003**). **[6]**
The physical properties and selected gradation curve for the aggregate are presented in Table (2) and Figure (1).

Table. 2 Physical Properties of Al-Nibaee Coarse Aggregates*.

Property	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity (ASTM C127 and C128)	2.681	2.6303
Apparent Specific Gravity (ASTM C127 and C128)	2.602	2.46
Percent Water Absorption(ASTM C127 and C128)	0.45	0.53
Percent wear (Los-Angeles Abrasion) (ASTM C131)	20.12	……

*Tests are carried out in cooperation with National Center for Construction and Laboratories.

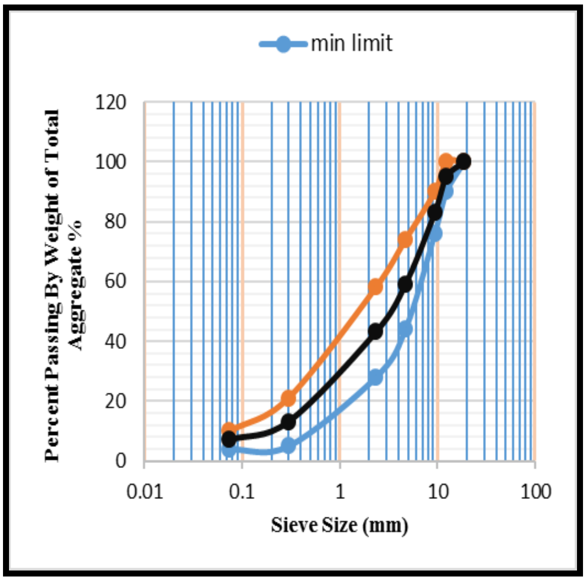

Figure 1. Specification Limits and Mid-Point Gradation of (SCRB,2003) for Wearing Course Layer.

3.3 Mineral Filler

One type of mineral filler (ordinary Portland cement) is used. It is thoroughly dry and free from lumps or aggregations of fine particles. The chemical composition and physical properties, are shown in Table (3).

Table. 3 Physical and chemical Properties of Portland Cement*.

Chemical Compound	% Content
Silica, Sio2	21.51
Lime, Cao	62.52
Magnesia, MgO	3.77
Sulfuric Anhydride, SO3	1.58
Alumina, Al2O3	5.54
Ferric Oxide, Fe2O3	3.35
Loss on Ignition	1.34
Total	99.44
Physical properties	
% Passing Sieve No.200 (0.075 mm)	98
Apparent Specific Gravity	3.4
Specific Surface Area (M^2/kg)	3.56

*Tests are carried out in cooperation with National Center for Construction and Laboratories.

3.4 Steel Fiber

The steel fibers used in this study were straight steel fibers manufactured by Bekaert Corporation. Each steel fiber has a diameter of about 175 μm and length of approximately 13 mm (Roux, 1996). The fibers have the properties described in Table (4) which is brought from China. A thin brass coating is applied to the fibers during the drawing process; therefore, virgin fibers may be gold/-colored. Figure (2) shows the ultra-fine steel fibers used throughout this study.

Table. 4 Properties of the Steel Fibers*.

Description	Straight
Length (mm)	13
Diameter (mm)	0.2
Density (Kg/m^3)	7800
Tensile Strength Fu (Mpa)	2600
Aspect Ratio	65

*Manufacturer Properties (Bekaert Corporation).

Figure 2. Steel Fiber

4. Testing Program

The testing program can be clarified in the flow chart shown in Figure (3).

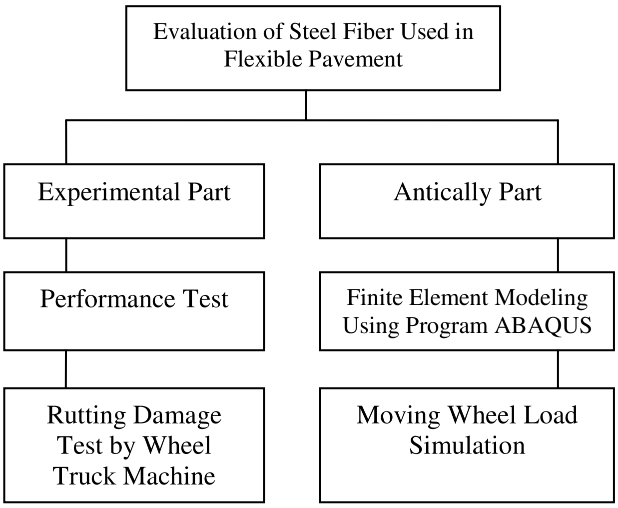

Figure 3. Work Plan for Evaluation of Steel Fiber used in Flexible Pavement.

5. Preparation of Slab Specimens

A rectangular specimen of (300 mm) in length, (50mm) in height and (300mm) in width is prepared. Steel rectangular mold of (300 mm) in length, (50mm) in height and (300mm) (*Wheel Tracking Machine at Petroleum R & D Center in Baghdad)* is used Figure (4a). Mold is heated on a hot plate to a temperature between (120-150ºC). The components of mixture are well mixed for about two minutes by asphalt mixer at a temperature of 160ºC Figure (4b). The asphalt mixture is placed in the preheated mold, the temperature of mixture immediately prior to compaction temperature is (160ºC) the mold assembly is placed on the roller compaction machine Figure (4c) and the specimen is compacted at constant pressure load, (0.54) MPa, pass through the monitoring arm (arm convex) on the form several times to get to the density ratio and the desired height. The slab is left to cool at room temperature and then testing by wheel tracking machine.

(a) Steel Mold

(b) Asphalt Mixer

(c) Roller Compaction Machine

(d) Final Preparation

Figure 4. Preparation of Slab Samples at Petroleum R & D Center in Baghdad.

6. Performance Test for Rutting

Permanent deformation, or rutting, is a complex phenomenon which poses significant challenges as far as performance evaluation is concerned. It is one of the most frequently observed and serious type of distress on hot-mix asphalt layers. Permanent deformation can lead to ponding of water in wheel tracks and can; therefore, be regarded as a serious road hazard in wet weather. Rutting can also lead to poor riding quality, which may result in increased vehicle operating costs.

6.1 Wheel Track Machine and Rut Depth Test

The Wheel tracking machine in the highway laboratory in the Petroleum R & D Center in Baghdad is used for rut depth test of asphalt slab sample. Figure (5) shows the wheel tracking machine.

The wheel of Machine moves at the speed of 42 passing per minute, which is made of rubber tire of 5 cm width and the pressure of 6.5 kg/cm^2. The test is conducted for 1 hour; thus the total passing is 2520. The Machine is facilitated by a computer that is able to provide a report on the relationship between the number of passing and rut depth. The computer records the number of passing and the rut depth at 1st, 5th, 10th, 15th, 30th, 45th, and 60th minute. The specimens are tested using Wheel Tracking Machine at temperatures of 70^{o}C Figure (6). The capability of asphalt concrete pavement to support rutting is defined by Dynamic Stability (DS) that expresses the number of passing needed to produce 1 mm rut depth. Dynamic Stability is formulated as follows:

$$\mathbf{DS = (L_{60} - L_{45}) / (D_{60} - D_{45})} \qquad (1)$$

Where:
DS = dynamic stability
L_{60} = Number of passing at 60th min., L_{45} = Number of passing at 45th min.
D_{60} = Rut depth at 60th min., D_{45} = Rut depth at 45th min.

Figure 5. Wheel Tracking Machine at The Petroleum R & D Center in Baghdad.

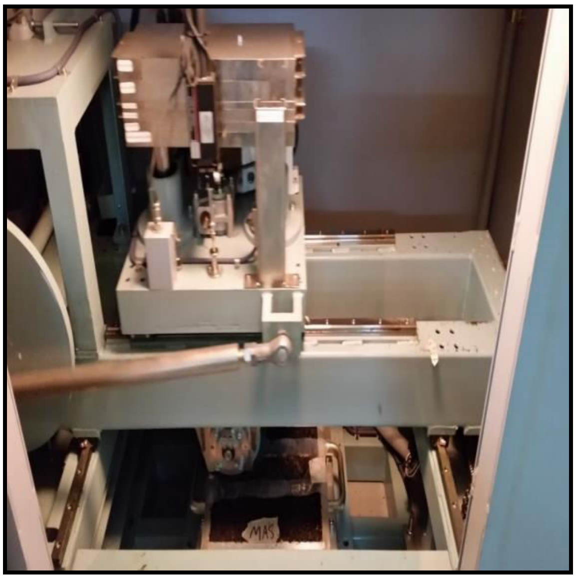

Figure 6. Sample Hold under Wheel and LVDT Transducer to Monitoring Rut Depth.

7. Finite Element Modeling by ABAQUS

Finite element method (FEM) is a numerical analysis technique proposed to be used in the present study to determine the stress, strain and deflection of the pavement layers. The finite element analysis is one of the most popular numerical methods used to obtain an approximate solution for complex problems in various fields of engineering. The finite element commercial code *ABAQUS 6.14-4* is used. The simulation procedure is done in several steps. First the exact geometry and dimensions and other data of experimental model **Al-Qadi et al. (2004)** were extracted to produce the numerical model. **[1]**

Second, the simplest materials model (linear Elastic behavior) is used to introduce materials behavior of pavement structure. Third, dynamic loading is also performed to acquire real simulation of experimental model.

Since the fundamental purpose of the *ABAQUS Version 6.14-4* program user is the representation of a particular situation or solving a specific problem and then to find a solution, therefore it, becomes necessary to deal with the program in its own language, which includes creating a model then analyzing it.

These modules should be used for defining geometry, material properties and other physical properties and then submitting the model for analysis. The following steps should be followed:

- **Part Module**
- **Property Module**
- **The Step Module**
- **Load Module**
- **Mesh Module**
- **Job module**
- **Visualization module**

The properties of the materials used in this analysis are summarized in Table (5). These properties regard the input parameters to the program. These parameters are: the elastic modulus (E), the Poisson's ratio (v) and the density.

Table 5. Thickness and Materials Properties.

Layer	Surface Layer	
Thickness (mm)	50	
Model	Model-1	Model-2
Density (kg/m^3)	2348	2362
Modulus of Elasticity (Mpa)	1230	1448
Poisson's ratio (ν)	0.35	0.35

8. Results

8.1 Effect of Steel Fiber on Rutting

The rutting profiles measurements are taken after 42 ,210, 420, 630 to 2520 pass of axle loads relative to the profile measurement (zero) before at 70 C. These results have been summarized and are represented in Figures (7), (8), (9), (10) and (11).

From Figure (7), show that the rutting increased about by (27.04 mm) in case of control mix. While the rutting decreased about by (22.42 mm) at 0.2% steel fiber content with optimum asphalt content 5.5 %, it can be seen that in Figure (8). Figure (9), presents that the rutting per pass which is decreased by about 6.6 % as compared with control mix. Also, Figure (10), shows that the number of passes to cause failure increased by about 28.6% as compared with control mix and from Figure (11), the dynamic stability is increased about by 6.4 % at 0.2% steel fiber content for asphalt mixture.

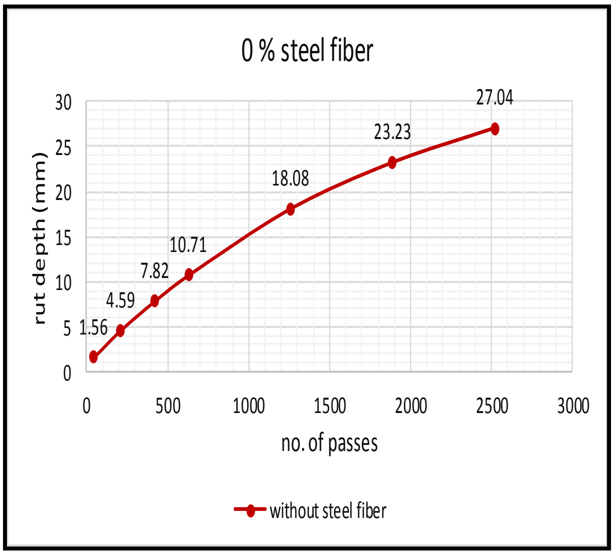

Figure 7. Rut Depth Versus No. of passes at 0% Steel Fiber Content.

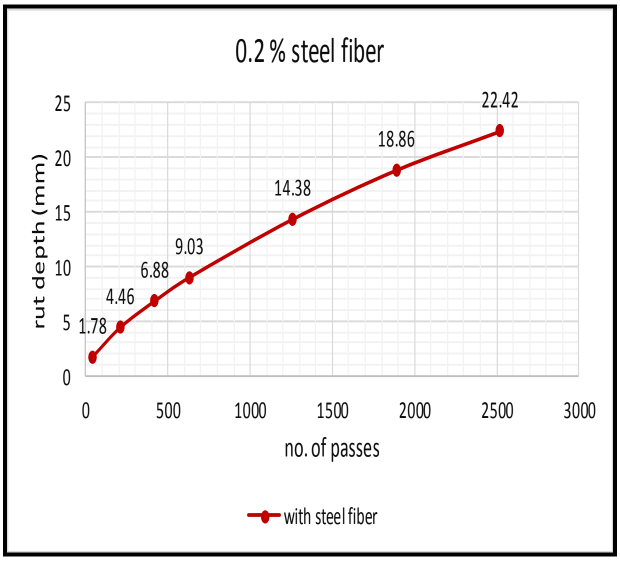

Figure 8. Rut Depth Versus No. of passes at 0.2 % Steel Fiber Content.

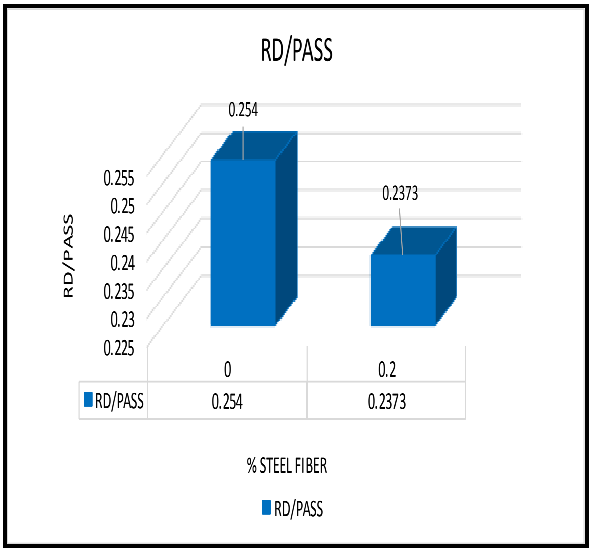

Figure 9. Effect of Steel Fiber Content on Rut Depth per Pass.

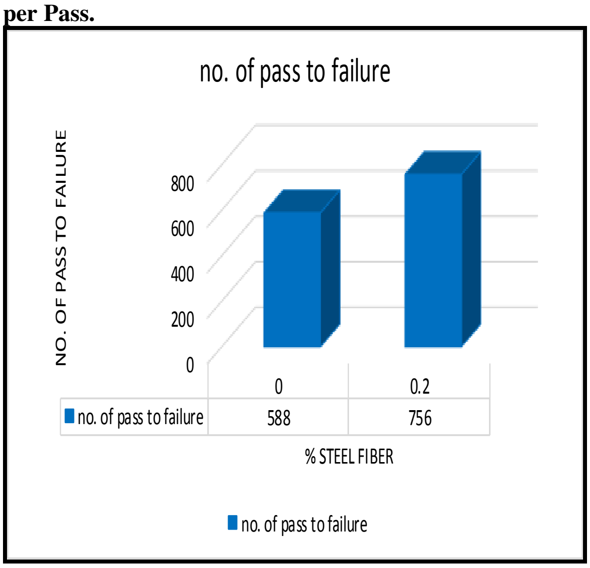

Figure 10. Effect of Steel Fiber on No. of Pass to Failure.

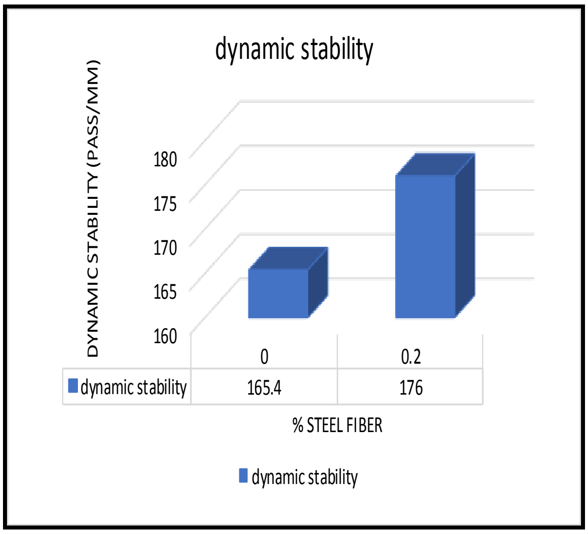

Figure 11. Effect of Steel Fiber Content on Dynamic Stability.

8.2. Finite Element ABAQUS Result

The outcome of the ABAQUS program results can be obtained through enter specific parameters for each model, specific parameters include diminution, modules of elasticity, poison ratio and time for number of passes, and then the laboratory results with ABAQUS model are simulated result. The result includes Permanent deformation, two model, one model for control mixture and other model for 0.2% steel fiber.

8.2.1. Permanent Deformation for Control Model-1

The result of lab. and ABAQUS program for control ***Model-1*** shown in Figures (12) and (13) shows the output of ABAQUS. Increase the number of load repetition will increase permanent deformation without steel fiber.

8.2.2. Permanent Deformation for Model-2

The result of lab. and ABAQUS program for ***Model-2*** shown in Figures (14) and (15) shows the output of ABAQUS. Increase the number of load repetition will decrease permanent deformation with steel fiber.

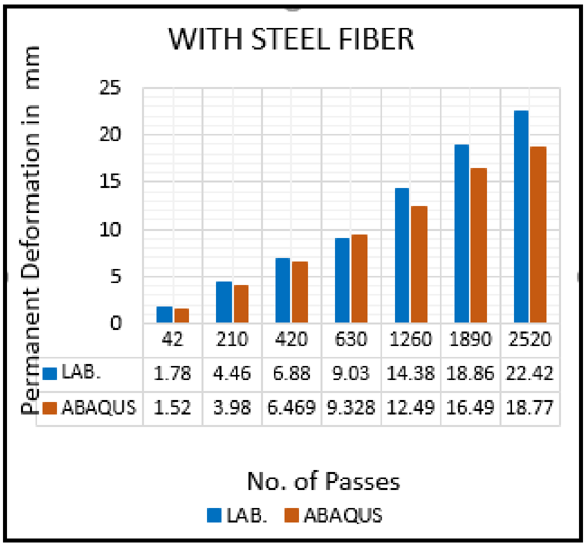

Figure 12. Show Result of Lab and ABAQUS Program Control Model-1.

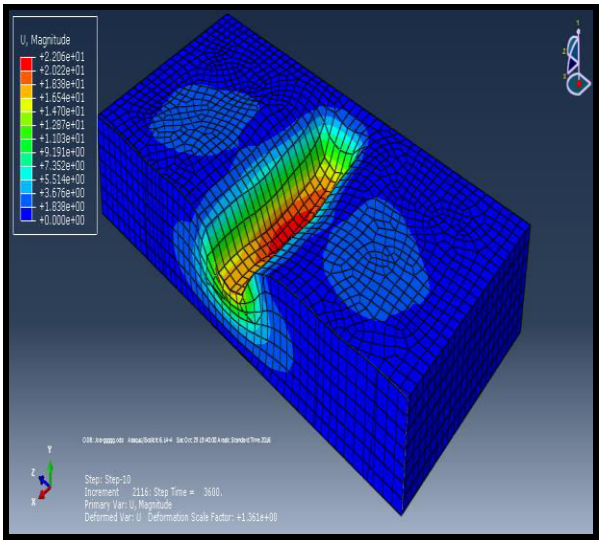

Figure 13. Vertical Deformation at Number of Passes 2520 Control Model-1.

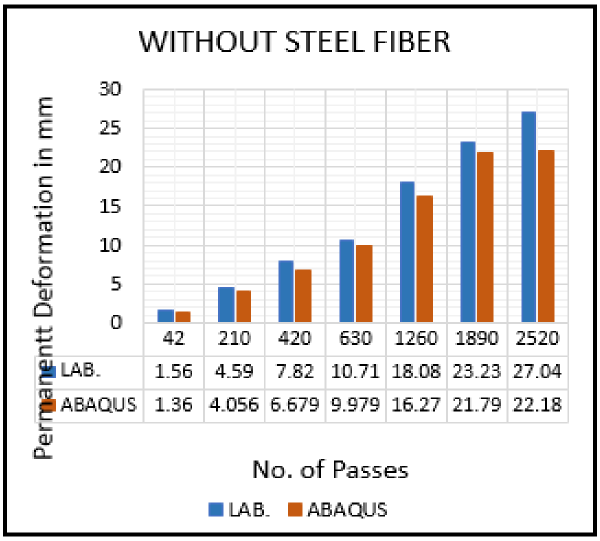

Figure 14. Show Result of Lab and ABAQUS Program Model-2.

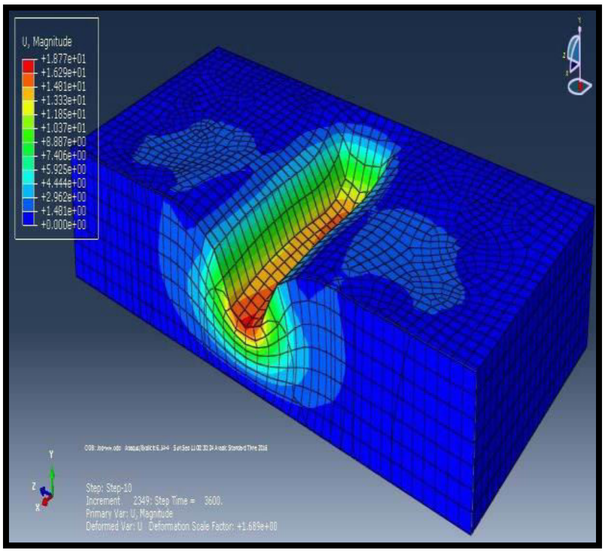

Figure 15. Vertical Deformation at Number of Passes 2520 Control Model-2.

9. Conclusions

Based on the obtained results and limitations, the following points could be drawn:

1. The increase in the steel fibers additive increases the number of passes which reaches the same value of rutting (value in the case of the control). the rutting increased about by (27.04 mm) in case of control mix. While the rutting decreased about by (22.42 mm) at 0.2% steel fiber content with optimum asphalt content 5.5 %.
2. The number of passes to cause failure increased by about 28.6% as compared with control mix.
3. The dynamic stability is increased about by 6.4 % at 0.2% steel fiber content for asphalt mixture.
4. The simulation of lab models, using ABAQUS program shows that, the program shows a good agreement with finite element results.

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