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# Retarding premature reflective cracking in bituminous pavement using geosynthetics.

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## ABSTRACT

These cracks are developed as fatigue cracks (top down or bottom up cracking), longitudinal cracks and transverse cracks. One of the most challenging type of crack encountered is the development of reflective cracks that originate over an existing overlaid surface. One way to overcome the reflective cracks is by providing geosynthetic materials which act as an reinforcing materials in controlling the propagation of top down and bottom up cracking.. It has been proven in many studies that using geosynthetics delayed reflective crack initiation and reduced the speed of crack propagation. The objectives of this study was to assess the effects laying Needle Punched Woven Geotextile in an asphalt mix at various position and to study the accumulation of permanent deformation and also to test the strength and stability of bituminous mix for fatigue cracks. Tensile strength ratio, initial tensile strain, and number of cycles to crack initiation were determined using Marshall Test, indirect tensile strength test and indirect stiffness modulus test and fatigue test results were compared. The propagation of crack growth rate of conventional mix without Geotextile and with geotextiles placed at one-third, half and three-fourth depth from the bottom of the mix were compared and their efficiency towards sustainability was identified. Placement of the Geotextile at a one-third depth of overlay thickness from the bottom provided the maximum service life by reducing the permanent deformation in flexible pavements which in turn retards the premature reflective crack and increases the lifetime of the pavement.

**KEYWORDS:** Reflective Cracking, Geotextiles, Indirect Tensile Strength, Stiffness Modulus, Residual Strain Tensile Strength Ratio, Cyclic Loading.

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# 1. INTRODUCTION

## *1.1 Introduction*

With an increase in traffic volume and axle loads, the flexible pavements undergo premature failure and they do not sustain their design life of 10 – 15 years. One of the major distresses of pavement is cracking. Cracking is developed when the stress developed in the pavement exceeds the strength of the asphalt mixture. The cracks may be defined as fatigue cracks (top to bottom and bottom up), longitudinal cracks and transverse cracks. Cracks allow the penetration of the water into the subsurface layers and in some cases allows the capillary rise of water from the poor subgrade, base and sub base layer. These cracks cause in due course of time cause a deterioration of the pavements. Mitigation and controlling the cracks is a herculean task since the cracks may be working cracks which propagate. Application of crack sealants may be only a short term measure. The best way to rectify and recover damaged and distressed flexible pavements is by bituminous overlay. Although the existing pavements are overlaid, the cracks at times start to propagate over the newly laid pavement. This phenomenon is termed as 'reflective crack'. The cracking development starts when three types of stresses exceed the asphalt mixture strength the two main parameters which enhance the reflection cracking are - the wheel load which causes high levels of stress and strain in the overlays which are above an existing crack. The second parameter being the repetition of traffic loads and variation in the daily temperature. Nunn[1] in 1989 proved that the stresses may arise due to the cyclic thermal expansion and contraction, thermal gradient variations and due to the loading condition causing reflective cracks. Several remedial techniques have been incorporated into Hot Mix Asphalt (HMA) overlays to control reflective cracking. One such method is the use of Geosynthetics.

Geosynthetics, are a class of polymeric material, which are usually employed in asphalt pavements as reinforcement, separation, drainage and water proofing layers. Geosynthetics are generally of five types: Geotextile, Geonets, Geogrids, Geomembranes and Geocomposites. These products have high tensile strength are efficient in reinforcing materials that are weak in tension. Many research studies have proven that the use of geosynthetics is highly effective in controlling the propagation of cracks**.** Koerner[2] in 2005 studies on the properties of modern geotextiles found that it usually is made from synthetic polymers in the following proportion- polypropylenes (85%), polyesters (12%), polyethylene (2%), and polyamides (1%) which do not decay under biological and chemical processes The use of polymeric geosynthetics has its advantages by increasing the life of the pavements by acting as good reinforcing material when compared to pavements without geotextiles. The thickness of the Geosynthetic layer is usually between 25 to 100 mm when used beneath a bituminous overlay. Rongzong[3] in 2003 showed that Geotextile layer when combined with asphalt sealant or tack coat formed a membrane interface layer termed as a paving fabric interlayer which acts as a cushion or fluid barrier when placed below an asphalt overlay. Paving fabrics have the ability to provide a water proof interlayer in a spray seal that enhances the strength and life span of a pavement as studied by Rod Fyfe[4] in 2007.

## *1.2Literature review*

For the past three decades, geotextiles have been known to be good for improving the performance of paved or unpaved roads. Woven and nonwoven geotextiles are effectively used in the separation and stabilization of primary highway, secondary or low volume roads, unpaved and paved roads, parking lots, and industrial yards.

Fereidoon[5] in 2014 researched on simulation of cracked pavement with five types of geosynthetics in the laboratory. The tested specimen contained three layers, a 75-mm thick layer that simulated the old cracked pavement, a Geosynthetic layer and an overlay; the dimensions of sample specimen were H 250 mm x W 150 mm x L 380 mm. Each type of Geosynthetics was used for preparation of the specimen with three overlay thicknesses of 50, 75 and 100 mm. 100 mm thick overlay reduced the rate of propagation in all types of Geosynthetics used. The growth rate of cracks was predicted with maximum strains by Castell[6] in 2000. He concluded that bottom-up cracking was predominant than top-down cracking. Uhlmeyer[7] in 2000 investigated on thick overlays and found that the cracks originated at the surface and propagated downward as top down cracking.

The use of nonwoven geotextiles in controlling the anti-reflective cracking was carried out by Natália[8] in 2009 by using nine different types of needle-punched polyester and polypropylene (PP) nonwoven geotextiles having different mass per unit area purchased from different manufacturers. The tensile strength test result showed that impregnation of nonwoven geotextiles enhanced the initial stiffness due to anti-reflective cracking systems.

The Apparent Opening Size ( AOS) for nonwoven needle punched geotextiles in the mass per unit area range of 116–670 g/m$^2$ was investigated by Dhani[9] in 2003. Woven coir geotextiles as reinforcing material in a two-layer pavement section was experimented by Chandrakaran[10] in 2009 and they concluded that the ultimate bearing capacity increased to 366 kPa when the geotextile were placed at the interface of subgrade and base course and to 433 kPa when the same geotextile was placed within the base course at mid depth. The increases in bearing capacity was observed to be 45% and 75% and rut depth was 68% and 44% when placed at the interface and mid depth of the base respectively.

Kuo[11] in 2003 placed the geogrids at different depth in an asphalt overlay and proved that placing the geogrid at one-third depth of asphalt overlay thickness from the bottom resulted in a minimum tensile strain. Ali Khodaii[12] in 2007 studied the best location for placing the geogrids to prevent reflection cracking and found that placing them at one-third depth from the bottom of the overlay resulted in a fatigue life which was 6.7 times greater than the unreinforced specimen.

Hosseini[13] in 2009 used two types of Geosynthetic to explain the destruction of asphalt pavements of air field, non-reinforced, reinforced with a Geogrids and Geotextile specimens with dimensions of 50 x 63 x 81 mm were obtained from the asphalt slab section. The test results of fatigue versus damage propagation rate lines were observed moving towards the bottom of the graphs for the non-reinforced condition, which indicated that reinforced specimens always had a lower propagation crack rate.

A complete guidelines for using geosynthetics in asphalt overlays to reduce reflective cracking was given by Joe[14] in 2006. He suggested that thicker fabrics made using polypropylene or polyester resulted in lower stresses at the tip of a crack than using a thinner one. Therefore, the thicker layers were more effective in delaying reflection cracking, provided the full thickness of the nonwoven fabric is saturated with asphalt.

## 2. MIXTURE CHARACTERIZATION

The material required for the study included aggregates, Needle Punched Woven Geotextile and Viscosity Grade of Bitumen were collected and tested for its properties.. Asphalt of Viscosity Grade-30 (VG-30) was tested as per Bureau of Indian Standards (BIS)[15.]The results of tests performed on VG 30 Bitumen are shown in Table 1 and basic tests performed on aggregates are shown in Table 2 as per BIS and the limits are as per the specifications of Ministry of Road Transport and Highways (MoRTH) 2001[16..]The asphalt mix design was done on a control gradation of Bituminous Concrete (BC) mixture grade 2 as per MoRTH.

**Table1 : Test Result of Bitumen (VG 30 Grade)**

| Sl.No | Property | Recommended Values | VG 30 Grade of Bitumen |
|---|---|---|---|
| 1 | Penetration (mm) at 25 ºC, 100 gm, 5 Sec. | 60 – 70 | 64 |
| 2 | Ductility (cm) at 27 ºC | 75 | 84 |
| 3 | Softening point (°C) | 45 - 60 | 54 |
| 4 | Specific Gravity | | 1.01 |
| 5 | Flash Point<br>Fire Point | -<br>- | 285ºC<br>296ºC |
| 6 | Viscosity ($cm^2$/sec) | 45-70 | 50 |

**Table2 : Test Result of Aggregates**

| **Sl.No** | **Property** | **Recommended values** | **Test Value** |
|---|---|---|---|
| 1 | Specific Gravity | 2.5 – 3.0 | 2.7 |
| 2 | Aggregate impact Value | 30 % (max) | 21% |
| 3 | Flakiness Index | 30% (max) | 30% |
| 4 | Elongation Index | - | 29% |
| 5 | Abrasion | 30% (max) | 30% |
| 6 | Water Absorption | ≤ 2% | 1.1% |

## *2.1 Needle Punched Woven Geotextile*

Geotextiles can be simply defined as 'a textile material used in a soil (geo) environment' and include woven, non-woven polymeric materials and natural materials, such as jute, manufactured using textile processes. Geotextiles made using polypropylene or polyester are most common. Polypropylene begins to melt at a temperature of about 325°F. Therefore, when using polypropylene products, the temperature of the paving mixture should not exceed 325°F when it contacts the geosynthetic. Needle Punched Woven Geotextile (Fig 1) was collected from Gorantla Geosynthetic Private Limited in Chennai. The fabric is made up of tangled threads of 100% polypropylene, which give it superior strength to stand up to the stresses of construction and installation and is good resistance to UV and natural degradation. The properties of the Needle Punched Polyester Geotextiles is shown in Table 3

**Fig 1. Needle-Punched Polyester**

**Table 3 Properties of Needle Punch Geotextile**

| Sl.No | Tests/Properties | ASTM method | Value |
|---|---|---|---|
| 1 | Mass per unit area, g/m$^2$ | D-5261 | 150 |
| 2 | Thickness, mm | D-5199 | 1 |
| 3 | Tensile strength, KN/m | D-4595 | 3 |
| 4 | Elongation at break, % | D-4595 | 60 |
| 5 | Trapezoidal tear, N | D-4533 | 120 |
| 6 | Permittivity, S | D-4491 | 2.7 |
| 7 | Apparent Opening Size(AOS), µm | D-4751 | 150 |
| 8 | Roll length, m | - | 150 |
| 9 | Roll width, m | - | 3/4 m |

Source: Gorantla Geosynthetic Pvt Ltd

### 2.1.1 Placing of geotextile at various depth of mix

Bituminous Concrete mix was prepared as per gradation recommended by MORTH specification. The Geosynthetics were placed at one third, middle and three fourth depths from top of layer of the prepared mix.

## *2.2 Experimental procedure*

Marshall mix design for Bituminous Concrete (BC) Grade 2 of thickness 30-40mm with nominal size of aggregates 13.2 was prepared in the laboratory. The aggregate gradation was done as shown in Fig 2. The volumetric analysis of various parameters in the mix design at varying bitumen content was performed to arrive at determination of Optimum Binder Content (OBC). The OBC value was 5.5 % by weight of aggregate. The properties of the Marshall design and limits for BC as per MoRTH specifications are given in Table 4. The volumetric properties investigated were the theoretical specific gravity ($G_t$), the bulk specific gravity of the mix (Gm), percent air voids (Vv), percent volume of bitumen ($V_b$), percent void in mixed aggregate (VMA) and percent voids filled with bitumen (VFB) .

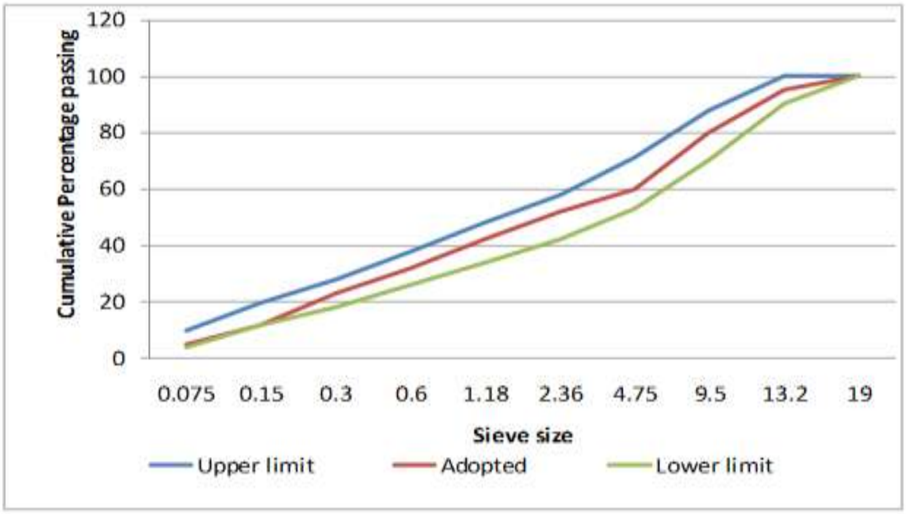



**Fig 2. Aggregate gradation for Bituminous Concrete Mix Grade 2.**

**Table 4: Bituminous Concrete Mix Design Values**

| Sl.No | Property | Results | Specified Limits |
|---|---|---|---|
| 1 | Minimum Binder content | 5.5% | 5.4% |
| 2 | Compaction level | 75 blows | 75 blows |
| 3 | Minimum Stability (kN) | 10 | 9 |
| 4 | Marshall flow (mm) | 3.1 | 2 – 4 |
| 5 | Density g/cc | 2.32 | - |
| 6 | % Air voids | 4% | 3 – 5 |
| 7 | % voids filled with bitumen | 71 | 65 – 75 |

## *2.3 indirect tensile strength*

Indirect Tensile Strength (ITS) test is done to assess the tensile strain at failure of the bituminous mix. It measures the splitting tensile strength of bituminous mixes and is useful in predicting cracking. The tensile characteristics of bituminous mixtures was evaluated by loading the Marshall specimen along a diametric plane with a compressive load at a constant rate acting of 51mm/minute, both along parallel and the vertical diametrical plane of the specimen through two opposite loading strips. The static indirect tensile strength of a specimen was determined using the procedure outlined in ASTM D6931. The peak load was recorded and it is divided by appropriate geometrical factors to obtain the split tensile strength using the following equation:

$$St=2000P/\pi tD$$

St = IDT strength, kPa

Where P = maximum load, t = specimen height immediately before test (63.0mm), D = specimen diameter (100mm).

The tensile strength ratio of the mix was found to be satisfying the specified requirements. As per MoRTH 2012, the minimum tensile strength ratio required for the mix with bitumen is 80%. The test results of various mixes without Geotextiles and with Geotextiles placed at 1/3 rd, half and 3/4th depth are given in Table5. Mix with geotextile placed at 1/3rd depth showed more tensile resistance for both wet and dry condition and hence the tensile strength ratio obtained was 84% hence providing a good resistance to moisture damage and creep. The cracking behaviour of the mix with and without geotextiles is as shown in Fig 3(a) and Fig 3(b).

**Table 5: Indirect Tensile Strength test**

| Mix | ITS dry KN/m$^2$ | ITS wet KN/m$^2$ | TSR % |
|---|---|---|---|
| Without Geotextile | 450 | 553 | 80 |
| 1/3rd depth | 1858 | 1555 | 84 |
| Half depth | 1769 | 1425 | 81 |
| 3/4th depth | 1798 | 1437 | 80 |

**Fig 3(a)**

**Fig 3(b)**

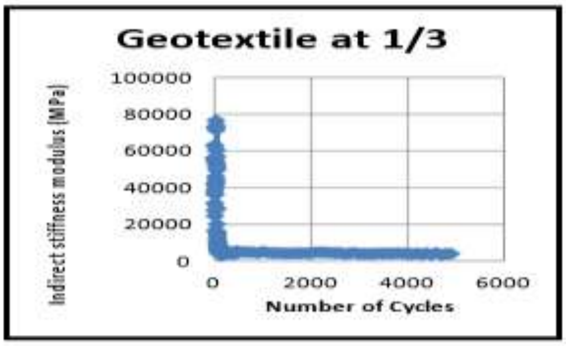
**Fig 3 (a) cracking behaviour without Geotextile and Fig 3(b) with Geotextile**

## *2.4 Indirect Tensile Stiffness modulus test*

The ITSM test is described in accordance with BS EN 12697-26; version 3.1.0, 1993[17] (BSI, 2004b; BSI, 1993) is one of the most commonly used tests for asphalt pavement samples because it is relatively simple to perform and non-destructive in nature. In the ITSM (Fig 4), a load pulse was applied to the vertical diameter of the specimen positioned centrally between the upper and the lower plates and the resultant peak transient deformation along the horizontal depth was measured. The method used rectangular beam specimens (400 mm x 50 mm x 50 mm) cut from the slabs in the laboratory.

**Fig 4. Stiffness Modulus Test Setup**

Inside the equipment the cut beams with and without geotextile specimens were maintained at 20$^0$C and one by one beams were tested at its defined depth of the beam (i.e. 1/3rd, half and 3/4th depth). With the frequency of 10Htz and 10 micro strain, the test method was set at a constant displacement for the stiffness modulus and the initial inputs of 5000 cycles were given. The initial peak-to-peak load amplitude and deformation magnitudes and stiffness values were recorded. Graphs were drawn for the recorded values for number of cycle vs stiffness modulus and number of cycle vs micro strain. The graphs for 1/3$^{rd}$, 1/2 and 3/4$^{th}$ depth are shown in Fig 5(a) & (b), Fig 6(a) & (b) and Fig 7(a) & (b) respectively



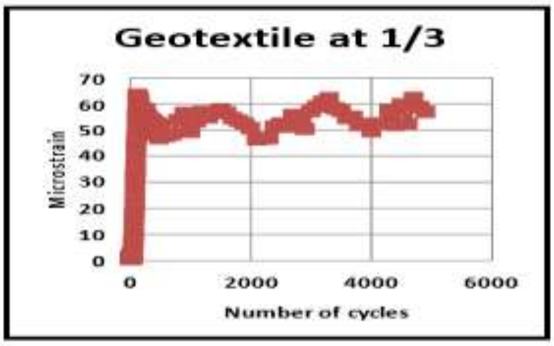
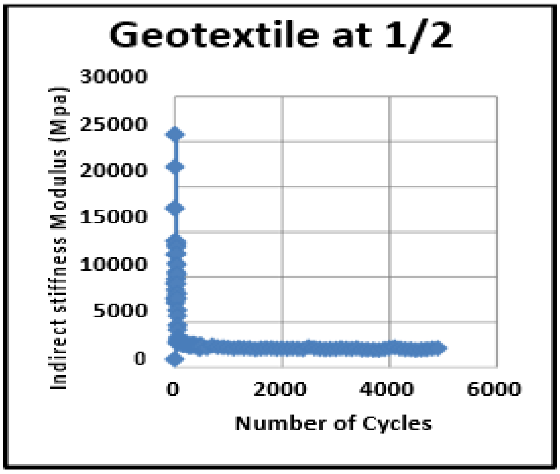




**Fig 5(a)** **Fig 5(b)**

**Fig 5(a) Number of cycle Vs stiffness Modulus and Fig 5(b)micro strain for geotextile at 1/3$^{rd}$ depth respectively.**

When geotextiles was placed at 1/3$^{rd}$ depth, for 5000 cycles, the stiffness modulus reached the value of 80000 hence it sustained more number of cycles. For that same no of cycles it produce 65 micro strain.



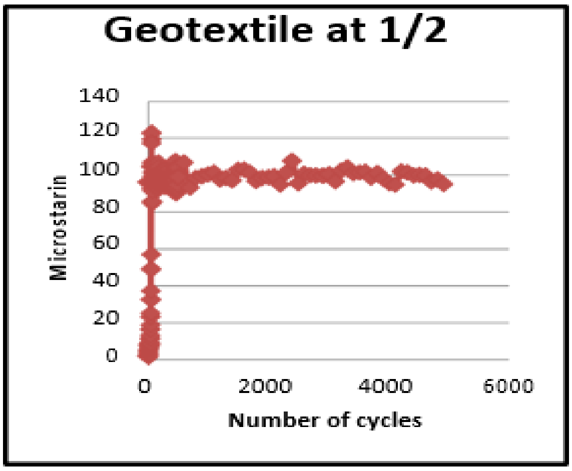
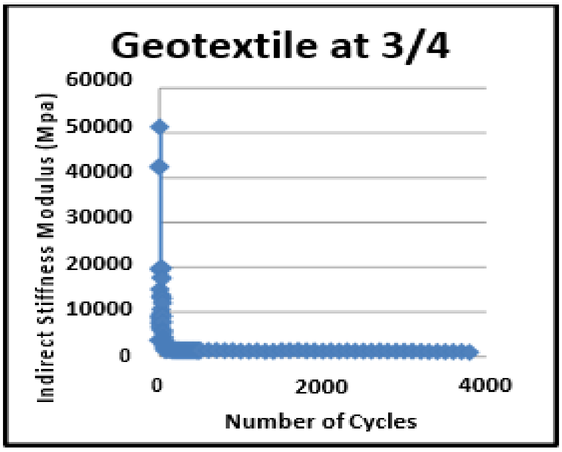




**Fig 6(a)** **Fig 6(b)**

**Fig 6(a) Graph showing no of cycle Vs stiffness Modulus and Fig 6(b) micro strain for geotextile at half depth respectively.**

For geotextile placed at half depth, the stiffness modulus reached the value of 25000 for 5000 cycles. For that same no of cycles it produces more number of 95 micro strains.



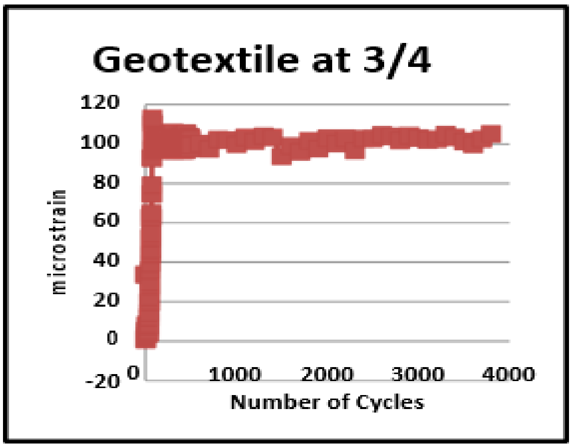




**Fig 7(a)** **Fig 7(b)**

**Fig 7(a) Graph Showing No of Cycle Vs Stiffness Modulus and Fig 7(b) Micro Strain For Geotextile at 3/4$^{th}$ Depth.**

For Geotextile at 3/4$^{th}$ depth, the stiffness modulus retains up to 3800 cycles and reached 50000 MPa. For that same no of cycles it produces more number of 110 micro strains. The stiffness modulus for various cycles is shown in Table 6.

**Table 6 Stiffness Modulus Test**

| Specification of mix | Cycles | Stiffness Modulus (MPa) | Micro strain |
|---|---|---|---|
| Without Geotextile | 3800 | 15000 | 150 |
| 1/3$^{rd}$depth | 4900 | 80000 | 65 |
| Half depth | 4900 | 26000 | 95 |
| 3/4$^{th}$ depth | 3800 | 50000 | 110 |

The mix with geotextile placed at 1/3$^{rd}$depth showed to sustain the maximum stiffness modulus than other specimens. Also it underwent lesser micro strain, hence the deformation is also minimum. It indicated that the mix with geotextile at 1/3rd depth yielded the stiffness modulus 5.33 times greater than conventional mix.

## 2.5 Beam fatigue test

Beam Fatigue Test (BFT) was carried out in accordance with Standards BS EN 12697-24; version 3.1.0. In this study, a repeated sinusoidal loading at a frequency of 10 Hz was used; in addition, the controlled strain mode was employed. The deflection of the beam specimen was measured using the control and data acquisition and it computed the strain in the specimen and adjusted the applied load by the loading device (AASHTO T321)[18]. All tests were performed in a temperature-controlled chamber at 20 ± 0.5°C. The load cycles, applied load, and beam deflections were recorded. Failure was assumed to occur when the stiffness reached 50% of its initial value, which was determined from the load at approximately 50 repetitions; the test was terminated automatically when the load diminished by 50%. Based on these relationships, the stiffness modulus (Pa) was calculated for each cycle of the test.

Since the Stiffness Modulus Test for Geotextile placed at one third depth of the specimen showed good response, the same was chosen for the Fatigue beam test. The specimen was maintained at $20^{0}$C and set the frequency at 10Htz and 200 micro strain for the Beam fatigue test and the test method was controlled strain mode and the initial end value was set as 50% residual strain separately given to specimens. All beam specimens used for the tests were sawed from a slab of 40 cm long, 30 cm wide, and 5 cm deep, prepared in the rolling-wheel compaction apparatus. Beam specimens dimensions are 30 cm long, 15 cm wide and 5 cm deep shown in Fig 8.

Specimen without Geotextile (NGT) and specimen with Geotextile (GT) at 1/3rd depth of the specimen was designated. In preparing the GT specimens, before placing the Geotextile, the asphalt mix was lightly compacted in the steel mould to a required depth of placing the Geotextile. Before placing the Geotextile on this layer, the surface was sprayed with bitumen to make a bond between the Geotextile and asphalt mix.


**Fig 8. Images of Fatigue test beams**

Once the geotextile was placed, the remaining asphalt mix was added in the mould and the wheel compactor was applied to obtain a density comparable to Marshall's mix density. Table 7 shows the fatigue beam test results.

**Table 7: Fatigue Beam Results**

| Cycle | Initial stiffness | | |
|---|---|---|---|
| | 10% residual strain | 30% residual strain | 50% residual strain |
| 0 | 75000 | 75000 | 75000 |
| 1000 | 65000 | 60000 | 25000 |
| 25000 | 55000 | 45000 | 12000 |
| 50000 | 43000 | 25000 | 4000 |
| 100000 | 31000 | 10000 | 250 |
| 150000 | 20000 | 4000 | 85 |
| 200000 | 10000 | 1500 | 10 |

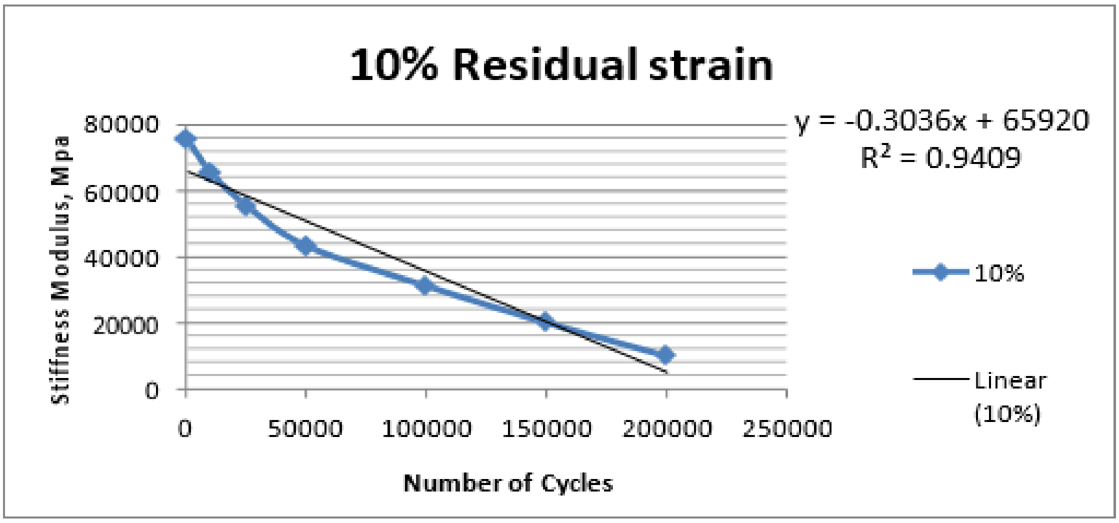



**Fig 9. Geotextile at 1/3rd depth- 10% residual strain**

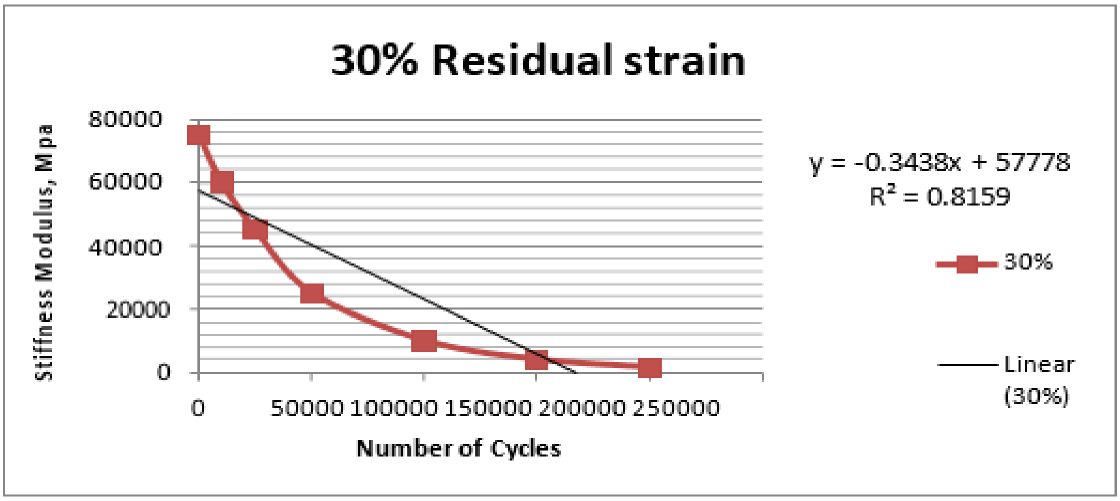



**Fig 10. Geotextile at 1/3rd depth- 30% residual strain**

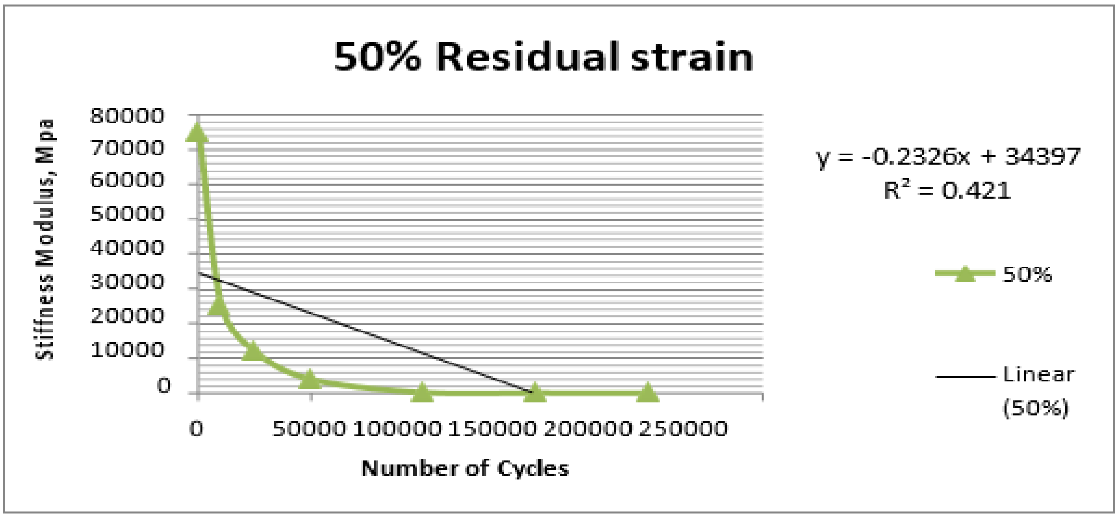



**Fig 11.Geotextile at 1/3rd Depth- 50% Residual Strain**

The Beam Fatigue Test for Geotextile placed at one third depth was correlated for 10%, 30% and 50% residual strain. From the results 10% residual strain graph showed better coefficient of determination with an $R^2$ value of 0.94 while 30% showed 0.81. The least was for 50% residual strain with $R^2$ value of 0.42.

## 3. RESULT AND DISCUSSION

Marshall test was conducted for 5.5, 6 and 6.5 percents of binder content and the optimum binder content at 5.5% produced higher stability and bulk density of the mix with minimum air voids. The process is repeated for preparing mould for indirect tensile strength test in which the geotextile material was placed at one third, middle, and three quarter depths of the mix to study its mix properties. The tensile strength ratios for conventional bituminous mix and also for mix with geotextile placed at various depths. From the test results, mix with geotextile which was placed at one third distance from top showed better results of 84% tensile strength ratio than others. The stiffness modulus values for BC mix without Geotextile was 15000 Mpa and with geotextiles placed at one third depth was 80000 Mpa. Mix with Geotextile placed at 1/3rddepth yielded stiffness modulus 5.33 times more than conventional mix without geotextiles. The Beam Fatigue Test was conducted for the Geotextile placed at one third depth, which was selected based on the results of stiffness modulus test. Then the test results were correlated for 10%, 30% and 50% residual strain. From those results 10% residual strain showed better coefficient of determination with an $R^2$ value of 0.94 which showed high accuracy of results.

## 4. CONCLUSION

Use of Geotextile in bituminous concrete improved its fatigue characteristics and arrest crack propagation than the conventional mix without geotextiles. The number of cycles required for crack propagation of the bituminous mix with geotextiles was greater than that of mix without Geotextile. Mix with Geotextile placed at one third distance from top showed better results of 84% tensile strength ratio than others. Overall specimens with geotextiles placed at one third depth from the top yields more resistance against bending and increases the tensile strength and stiffness modulus of the bituminous mix.

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