Effect of Interface Bonds on Pavement Performance

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Abstract

As per the five-year provincial roads plan (2017 edition), the Department of Transportation and Works of Government of Newfoundland and Labrador shifted its focus from the construction of new roads to the maintenance and rehabilitation of existing highways. With more than 270 km of road planned to be rehabilitated/upgraded in the province by 2022, appropriate strategies are needed to maintain and rehabilitate the roads. Many past studies reported that the life of overlays primarily depends on the interface condition between the existing pavement and overlay. In addition to this, the overlay fails mainly due to lack of proper maintenance for existing pavement before constructing the overlay. In this paper, Finite Element-based software program (ABAQUS) was employed to evaluate the interlayer damages between the existing pavement and overlay. Various interface conditions are modelled for evaluating the performance of the overlay. The results obtained from the analysis could help in selecting appropriate maintenance strategies for developing a sustainable overlay construction specification.

1. Introduction

In recent years, like other agencies, Newfoundland and Labrador's (NL) Department of Transportation and Works (DTW) has preferred to rehabilitate the existing pavements instead of constructing new pavements. Of all the rehabilitation techniques currently in use, an Asphalt concrete (AC) overlay over an existing Portland cement concrete (PCC) pavement is the most viable and cost-effective technique. Generally, a 2-inch thick layer of AC overlay is enough to treat any surface problems and restore the pavement's functional capabilities [1]. The advantages of an AC overlay over existing PCC pavement are as follows: 1) improved skid resistance, 2) restoration of the riding quality, 3) decrease of moisture intrusion into the base layers, 4) decrease in noise levels and 5) increase in service life. The limitations of the AC over PCC are 1) delamination and 2) reflective cracking near transverse and longitudinal joints.

If the bonding between the AC overlay and existing PCC pavement is sound, then the AC overlay performs well both structurally and functionally. A weak bond can often lead to delamination between the overlay and existing pavement, which reduces the performance and serviceability of a pavement. This may in turn also lead to cause early distresses just after the construction, such as cracking, slippage, peeling and distortion [2]. The causes of delamination are as follows: 1) Inadequate tack-coating, 2) Seepage of water through the surface layer, 3) A loose asphalt mixture. Delamination can also occur due to weak adhesive bonding and surface energy properties of binder which again can be affected by the aging of pavement layer [3]. Delamination of the surface layer is shown in Figure 1.

Figure 1: Delamination of Asphalt concrete surface layer [4]**.**

Out of the many failure mechanisms for an asphalt concrete overlay over an existing PCC pavement, reflective cracking is the primary pavement distress. Causes of reflective cracking in an AC overlay are: 1) due to change in seasonal temperature (thermal expansion and contraction), 2) due to heavy traffic loads, 3) due to the temperature gradient in the PCC pavement (warping) and 4) due to loss of subgrade below the existing PCC pavement.

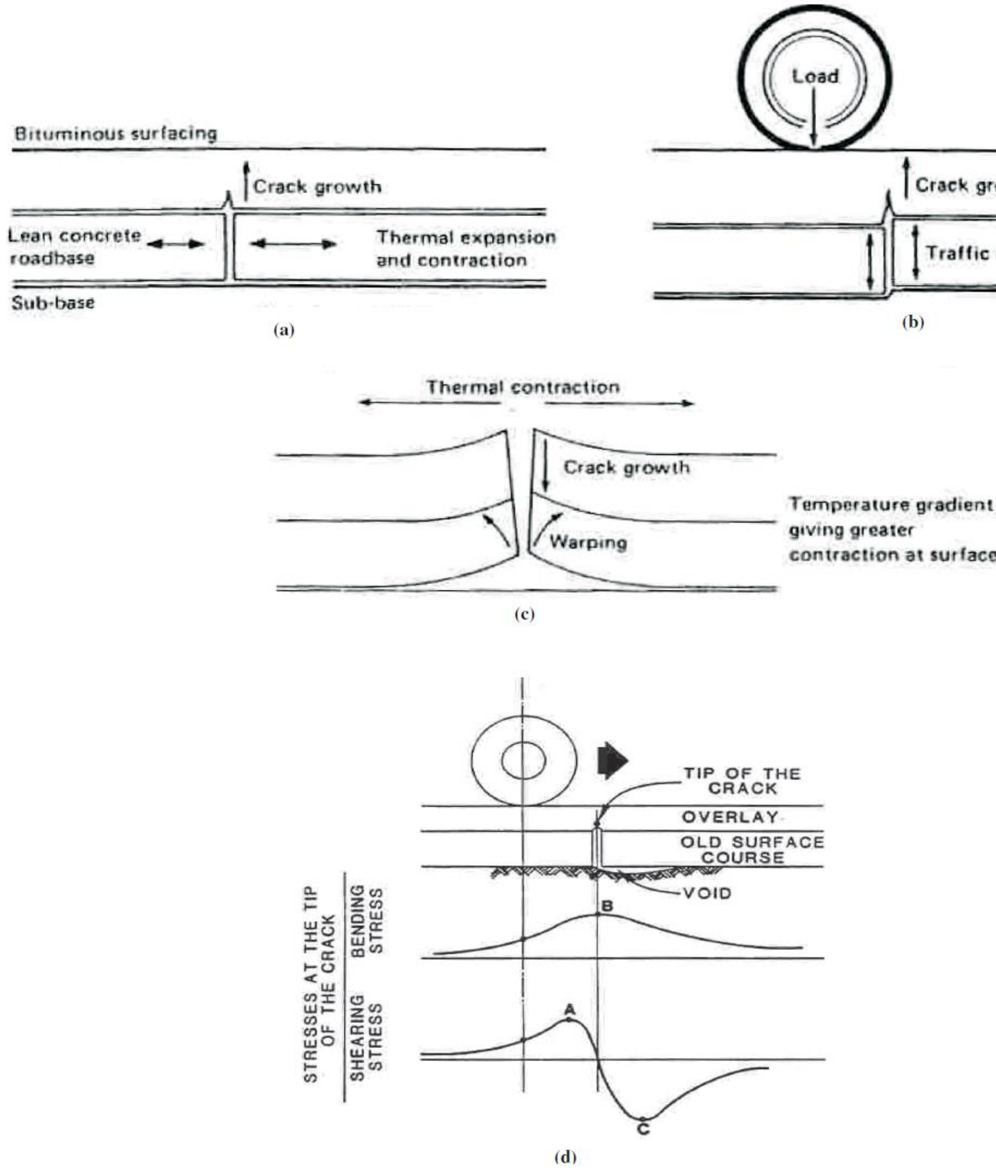

Figure 2: Causes of reflective cracking in AC overlay over a PCC pavement [5]**.**

There are many methods such as inserting stress relief layer, rubblizing the existing PCC, using geosynthetic layer, maintaining proper sealant before constructing overlay and so on used to prevent reflective cracking in AC overlay.

The primary motivation of this study is to better understand the effect of various interface conditions on pavement performance and to obtain the information on how the pavement responds to various rehabilitation strategies.

2. Objectives

The primary objective of this research is to determine the effect of interface bonding between asphalt concrete overlay over an existing Portland cement concrete pavement. Various interface conditions such as longitudinal tining, transverse tining and tack coating are considered to evaluate the effect of interface bonding on pavement performance.

3. Current Knowledge on AC- PCC Bonding

Bonding between asphalt overlay and the existing concrete pavement is necessary for maintaining the structure as monolithic, which improves the service life of the pavement. If the bonding is not sufficiently strong, then the pavement layers act independently, which reduces the service life of the pavement. Under the heavy loads, it may lead to instantaneous failure of the pavement. There are many techniques which can improve the bonding between pavement layers. The methods to improve bonding are chemical (tack coats, emulsions) or mechanical (milling, tining, etc.) bonding. In some cases, asphalt is diluted with water, which ensures proper bonding between the AC overlay over PCC pavement to enhance the life of the pavement. To transfer the tensile and shear stresses from overlay to the existing pavement and other structural layers of pavement, a robust bonding is necessary. Insufficient bonding causes distortion, slippage, cracking and instability in the overlay, reported many studies in the past.

Tayebali et al. [4] explained the reasons for delamination. The primary reasons for debonding/delamination are as follows:

- Presence of debris, dust, oil, rubber, dirt, water or any other non-adhesive materials on the existing PCC pavement during overlay placement;
- Use of excessive or inadequate tack coat;
- Highly polished aggregate on the existing pavement;
- Use of mixture having a high sand content;
- Lack of adequate degree of compaction of the AC layer.

In addition to these, delamination may also occur because of the following conditions:

- Improper field and temperature conditions

- Excessive load repetitions (heavy traffic)
- A very thin asphalt concrete overlay

Rahman et al. examined the interface adhesion properties of the asphalt layer using different types of laboratory shear tests with and without vertical loading [7]. The study found that the failure of the interface is effected by shear and tension stresses. A similar study [8] reported that tack coating does not affect shear strength. The same study also reported that the tack coating weakens the interface bonding between the overlay and existing pavement when compared to the pavements without tack coating. A laboratory study from Louisiana evaluated the interface bonding strength using tack coats and also tested for the optimum application rates of tack coating. In addition to this, they examined various tack coats and test temperatures [9]. Many studies conducted by the National Center for Asphalt Technology (NCAT) suggested a construction practice for overlaying without any tack coating.

Numerous studies have also suggested a wide variety of methods for determining the bond strength between pavement layers. During the 1970s, a direct shear test called an interface shear mold was used to determine the interface bond strength between pavement layers with penetration-grade bitumen as a tack coat at different temperatures [10]. Uzan et al. presented a systematic test method (direct shear test) for determining the bond shear strength between the layers with stress absorbing interlayers at an AAPT conference in the USA [11]. In Europe, a standard method (Swiss Standard SN 671 961) for obtaining bond strength using a Swiss LPDS tester was developed by Swiss Federal Laboratories for Materials Testing and Research [12]. Another study investigated the interface between layers with various tack coat types, application rates and different temperature conditions using Superpave Shear Tester [13]. A study from the United Kingdom also suggested the use of torsion tests for determining interface bond strength [12]. The Florida Department of Transportation (FDOT) developed a simple direct shear device which can also be tested using a Universal testing machine (UTM) or Marshall Stability equipment [14]. The Ancona Shear Testing Research and Analysis (ASTRA) apparatus was developed in Italy to measure the shear properties of the interface under the different surface and temperature conditions [15]–[17]. Various test methods used in many studies for evaluating the interface bond strength are summarized in Table 1.

Table 1: Test methods for evaluating the interface bond strength

Test Method	Variables Evaluated	Developed by	Author
Direct shear test	Penetration grade bitumen	Uzan et. Al.	Uzan et al. [10]
	Stress absorbing interlayers	Delft University of Technology	Heerkens et al. [11]
Swiss Standard SN 671 961	LPDS tester	Swiss Federal Laboratories for Materials Testing and Research	Roffe et al. [12]
Superpave Shear Tester	Various tack coat types, application rates and different temperature conditions	Mohammad et al.	Mohammad et al. [13]
Torsion test	Various tack coat types	In the UK	Roffe et al. [12]
Leutner test	Various bonding conditions	University of Nottingham	Collep et al.[18]
Simple direct shear device	Emulsion tack coat material	Florida Department of Transportation (FDOT)	Sholar et al.[14]
Ancona Shear Testing Research and Analysis (ASTRA)	Effects of temperature and surface	In Italy	Santagata et al. [15]–[17]
ATACKER™ device	Tensile mode or in torsion.	Instrotek, Inc	Instrotek, Inc (*ATACKER^{TM} InstroTek, Inc* 2005)
Direct Shear Test	Various interface conditions	Illinois Center for Transportation	Leng et al. [20]

4. Model Description

Finite element (FE) software programs such as ABAQUS, ANSYS, ADINA, developed in the mid-1990s, allow more tools for the simulation of pavements. In the current study, a new interface model is developed between the AC overlay and the existing PCC pavement with zero thickness. The various types of bonding between the existing pavement and overlay and the interface shear strength are among the main parameters considered for the Interface layer. Various tack coating materials and different application rates are considered to determine the effect of interface bonding on the service life of overlay. In addition to this, effects of various PCC surface textures such as smooth, longitudinal tining and transverse tining are also studied.

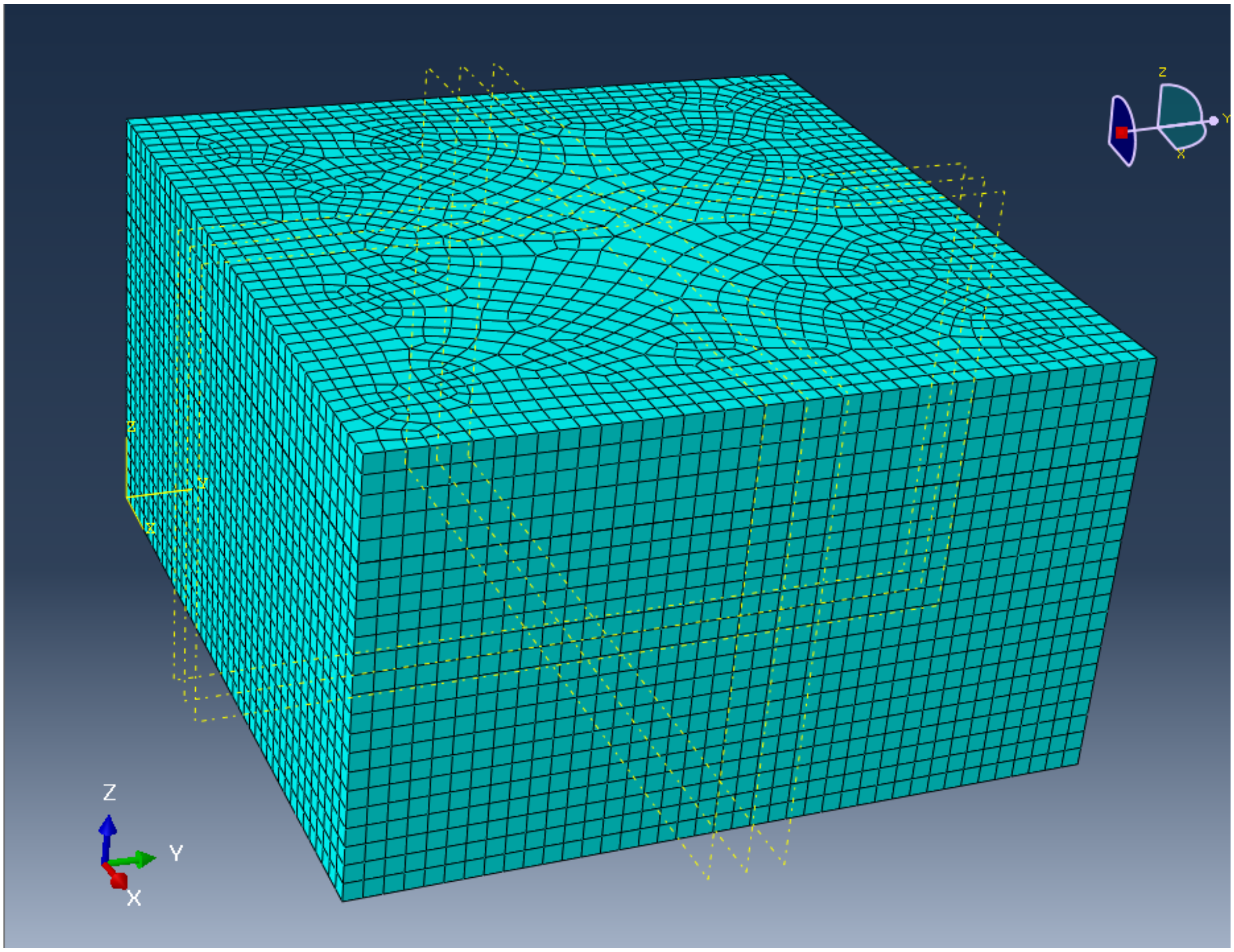

Figure 3: Finite element model of pavement: AC overlay over existing PCC pavement

The finite element model, which is developed to determine the service life of pavement with various interface conditions, is presented in Figure 3. The pavement details considered for analysis are shown in Table 2. The interface bond strength data are obtained from Leng et al. 2009 [20]. A standard axle load of 80 KN is applied for determining the stresses and strains below the asphalt overlay.

Table 2: Properties of the pavement system

Layer Details	Density (ρ) (kg/m^3)	Elastic Modulus (N/mm^2)	Poisson's Ratio (μ)	Thickness (mm)
AC Overlay	2250	2500	0.35	60
Existing PCC layer	2400	15000	0.15	200
Sub Base	1900	400	0.35	200
Sub Grade	1800	40	0.35	infinite

5. Results and Discussion:

The results from the finite element modeling are shown in Table 3. Lateral and longitudinal strains at the bottom of the AC layer are evaluated which represents the fatigue life of the pavement. The contour diagram of strains distributed in the pavement layers is presented in Figure 4. Moreover, the effect of the interface shear strength on the formation of strain at the bottom of the AC overlay is presented in Figure 5. The optimum residual tack coat application rate is reported to be 0.05 gal/yd^2 determined from a substantial experimental work conducted by the Illinois Center for Transportation is utilized for our parametric study [20].

Table 3: Strain at the bottom of the AC overlay for various interface conditions

Interface Type	Tack Coat Application Rate (gal/yd^2)	Interface Shear Strength (KPa)	Longitudinal Strain (ϵ_x) (x10^6)	Transverse Strain (ϵ_y)(x10^6)
Frictionless	0	0	343.1	398.71
Smooth	0	61.93	324.6	374.43
Smooth	0.02	95.67	309.8	354.98
Longitudinal Tining	0.02	166.73	272	309.83
Transverse Tining	0.02	186.23	257.61	292.98
Transverse Tining	0.09	312.67	145.89	163.58
Longitudinal Tining	0.09	313.1	145.43	163.06

Smooth	0.09	323.03	134.67	150.77
Longitudinal Tining	0.05	328.7	128.4	143.62
Transverse Tining	0.05	329.13	127.92	143.08
Smooth	0.05	407.27	34.25	36.89

In the parametric study, the combination of tining and tack coating are also considered. The pavement with optimum tack coating and without tining performs better compared to all other combinations, as can be seen from the data obtained from finite element analysis. It is well established that the strain at the bottom of the pavement is inversely proportional to the fatigue life of the pavement [21]. The analysis shows that there is no significant effect of the direction of tining on the performance of the pavement. Finite element data are summarized in Table 3.

At a lower application rate (0.02 gal/yd^2) of tack coat, tined interface performs better compared to a smooth interface. At the optimum rate (0.05 gal/yd^2) of application of tack coat, both tined and smooth interface perform more or less the same. It is also observed that a high application rate (0.09 gal/yd^2) of tack coat reduces the interface bond strength, which ultimately reduces the life of the pavement. One possible explanation of this weakening effect is that a high application rate of tack coat creates a thin soft layer between the pavement layers.

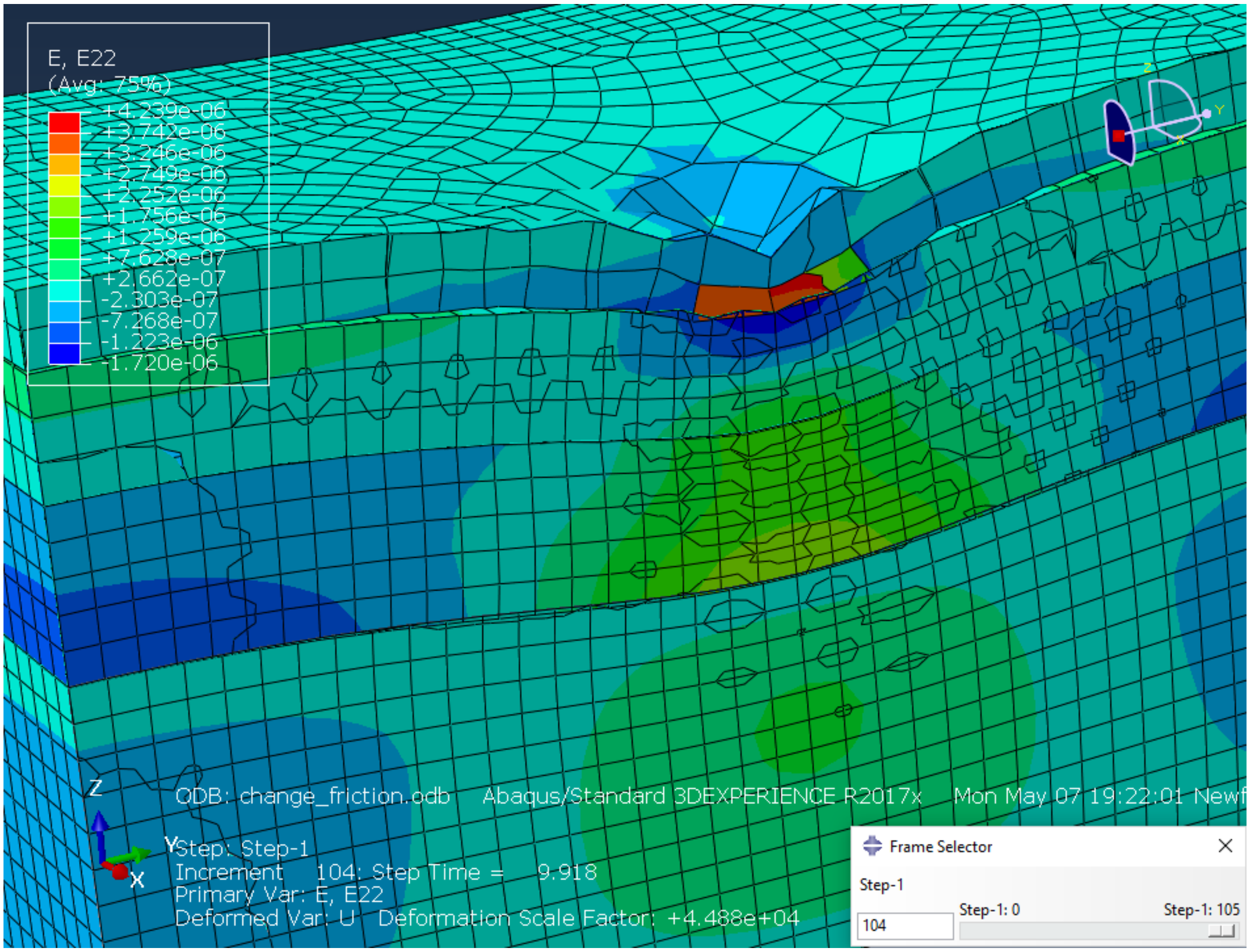

Figure 4: Contour diagram of strain in the pavement layer system

From Figure 4, we can observe how the strains are distributed throughout the pavement layer system. Red represents the tensile strain and blue represents a compressive strain. Strains are maximum and tensile at the bottom of the AC overlay (at the interface).

Figure 5 presents the relationship between the strains and the interface shear strength at the bottom of the AC overlay and it can be seen that the strains are reducing as shear strengths are increasing. Recall that a low strain represents a higher fatigue life of pavement with an increase in interface bond strength between the AC overlay and existing PCC pavement.

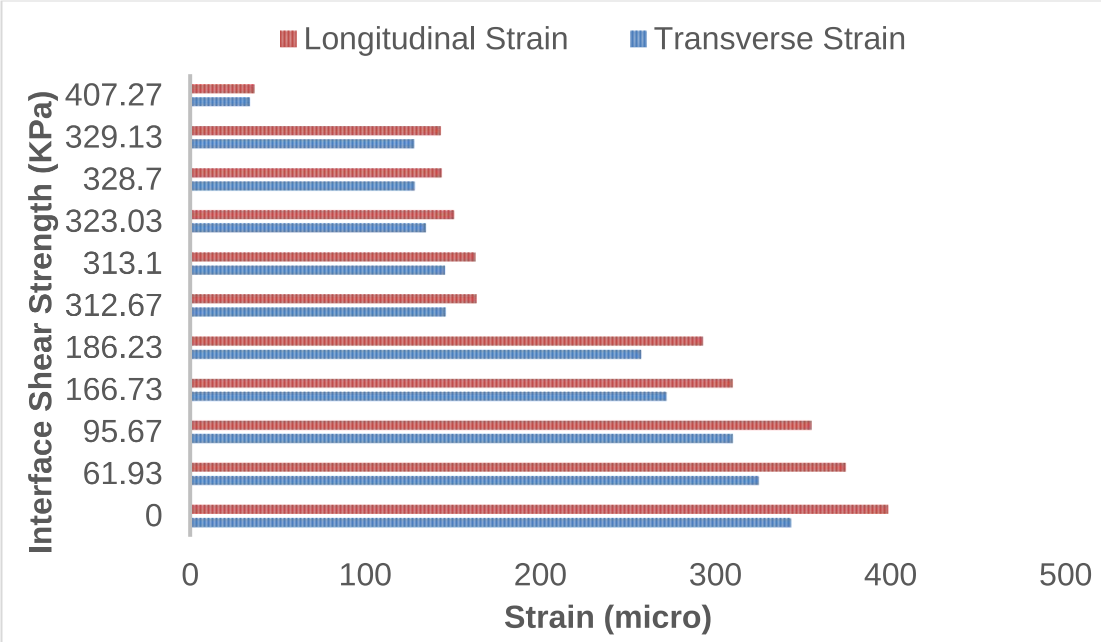

Figure 5: Effect of Interface Shear Strength on Strain

6. Conclusion

Various interfaces between AC overlay and existing PCC pavement are modeled using the finite element based program, to evaluate the performance of the pavement. The results from finite element modeling enable us to make the following conclusions:

- When there is an increase in interface bond strength between the AC overlay and existing PCC pavement, the strains at the bottom of the AC overlay are reduced, which corresponds to the high fatigue life of the pavement.
- The combination of tining and a tack coat performs well when the application rate of tack coat is less; but at the optimum application of the tack coat, a smooth interface can provide better bonding than a tined interface.
- An overlay without any interface bonding will lead to the premature cracking of pavement.

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