# Laboratory Investigation of Behavioural Changes in Tensile Strength of Bituminous Concrete Mixes Subjected to Differential Loading Temperature

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**Abstract**

This paper presents a laboratory investigation of the behaviour of bituminous concrete mixtures when subjected to differential loadings in temperature with respect to tensile strength. The study became necessary because previous works have revealed that bitumen which is the binding agent in bituminous concrete can easily flow or flush under increased temperature causing separation from aggregates. For the present study, laboratory specimens of bituminous concretes were prepared in accordance with specified standards and two indirect tensile testing methods (split cylinder and double punch tests) were used to evaluate the behavioural changes in tensile strength that occurred. The laboratory procedure involved testing the specimens under increasing temperature of loading between 20°C - 60°C with incremental loadings of 10°C. The study was carried out for three categories of traffic – Light, Medium and Heavy traffic categories respectively. The results obtained revealed that increase in mix temperature of asphalt/bituminous concretes from 20°C - 60°C adversely affected the tensile strength behaviour of the concrete under external traffic loading. Furthermore, results of tensile strength from the double punch test were better than those from split cylinder test for all categories of traffic under varying temperature between 20°C - 60°C.

**Key words:** Bituminous concrete, temperature, Tensile Strength, Split Cylinder Test and Double Punch Test.

## 1.0 Introduction

In this paper the terms asphalt and bitumen have been used simultaneously; furthermore the term asphalt/bituminous concrete have also been used synonymously as flexible pavement.

Research findings have proven that four main parameters affect the behaviour and performance of bituminous concrete mixes which includes – traffic loading, temperature loading, moisture and material properties of the pavement (**Robbins 2009**).

**Ekwulo and Igwe (2011)** studied the impact of traffic loading frequency on dynamic modulus for a rubber latex modified bituminous concrete. Their result concluded that dynamic modulus increased with increasing traffic loading frequency up to a threshold value of 0.5% rubber latex addition into the bituminous concrete within design life of the pavement. Their work further revealed that as traffic loading increased there was decrease in air voids due to additional compaction resulting in greater stiffness. In similar study, **Igwe and Agwunwamba (2015)** carried out a laboratory investigation on the impact of loading frequency on fatigue life of flexible pavements with the particular case candle wax modified asphalt concrete mixtures for heavy traffic. Results obtained revealed that the fatigue life of both the unmodified and candle wax-modified asphalt concrete mixtures decreased as the loading frequency increased from 0.1 – 25 Hz respectively. Furthermore, the optimum fatigue life was obtained at 15% candle wax content for all frequencies. Overall, the pavement life reduced as loading frequency increased.

In contrast, studies have also revealed the behaviour of asphalt/bituminous pavement when submerged in moisture. In a previous study, **Diefenderfer (2008)** concluded that there are at least six negative effects on pavement properties that occur when pavements are subjected to excessive moisture. Their findings showed that there is reduction of shear strength of unbound materials, differential swelling on expansive sub grade soils, movement of unbound fines in flexible pavement base and sub base layers, pumping of fines and durability cracking in rigid pavements, frost-heave and thaw weakening, and stripping of asphalt in flexible pavements are some of the negative effects of increase moisture. Corroborating their study, **Magdi, (2014)** concluded that one of the major contributors to pavement failure is moisture when allowed to settle longer that should be on the pavement. In a more recent on moisture effect on asphalt/bituminous pavement, **Igwe, et al (2016)** carried out a laboratory investigation of the effect of moisture on stiffness of bituminous concretes. The results from the study revealed that flexible pavement simulated as asphalt/bituminous concretes in the laboratory when continuously under moisture loses bind-ability due to reduction in stiffness. Their work revealed that reduction in stiffness was due to separation between the aggregates and asphalt cement therefore results in stripping of the pavement under repeated traffic loads.

Behavioural changes of asphalt/bituminous concrete with respect to material property have also been studied by previous works. For instance, **Tayebali et al, (1994)** concluded that stiffness of asphalt-aggregate mixes is of paramount importance in determining how well a pavement performs and is fundamental to the analysis of pavement response to traffic loading. Furthermore, their findings revealed that all stiffness test systems that were investigated were found to be responsive to mix behaviour and test variables such as asphalt type, asphalt content, aggregate type, and amount of air-voids and temperature. The results showed that each of these variables had either a direct effect on stiffness or an indirect effect through interactions with other variables and temperature having by far the most influence on axial, diametral, and flexural stiffnesses. Other studies related to behavioural changes of asphalt/bituminous concrete due to material property are mostly related to either modifications of the asphalt/bitumen or modification of the asphalt/bituminous concrete such that changes result in the material property of the concrete therefore affecting overall performance of the pavement.

Research has shown that the limitations of bitumen as a road-paving material are associated with the problems of oxidation **(Othmer, 1963)**, which results in the cracking of the pavement and its instability with respect to local temperature variations, hence, various forms of modifications of the physical properties of bitumen have evolved over the years using different materials like natural rubber (**Van-Rooijen, 1938**; **Decker and Nijveld, 1951**; **Mason et al, 1957; Mummah and Muktar, 2001**). Other forms of modification include the use of recycled polyethylene from grocery bags (**Flynn, 1993**) and also from recycled plastics and low density polyethylene (**Collins and Ciesielski, 1993**; **Federal Highway Administration, 1993**; **Khan et al, 1999**; **Zoorob, 2000**; **Zoorob and Suparma, 2000**). The study by **Punith (2001**) further corroborates previous studies in the use of processed plastic bags for modification of material property.

Earlier study by **Phillips and Traxler (1963)** listed a number of factors which may reduce the binding properties of asphalt which in turn affects stability and flow of asphalt concretes. The study revealed that time and temperature were major parameters affecting many long-term aging factors.

Other behavioural changes of asphalt concretes with respect to temperature have also been studied. For instance, **Kamal et al (2005)** studied resilient behavior of asphalt concrete mixes under varying temperature and time of loading to understand the pavement behavior under Pakistani climatic conditions and to address the problem according to mode of distress. Hi work revealed that resilient modulus reduces up to about 85% with just an increase of 15º C (i.e., from 25 to 40º C) in temperature.

In a later study **Yener and Hınıslıoğlu (2014)** investigated the effects of temperature level and its exposure time on hot mix asphalt production stages on the conventional and rheological properties of asphalt cement through laboratory experimentation. Their result which corroborates a previous study (**Yener and Hınıslıoğlu, 2011**) showed that the variations in exposure time and temperature distinctly changed the properties of binders in a wide range.

In a very recent study, **Igwe and Nyebuchi (2017)** investigated the effects of temperature on mix design property of asphalt concrete. Their study revealed that increase in mix temperature from 20°C - 60°C resulted in increased flow of the asphalt concrete for all categories of traffic considered which initiates premature failure of pavement (asphalt concrete). Similarly, increase in mix temperature from 20°C - 60°C resulted in decreased stability of the asphalt concrete for all categories of traffic considered which furthers premature failure of pavement (asphalt concrete). On this basis the present study was saddled with laboratory investigation of changes in tensile strength of asphalt/bituminous concretes when subjected to differential temperature loading.

The tensile strength of concrete is usually determined from indirect tensile tests rather than from direct pull tests on briquettes or from flexural tests on beams although flexural tests are valuable in connection with road and runway work (**Chen and Yuan 1995**). There are various types of indirect tensile testing methods used to determine tensile strengths of asphalt/bituminous concrete (**Emesiobi, 2000**).However, for purpose of the present study the scope was limited to indirect tensile testing using the methods of (a) split cylinder and (b) double punch test developed by **Chen (1970)**.

## 2.0 Materials and Methods

### 2.1. Sample collection

The materials used for this study were asphalt cement, coarse and fine aggregates and gravel dust. The asphalt cement and gravel dust used were collected from a private asphalt plant company H & H situated at Mbiama, in Ahoada West Local Government Area of Rivers State, Nigeria. On the other hand the coarse and fine aggregate used were obtained from a private construction site at Rumuagholu in Obio/Akpor Local Government Area of Rivers State. After sampling of the materials, laboratory tests - specific gravity, grading of asphalt and sieve analysis of the aggregates used for mix-proportioning by Rothfuch's method - were carried out.

### 2.2. Sample preparation

Samples preparation was preceded by aggregate gradation and blending. The Rothfuch's method of blending which allows for more than two aggregates to be blended was adopted. After aggregate gradation and blending Marshal Design Procedures for asphalt concrete mixes as presented in **Asphalt Institute (1981)**, **National Asphalt Pavement Association (1982)** and **Roberts et al (1996)** was adopted for mix design.

The procedures involved the preparation of a series of test specimens for a range of asphalt (bitumen) contents such that test data curves showed well defined optimum values. Tests were scheduled on the bases of 0.5 percent increments of asphalt content with at least 3-asphalt contents above and below the optimum asphalt content. In order to provide adequate data, three replicate test specimens were prepared for each set of asphalt content used. During the preparation of the unmodified asphalt concrete samples, the aggregates were first heated for about 5 minutes before asphalt was added to allow for absorption into the aggregates. After which the mix was poured into a mould and compacted on both faces with 35, 50 and 75 blows representing light, medium and heavy traffic respectively using a 6.5kg-rammer falling freely from a height of 450mm - see appendix 1, Figure 1. Compacted specimens were subjected to bulk specific gravity test, stability and flow, density and voids analyses at $54^0$C. The results obtained were used to determine the optimum asphalt content of the unmodified asphalt concrete. After obtaining the optimum asphalt content the design value of asphalt cement content was used to re-prepare samples that were subjected to varying temperatures between $20^0$C - $60^0$C at increments of $10^0$C at a design asphalt cement contents of 4.6%, 4.8% and 4.9% respectively for light, medium and heavy traffic categories respectively.

## 2.3. Indirect Tensile Test using Split Cylinder

The tensile characteristics of the asphalt/bituminous concrete were evaluated by loading the Marshall specimen along diametrical plane with a compressive load at a constant rate acting parallel to and along the vertical diametrical plane of the specimen through two opposite loading strips. The loading configuration developed a relatively uniform tensile stress perpendicular to the direction of the applied load and along the vertical diametrical plane, ultimately causing the specimen being tested to fail by splitting along the vertical diameter. The procedure involved placing a 0.5 inch wide strip along the length of the cylinder measuring 102 mm diameter and 64mm thick specimen to provide a uniform loading with which produced a nearly uniform stress distribution. The static indirect tensile strength of each specimen was determined using the procedure outlined in ASTM D 6931 were a loading rate of 51mm/minute was adopted causing tensile failure to occur in the sample rather than the compressive failure. The compressive load indirectly created tensile load in the horizontal direction of the sample and the peak load at failure of specimen was recorded. The tensile strength for each cylinder was computed by applying the theory of linear elasticity (Timoshenko, 1934: pp.104-108) for a solid disc as shown below using equation 1:

$$\sigma_{sp} = \frac{2p}{\lambda t D} \qquad 1$$

Where;
$\sigma_{sp}$ = Tensile Strength from split cylinder test – N/mm$^2$
P = Maximum load at failure, N
t = specimen height immediately before test, mm
D = specimen diameter, mm

The procedure was repeated for the various temperature modified asphalt/bituminous concretes at varying degrees between $20^0$C - $60^0$C and peak loads measured at failure to ascertain the effect of temperature differential on the indirect tensile strengths of the concretes.

## 2.4. Double Punch Test

The test was performed by loading concentrically an asphalt concrete cylinder of 64mm height and 102mm diameter top and bottom using two cylindrical steel punches of 25mm diameter at a rate of 25mm/minute until failure occurred. The load was applied perpendicular to the diameter of the concretes and generated an almost uniform tensile stress across the vertical planes containing the load causing the specimen to split across the planes similar to that of the split cylinder test. The tensile strength was computed by adopting the equation developed by (Chen, 1969) as follows:

$$f_t = \frac{Q}{1.2bH - a^2} \qquad 2$$

Where;

$f_t$ = Tensile Strength from double punch test – $N/mm^2$

Q = maximum load at failure

a = radius of punch = 12.5mm

b = radius of specimen = 51mm

H = height of specimen = 64mm

## 3.0 Results (See Tables 1-4 & Figures 1-3)

Results obtained from preliminary laboratory tests and analysis from the test results are tabulated in the following tables as follows;

**Table 1: Laboratory test results of stated materials**

| Material | Gravel Dust | Asphalt | Sand | Gravel |
|---|---|---|---|---|
| Specific gravity | 2.93 | 1.03 | 2.80 | 3.07 |
| Grade of binder material | - | 60/70 | - | - |
| Mix proportion (%) | 35 | - | 22 | 43 |
| Viscosity of binder | - | $1.16*(10^{-6})$ | - | - |
| (poise) | - | 44°C | - | - |
| Softening point | - | 66mm | - | - |
| Penetration value | | | | |

**Table 2: Schedule of Aggregates used for mix proportion (ASTM: 1951)**

| Sieve size (mm) | Specification limit | Aggregate Gravel 0.43A | Aggregate Sand 0.22B | Aggregate Gravel Dust 0.35C | Mix Proportion 0.43A+0.22B + 0.35C |
|---|---|---|---|---|---|
| 19 | 100 | 100 | 100 | 100 | 100 |
| 13.2 | 80-100 | 100 | 85.20 | 100 | 96.74 |
| 9.5 | 70 – 90 | 100 | 46.57 | 100 | 88.25 |
| 6.7 | 45 – 70 | 100 | 10.83 | 97.44 | 60.76 |
| 4.5 | 48 – 65 | 91.18 | 0 | 90.48 | 52.08 |
| 2.30 | 35– 50 | 75.37 | 0 | 69.23 | 40.81 |
| 1.18 | 22 – 40 | 56.62 | 0 | 56.78 | 44.22 |
| 0.60 | 16 – 30 | 33.09 | 0 | 45.42 | 30.00 |
| 0.30 | 13 – 23 | 11.40 | 0 | 27.47 | 14.52 |
| 0.15 | 7 – 15 | 1.11 | 0 | 4.76 | 2.14 |

| | | | | | |
|---|---|---|---|---|---|
| 0.075 | 0 | 0 | 0 | 0 | 0 |

**Table 3: Peak Loads at Failure of asphalt During Indirect Tensile Test**

| Temperature (ºC) | Split Cylinder Tests (N) | | | Double Punch Test (N) | | |
|---|---|---|---|---|---|---|
| | Light | Medium | Heavy | Light | Medium | Heavy |
| 20 | 3290 | 7153 | 9376 | 1828 | 3974 | 5209 |
| 30 | 2921 | 6364 | 8015 | 1623 | 3536 | 4453 |
| 40 | 2673 | 4477 | 6622 | 1485 | 2487 | 3679 |
| 50 | 2574 | 3279 | 5661 | 1430 | 1822 | 3145 |
| 60 | 2552 | 2377 | 5339 | 1418 | 1321 | 2966 |

**Table 4: Results of Tensile Strength from Indirect Tensile Tests**

| Temperature (ºC) | Split Cylinder Tests (MPa) | | | Double Punch Test (MPa) | | |
|---|---|---|---|---|---|---|
| | Light | Medium | Heavy | Light | Medium | Heavy |
| 20 | 0.320755 | 0.69748 | 0.914242 | 0.490038 | 1.065586 | 1.396747 |
| 30 | 0.284774 | 0.620546 | 0.781533 | 0.435068 | 0.948048 | 1.193998 |
| 40 | 0.260641 | 0.436547 | 0.645703 | 0.398198 | 0.666941 | 0.986482 |
| 50 | 0.250988 | 0.319731 | 0.551997 | 0.38345 | 0.488474 | 0.843322 |
| 60 | 0.248794 | 0.231778 | 0.520599 | 0.380098 | 0.354103 | 0.795353 |

The results in Table 4 above were obtained by applying equations 1 and 2 for split cylinder and double punch tests respectively.

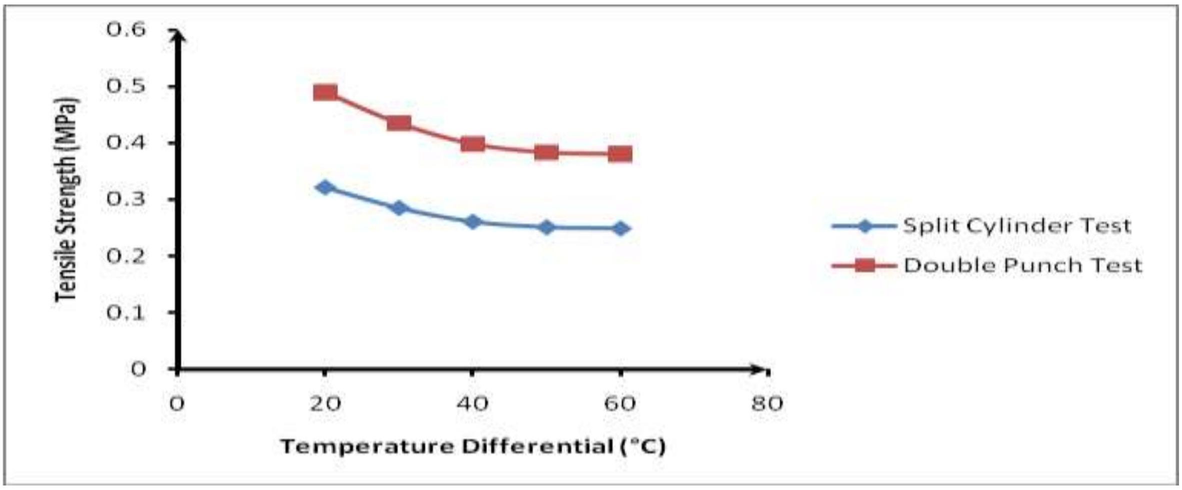


**Figure 1:** Tensile Strength Variation with Temperature Changes for Light Traffic

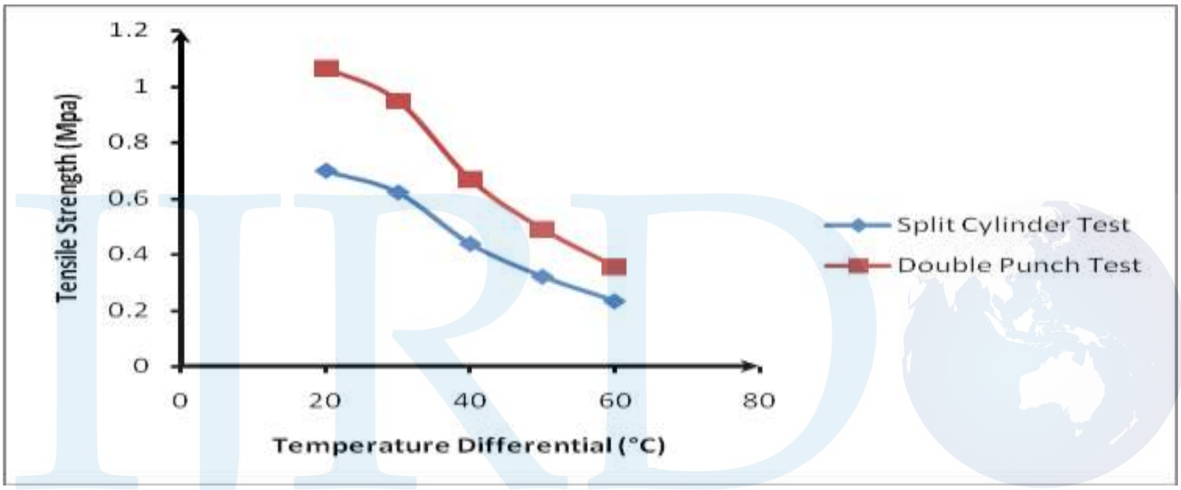


**Figure 2:** Tensile Strength Variation with Temperature Changes for Medium Traffic

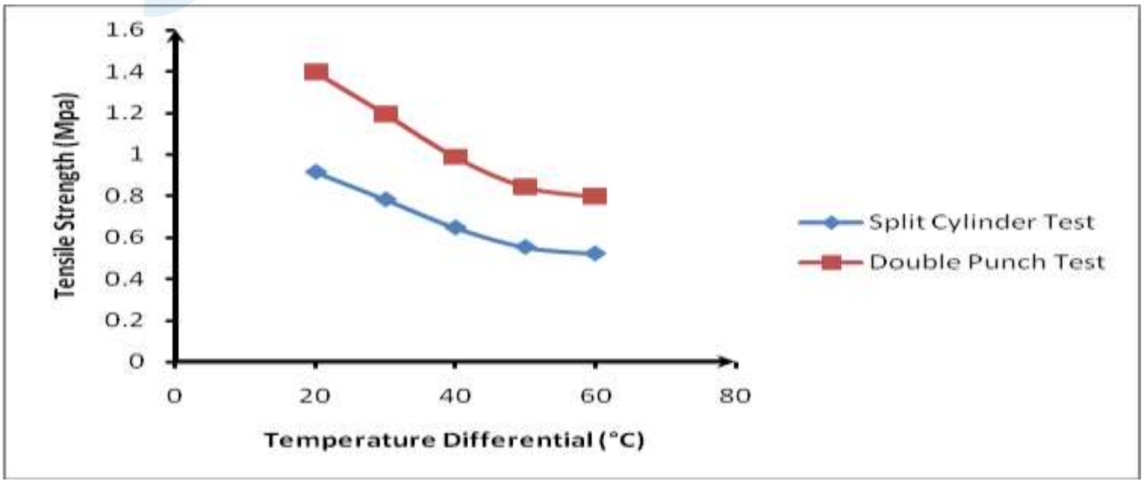


**Figure 3:** Tensile Strength Variation with Temperature Changes for Heavy Traffic

### 4.0 Result Discussions

The results from Table 4 and Figures 1-3 revealed that a gradual increase in the mix temperature of the asphalt/bituminous concretes from 20°C - 60°C resulted in decrease in both the split cylinder tensile strength and double punch tensile strength behaviour of the concretes for the three categories of traffic considered. This phenomenon can be explained in relation to previous studies by Traxler (1963); and Yener and Hinislioglu (2014). Their studies suggested that as mix temperature increases, the viscosity of the bitumen which binds the aggregates tends to reduce; therefore causing separation from the aggregates. In effect the cohesion between bitumen and aggregate matrix is weakened and thus negatively affects the tensile strength of the concrete under external loading of traffic.

Secondly, it was observed that tensile strength from the double punch test were generally higher than that from the split cylinder test for all categories of traffic considered under varying temperature from 20°C - 60°C.

## 5.0 Conclusion

From the laboratory tests and investigations carried out plus analysis of the laboratory results the following conclusions were made:

1. That increasing mix temperature of asphalt/bituminous concretes from 20°C - 60°C adversely affects the tensile strength behaviour of the concrete under external traffic loading for all categories of traffic.

2. That the double punch test produced better tensile strength results than that of split cylinder test for all categories of traffic under varying temperature between 20°C - 60°C.

3. That in actual design mixing temperature should be a function of the average prevailing temperature of that region to accommodate for effects of worst conditions of temperature.

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**Appendix 1**


**Figure 1**: Marshall Test Set Up