# THE EFFECT OF TRAFFICKING ON THE RHEOLOGICAL PROPERTIES OF BINDER RECOVERED FROM A ONE YEAR OLD ROAD

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## ABSTRACT

Asphalt cores were sampled from four sites along a major route in Tanzania, where asphalt surfacing was constructed approximately one year ago. The bituminous binder was recovered from cores taken from the wheel path as well as from cores taken from the shoulder, in order to assess whether the action of vehicular trafficking had any effect on the rheological properties of the recovered binders. A range of rheological tests were conducted on the recovered binder, including empirical tests such as penetration and softening point, as well as more fundamental tests such as the G*/sinδ and the multi-stress creep recovery test.

## 1. INTRODUCTION

In September 2015, the authors visited a section of a major route in Tanzania, which is approximately a 39.5 km length of road, and which has been in service for approximately one year. Upon inspection of the section, it was observed that various sections were rutting and/or flushing/bleeding. Rutting was most severe on the approach to and departure from speed humps as was observed in Figure 1. The authors were tasked to investigate the cause of the observed rutting.

**Figure 1: Rutting on the departure from a speed hump.**

Test pits were excavated and core samples were taken from two non-rutting areas and two rutting areas. Table 1 summarises the location and condition of the four sampling areas.

**Table 1: Four Locations investigated along a major route between in Tanzania**

| Area Identity | Kilometre Posting | Description |
|---|---|---|
| Location 1 | km 31.940 North | Severe rutting after the road humps. |
| Location 2 | km 37.000 North | Rutting not visually evident. No road humps present. |
| Location 3 | km 51.300 North | Rutting not visually evident. No road humps present. |
| Location 4 | km 54.560 North | Severe rutting after the road humps. |

A fundamental question which arose during sampling was with regards to the sampling position of the asphalt surfacing cores. The volumetric investigations needed to be carried out on cores from the shoulders where the asphalt mix is relatively undisturbed. Accurate air voids could not be measured within the rutted areas, because the asphalt mix had been so distorted by shear action as to render the values meaningless. On the other hand, it was feared that the recovered binder properties from the shoulder might differ from those obtained from the trafficked road surface. It was suspected by the authors that the kneading effect of traffic and the closing up of voids on the trafficked surface could affect the ageing rates and rheological properties of the binder. Furthermore, Jenkins and Twagira (2008) have reported that the properties of binder recovered from 5 to 10 year old bitumen treated base differs, depending on whether the binder was taken from trafficked or un-trafficked areas .

## 2. METHODOLOGY

An approach was adopted whereby asphalt cores for binder recovery were sampled from the shoulder as well as the left wheel track. The recovered binder was evaluated and analysed statistically using the paired Student t-test, which was applied to the two sets of results to determine if there was a statistically significant difference between the mean values.

### 2.1. Evaluation of Recovered Binder

The binder was recovered from the asphalt mix cores using test method BE-TM-BINDER-1-2006, a CSIR method based on Abson distillation and using a mixture of toluene (85% v/v) and ethanol (15% v/v) as extraction solvent. The following tests were performed on the recovered binders:

- Ash Content (ASTM D482): The ash content is a quality control measure used during the recovery process to ensure that the mineral fines are sufficiently removed from the recovered binder. Results should be treated with caution when the ash content exceeds 2% m/m. Increasing ash content would result in an increase in the binder stiffness.

- Gas Chromatography (BE-TM-BINDER-5-2010) for solvent detection: The solvent detection using gas chromatography is a quality control measure used during the recovery process to ensure that the extraction solvent is sufficiently removed from the recovered binder. Results should be treated with caution when the solvent concentration exceeds 50 000 area counts. Increasing residual solvent would result in an decrease in the binder stiffness.

- Softening Point (ASTM D36M): The principle behind the test is that softening point is the temperature at which a disk of the bitumen attains a particular degree of softening under the specified conditions of the test in order to allow a defined stainless steel ball to pass through and travel a defined distance through water (Figure 2).

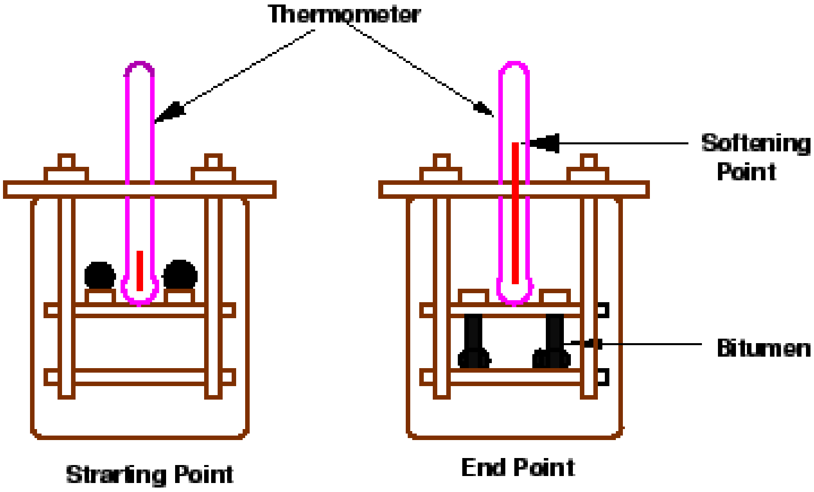

**Figure 2: Softening Point Test (www.civil.iitb.ac.in, 2016)**.

- Penetration (EN 1426): The penetration test determines the stiffness of bitumen under specified conditions, namely-
  - Melted and cooled bituminous binder sample under controlled conditions.
  - Penetration measured using a standard needle into the bituminous binder sample using,
    - Load = 100 grams
    - Temperature = 25° C (77° F)
    - Time = 5 seconds

  The depth of penetration is measured in units of 0.1 mm and reported in penetration units. The lower the value that is obtained, the harder the bitumen.

- G*/sinδ (AASHTO T315 / AASHTO M320): G*/sinδ is a rutting parameter employed in the SUPERPAVE© performance graded binder specification, where G* is the complex modulus and δ is the phase angle, both properties being measured by a dynamic shear rheometer (DSR). The specification requirements for G*/sinδ as given in AASHTO M320 are that G*/sinδ ≥ 2.2 kPa at the maximum average 7-day pavement temperature at 20 mm depth, after the binder has undergone short term ageing in the Rolling Thin Film

Oven Test. The higher the value obtained, the greater the resistance to deformation.

- Non-recoverable Compliance, $J_{nr}$ (AASHTO T350 / AASHTO M332): Using a damage resistance approach, $J_{nr}$, determined from the Multi Stress Creep Recovery (MSCR) test, is a more realistic approach to link bitumen laboratory testing with actual pavement resistance to deformation under repeated load (D'Angelo *et al*, 2007). It was adopted by AASHTO T350 and introduced in the PG specification of AASHTO M332. During the test, a one–second creep load is applied to the asphalt binder sample. After the 1–second load is removed, the sample is allowed to recover for 9 seconds. This constitutes one cycle. The test is complete after the application of ten cycles at an applied stress level 3.2 kPa creep stress. The non-recoverable compliance parameter, $J_{nr}$, is calculated by dividing the average permanent (non-recoverable) strain per cycle by the applied stress (Figure 3). A lower value implies an improved resistance to deformation.

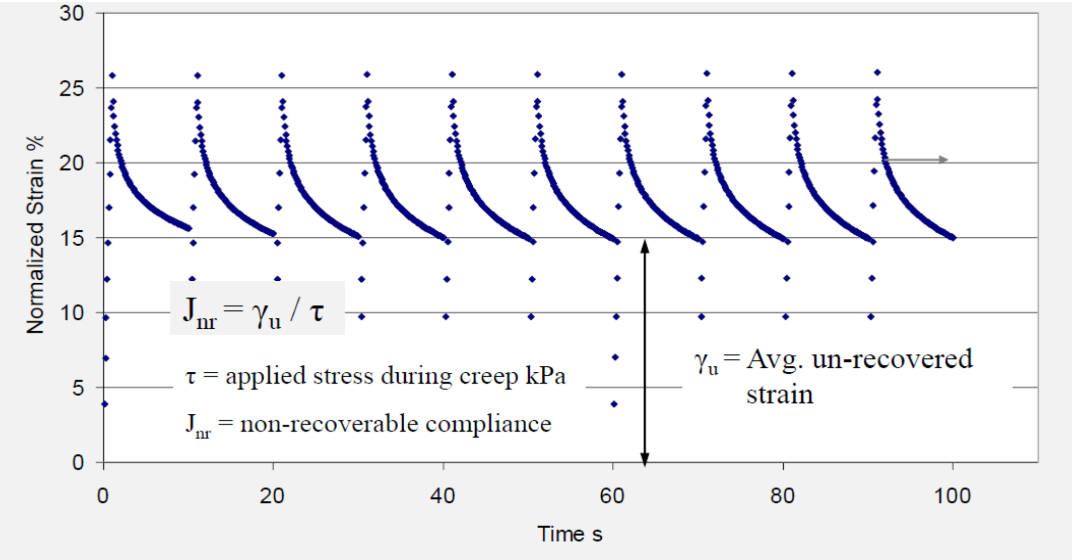

**Figure 3: MSCR Test (D'Angelo, 2010).**

## 2.2. Statistical Evaluation of the Results

Student's t-test compares the mean values ($\mu_1$ and $\mu_2$) of two populations using inference based on "small" samples. For this study, the two populations were defined as the entire HMA production in the project which was placed on the shoulder (un-trafficked) for population 1; and the entire HMA production in the project which was placed in the vicinity of the of the left wheel track for population 2. The mean value is dependent on the recovered binder property which is being examined.

The most common measure used to describe a sample set , which is a subset of the whole population is the mean ($\bar{x}$), and is defined in Equation 1as:

$$\bar{x} = x_1 + x_2 + x_3 + ..... + x_n = \frac{\sum_1^n x_i}{n} \qquad (1)$$

The variance of a sample or population is another commonly used statistic. The variance is a measure of the scatter of individual measurements about the mean value. A small variance is reflected in a tight clustering of values about the mean, whereas a large variance indicates that the values are widely spread. The variance for a population is denoted as:

$$Var_p = \frac{\sum_{1}^{n}(x_i - \bar{x})^2}{n} \qquad (2)$$

whereas the variance for a sample is denoted as:

$$Var_s = \frac{\sum_{1}^{n}(x_i - \bar{x})^2}{n-1} \qquad (3)$$

The square root of the variance is the more common measure, termed the standard deviation, and is denoted by σ for a population or *s* for a sample.

The calculated mean ($\bar{x}$) of a sample and standard deviation (*s*) of that sample may by chance deviate from the "real" mean (μ) and standard deviation (σ) of the population. The probability increases that the true mean size (μ) of a sample is "closer" to the mean calculated from a sample of N as the sample size increases. For example, If N=5, 95% of the time the actual mean (μ) would be in the range: $X_{avg} \pm 2.776.\sigma / N^{1/2}$; if N=10: $X_{avg} \pm 2.262.\sigma / N^{1/2}$. In other words, tests are conducted at discrete points within a population to determine parameters such as the mean or standard deviation of the properties selected. The test results are combined to form a sample set of the overall population. As the testing frequency increases, the number of results in the sample set increases, and the sample more accurately reflects the overall population's true mean and variance values. In the extreme, if every possible test location were tested, the sample set would match the population. However, for obvious reasons this not practical from a time and financial point of view.

It is the aim of Student's t-test to compare the extent of overlap of the statistical range for (μ) between two samples and thereby declare whether the null hypothesis, which states that the population mean (μ) for both samples are statistically equal for a given probability, is valid or invalid.

The student t-test is based on the assumption that the sample and population attributes assume a normal distribution, which is a statistical tool used to model the distribution of continuous variables in a population. The normal distribution is a bell shaped curve that can be characterized fully by two parameters, which are the mean and standard deviation. The normal distribution predicts both excessively large and even negative values at extremely low probabilities.

The Student's t-test is a statistical procedure for determining whether differences occur between two sample sets at a given significance level. A significance level of α

= 0.05 implies that there is 5.0 percent chance of rejecting a null hypothesis when it is actually true.

If the magnitude of the significance level were increased (say α = 0.10), the allowable difference between samples would be reduced, and the percentage of samples that exhibited statistical differences would get larger. The null hypothesis in this study was that the means of the samples for the trafficked and un-trafficked areas are equal (as related to the population means).

Null hypothesis $H_0 : \overline{x_t} - \overline{x_u} = 0$ (4)

Where $\overline{x_t}$ is the mean value for the trafficked sample set and $\overline{x_u}$ is the mean value for the un-trafficked sample set.

If the null hypothesis is proved to be false, then the alternative hypothesis must be true.

Alternative hypothesis $H_1 : \overline{x_t} - \overline{x_u} \neq 0$ (5)

The calculated t-statistic for samples with unequal variances is defined as:

$$t = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \qquad (6)$$

If the calculated t-statistic is less than the critical t-statistic (based on the significance level from the t-table), then the null hypothesis is not disproved. If the calculated t-statistic based on the data examined is larger than the critical t-statistic, then the null hypothesis ($H_0$) is disproved, and the alternate hypothesis ($H_1$) that the means are different is accepted.

The t-test also depends upon the number of both the sample sizes. The sample sizes are used to compute a single measure of the number of degrees of freedom of the test, denoted $d_f$. This is an important concept in that small sample sizes reduce the resolution of the t-test as illustrated in Figure 4.

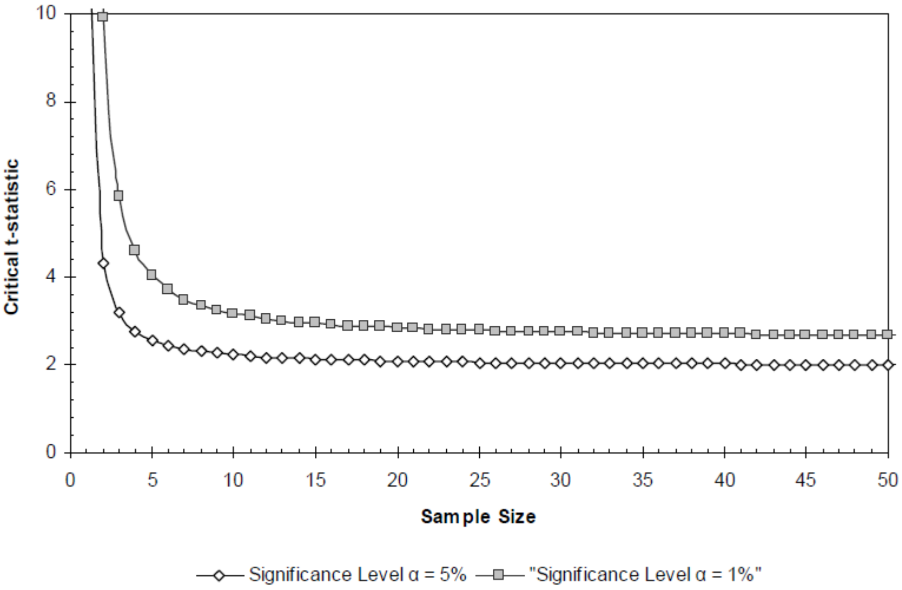

**Figure 4: Variation of the Critical t-statistic with sample size (La Vasar *et al*, 2009)**

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The statistical tests are dependent upon the sample sizes to determine both the t-statistic and the critical t values. As the sample size increases, the t-statistic increases, and the critical t-value decreases. This increases the probability that small differences between mean values will be statistically significant. The magnitude of these significant differences can then easily become smaller than the inherent variability of the testing procedure, which is problematic with regards to interpreting the results of the t-test .

The allowable testing difference, or D2S filter, compares the difference between two sets of test results to the established standard deviation of the test method to determine whether they are significantly different. The allowable testing difference between test means is calculated as follows:

$$\Delta\bar{x} = \frac{2s}{\sqrt{\frac{1}{n_1}+\frac{1}{n_2}}} \tag{7}$$

where:

$\Delta\bar{x}$ = allowable testing difference between means
s = standard deviation for the test method
n = number of values for the related set

Table 2 shows the calculated standard deviation results inherent in the test methods as carried out in our laboratories.

**Table 2: Typical Coefficient of variation (COV) results as determined for our laboratories for recovered unmodified binders**

| Property | Single Operator COV | Multi-operator COV | Reference |
|---|---|---|---|
| Penetration (dmm) | 2.5% | 2.8% | (O’Connell *et al*, 2009a) |
| Softening Point (ºC) | 0.55% | 0.55% | (O’Connell, 2009b) |
| G*/sinδ @ 64°C | 2.3% | 2.8% | (O’Connell *et al*, 2009c) |
| $J_{nr}$ at 64°C, σ = 3.2 kPa ($kPa^{-1}$) | No data available | | |

A paired t-test is a special case, used to compare two population means where you have two samples in which observations in one sample can be paired with observations in the other sample. This special case is relevant to our study. The calculated t-value is determined using Equation 8.

$$t = \frac{\overline{X}_D - \mu_0}{\frac{s_D}{\sqrt{n}}} \qquad (8)$$

Where, t = calculated t-value
$X_D$ = average of the differences between the paired values
$\mu_0$ = 0 for the nul hypotheisis
$s_D$ = standard deviation of the differences
n = number of pairs

## 3. TEST RESULTS

The test results are given in Table 3 (O’Connell *et al*, 2015). The paired student t-test was applied to the results to determine if there was a statistical difference between the data from the shoulder and the data from the left wheel track using a 95% confidence level.

**Table 3: Recovered Binder Results**

| Property | Location 1 | | Location 2 | | Location 3 | | Location 4 | |
|---|---|---|---|---|---|---|---|---|
| | Shoulder | Wheel track | Shoulder | Wheel track | Shoulder | Wheel track | Shoulder | Wheel track |
| Penetration (dmm) | 50 | 42 | 37 | 42 | 36 | 33 | 39 | 44 |
| Softening Point (ºC) | 55.0 | 57.0 | 54.4 | 53.6 | 54.4 | 54.4 | 54.2 | 53.6 |
| Ash Content (m/m %) | 0.5 | 1.3 | 0.3 | 0.4 | 0.3 | 0.4 | 0.7 | 2.4 |
| Solvent Gas Chromatography (area counts) | 61 400 | 24 900 | 36 800 | 23 200 | 30 100 | 29 700 | 41 000 | 53 200 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| G*/sinδ @ 64°C (kPa) | 2.3 | 3.1 | 2.9 | 2.4 | 3.0 | 3.2 | 3.2 | 2.7 |
| $J_{nr}$ at 64°C, σ = 3.2 kPa (kPa$^{-1}$) | 4.3 | 3.2 | 3.5 | 4.3 | 3.3 | 3.1 | 3.1 | 3.7 |

The results of the paired t-test is presented in Table 4, as evaluated using Excel.

**Table 4: Results of the paired t-test**

| **Property** | **Penetration (dmm)** | | **Softening Point (ºC)** | | **G*/sinδ @ 64°C** | | **$J_{nr}$ at 64°C, σ = 3.2 kPa (kPa$^{-1}$)** | |
|---|---|---|---|---|---|---|---|---|
| | Shoulder | Wheel track | Shoulder | Wheel track | Shoulder | Wheel track | Shoulder | Wheel track |
| Mean | 40.5 | 40.25 | 54.5 | 54.65 | 2.85 | 2.85 | 3.55 | 3.575 |
| Mean difference | 0.25 | | 0.15 | | 0.00 | | 0.025 | |
| $s_D$ | 6.39 | | 1.28 | | 0.63 | | 0.87 | |
| n | 4 | | 4 | | 4 | | 4 | |
| Calculated t-value | 0.078 | | 0.234 | | 0.000 | | 0.057 | |
| t-critical | 2.353 | | 2.353 | | 2.353 | | 2.353 | |
| Nul hypothesis | accepted | | accepted | | accepted | | accepted | |

Because the null hypothesis was accepted for all four cases, it is not a requirement to determine the allowable testing difference between the averages. However, for the sake of completeness, the allowable testing difference between averages were calculated using the multi-operator standard deviation and compared with the actual differences in Table 5.

**Table 5: Allowable Testing Difference**

| **Property** | **Penetration (dmm)** | | **Softening Point (ºC)** | | **G*/sinδ @ 64°C (kPa)** | |
|---|---|---|---|---|---|---|
| | Shoulder | Wheel track | Shoulder | Wheel track | Shoulder | Wheel track |
| Mean | 40.5 | 40.25 | 54.5 | 54.65 | 2.85 | 2.85 |
| Mean difference | 0.25 | | 0.15 | | 0.00 | |
| Coefficient of variation | 2.8% | | 0.55% | | 2.8% | |
| s (Standard deviation) | 1.1 | | 0.3 | | 0.1 | |
| Allowable Testing difference | 3.1 | | 0.9 | | 0.2 | |
| Within allowable testing difference | Yes | | Yes | | Yes | |

## 4. DISCUSSION AND CONCLUSION

The null hypothesis was not rejected for any of the four properties at the 95% confidence level. This implies that no statistical difference between the samples from the shoulder and the left wheel track with regards to these four properties could be shown to exist.

Statistically, there was no proven effect on the investigated rheological properties of the recovered binder as a result of traffic loading after one year.

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