EVALUATING THE EFFECTS OF COMPACTION OF HOT MIX ASPHALT ON SELECTED LABORATORY TEST

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ABSTRACT

A general concern exists regarding the ability of the South African Hot Mix Asphalt (HMA) design method to accurately predict the rutting performance of HMA designs through laboratory evaluation. Since 2000 various studies have focused on this issue, and several HMA mixes from construction projects and laboratory prepared slabs were tested using a range of laboratory wheel tracking tests to assess the rutting potential of the mixes. The data from these tests were compared with field performance of the HMA. Although some of the tests appeared to be well correlated with rutting in the field, there are at present no generally accepted and quantified relationships to link laboratory test results to rutting in the field under variable traffic loading and environmental conditions. Other tests that are available for the assessment of rutting, such as the Axial Loading Slab (ALS) are essentially axial tests and do not simulate a rolling wheel load. These tests mainly evaluate the resistance of asphalt to volume change, and not shear response. Shear deformation is known to be the dominant mode of deformation causing rutting in pavements. It is also more sensitive to temperature and rate of loading than volume change.

In a current study on the development of rutting in a standard HMA mix under varying traffic and environmental conditions, the focus is on the evaluation of the effects of different compaction methods on the data obtained from a range of laboratory tests. The aim of this work is to provide input for the selection of appropriate and validated laboratory tests for the evaluation of rut resistance of HMA mixes.

In the paper, the background to the study is firstly provided, followed by a brief discussion on the parameters evaluated. Next, the data obtained from a range of laboratory tests on samples compacted using field and a range of laboratory compaction methods are evaluated and compared, and conclusions are drawn regarding the effect of compaction method on the data obtained from the various laboratory tests. This paper forms part of the research for an M.Tech degree at the Tshwane University of Technology (TUT).

1 INTRODUCTION

Hot Mix Asphalt (HMA) surfaced roads provide good riding quality when properly constructed, but there are serious distresses associated with HMA, and asphalt rutting is one of them. The existence of rutting on roads results in ponding of water in the wheel tracks, increasing the potential for aquaplaning during wet weather, poor riding quality and increasing vehicle operating costs. Fatigue cracking compromises the structural integrity of the pavement and enables water to penetrate into the pavement structure, causing secondary distress. This paper only concentrates on rutting. There is a need for developing improved laboratory testing methods and appropriate acceptance criteria for rutting in South Africa. The latter was echoed during the 9th Conference on Asphalt Pavement of Southern Africa. The outcomes of this study will address some of the issues surrounding laboratory tests for evaluating rutting.

2 BACKGROUND

Rutting background

Ruts in asphalt are depressions extended in length and confined in width (TRH6, 1985), which form under the wheel path in asphalt layers. Rutting is mainly caused by traffic loading, but climate can also have a large influence, especially when the pavement subgrade undergoes seasonal variations in bearing capacity, or when bituminous layers are subjected to high temperatures (Brown, Kandhal and Zhang, 2004). Failures in asphalt layers occur regularly on asphalt projects in southern Africa. Most of these failures can be attributed to some problem during the mix design, manufacturing or paving operation, and increases in axle loads and tyre inflation pressures. Instability rutting occurs when the structural properties of the compacted pavement are inadequate to resist the stresses imposed upon it, and on the material level, instability is manifested in a rearrangement of aggregate structure (Birgisson et al, 2004).

Design methods background

A general concern exists regarding the ability of the South African HMA design method to accurately predict the rutting performance of selected HMA designs through laboratory evaluation. Since 2000 various studies have focused on the issue, and several HMA mixes from construction projects and laboratory prepared slabs were tested using a range of laboratory wheel tracking tests to assess the rutting potential of the mixes (Steyn and Verhaeghe, 2006). The data from these tests were compared to field performance of the HMA. Although some of the tests appeared to be well correlated with rutting in the field, there are at present no generally accepted and quantified relationships to link laboratory test results to rutting in the field under variable traffic loading and environmental conditions. Other tests that are available for the assessment of rutting, such as the Axial Loading Slab (ALS) tests, are essentially axial tests and do not simulate a rolling wheel load. These tests mainly evaluate the resistance of asphalt to volume change, and not shear response. Shear deformation is known to be the dominant mode of deformation causing rutting in pavements.

In a current study on the development of rutting in a standard HMA mix under varying traffic and environmental conditions, the focus is on the evaluation of the effects of different compaction methods on the data obtained from a range of laboratory tests. The aim of the work described in this paper is to provide input for the selection of appropriate and validated laboratory tests for the evaluation of rut resistance of HMA mixes.

3 RESEARCH

Need for Research

A need exists for the development and verification of appropriate laboratory test methods, and associated acceptance criteria that can be used reliably and accurately in the assessment of rutting potential in HMA. The research is required as there is a lack of the following (Steyn, 2005):

- Reliable test procedures and associated acceptance criteria for the assessment of rutting potential that would cater for different mix types and that would be sufficiently flexible to accommodate the prevailing environment (traffic loading and HMA temperatures) in which the HMA mixes would perform;
- An understanding of the effect of different contact stresses on the behavioural characteristics and performance of HMA wearing courses, and
- Test methods that would assess the durability of HMA (although not directly related to permanent deformation, but often a consequence of design for rut prevention), including field and laboratory procedures and acceptance criteria for permeability.

Based on the need for research on HMA, a study was initiated by the Gauteng Department of Public Transport, Roads and Works (GDPTRW) in 2006. The specific scope of this study includes:

- Characterisation of a standard HMA mix in the laboratory, to ensure that all its properties are well known and understood;
- Accelerated Pavement Testing of the mix in the field to evaluate its potential field performance, and
- Laboratory testing of the standard HMA mix to determine its resistance to rutting using the following specific test methods:
  - Transportek Wheel Tracking Test (TWTT);
  - Hamburg Wheel-Track Testing (HWTT);
  - Dynamic Creep;
  - Indirect Tension Test (ITT), and
  - Indirect Tensile Strength (ITS).

Material Source

The asphalt for this work was supplied by a commercial asphalt plant. The first set of samples tested in the laboratory was sourced from the field during the construction of the tests sections (cores), the second set was mixed and compacted in the laboratory (standard laboratory design mix) and the third set was slabs and cores drilled from the test sections (field compacted). In this paper the field compacted samples (one sourced from the plant and compacted in the field and the other one mixed and compacted in the laboratory) are discussed. The laboratory design mixed is represented by short-term aged mixed and design mix (fresh mix in the laboratory). The type of mix discussed in this study is summarised in Tables 1 and 2 and Figure 1. Detailed information about the mix is discussed in Denneman (2007).

Table 1: Binder properties.

Grade/Type	60/70 PEN	**Mixing Temperature**	150 ℃	**Compaction Temp**	135 ℃
Penetration	64	**Density @ 20 ℃**	1.028	**Softening Point**	50

Table 2: Selected engineering properties of design mix.

Property	Value
Binder content	5 %
Bulk Relative Density	2.582
Maximum Theoretical Density	2.690
% Voids-in-Mix	4.3%
% V.M.A	15%

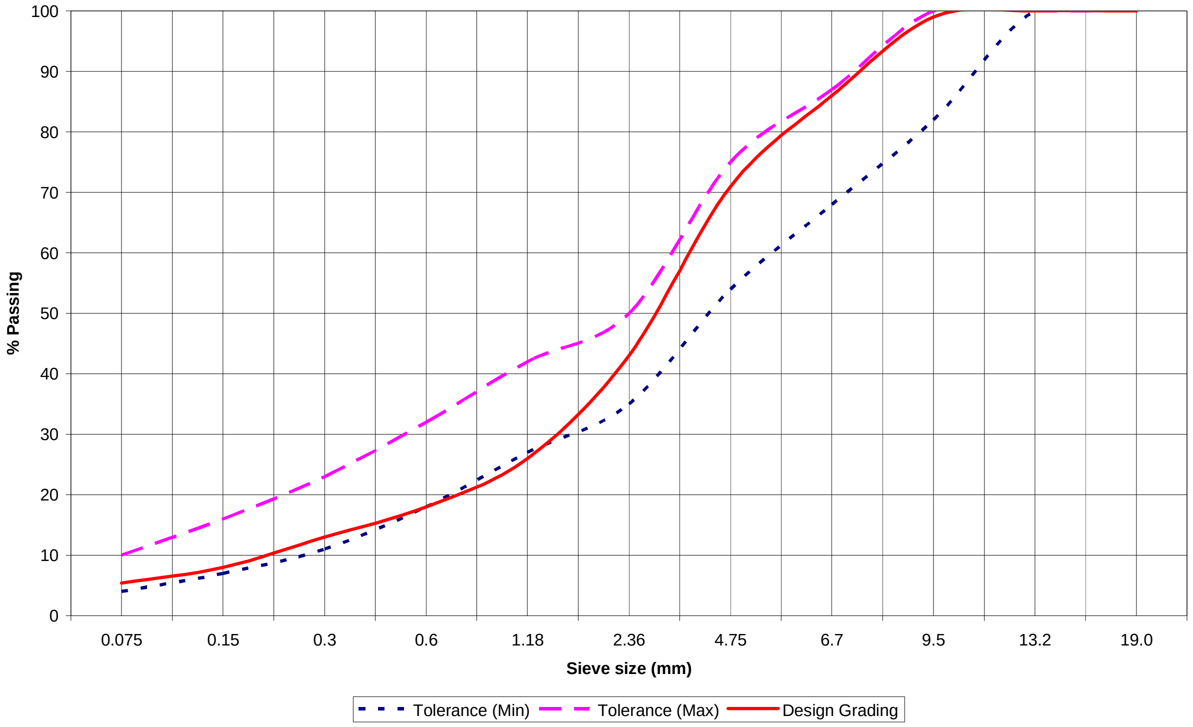

Figure 1: Grading Analysis of asphalt aggregate.

Sample Preparation

A standard mix design was used for the preparation of the samples. The samples were compacted using different methods in the laboratory. The objective was to identify a compaction method that closely resembles field compaction. All samples discussed in this paper were compacted to design voids (4 per cent). The following compaction methods were used in preparation of the samples:

- Gyratory compaction;
- Marshall compaction;
- Slab compaction, and
- Field compaction (smooth drum roller).

4 Data Analysis

Transportek Wheel Tracking Test (TWTT)

Short-term aged (SA) and laboratory design mix samples were evaluated using the TWTT. The SA samples were considered as they are perceived to better simulate the properties of the mix after manufacturing and placement of the HMA. These samples were kept in an oven for 4 hours at 135℃ before they were compacted as specified by the Superpave methodology (Bell *et al,* 1994). Standard laboratory design mix samples are referred herein as samples mixed and compacted in the laboratory using a slab compactor. Field samples are samples mixed in the plant and compacted in the field during construction of HMA surface layer using a smooth drum roller.

Table 3 and Figure 2 show that the rutting observed on laboratory compacted short-term aged samples (SA) is approximately double the value achieved on the field sample (both after 4 000 repetitions), while the rutting observed on the standard laboratory design mix samples is almost four times the value observed for the field sample after the same repetitions. The test results of the SA sample appear to simulate the field results better. Both the field prepared samples and short-term aged sample are classified as good in this case (Taute *et al*, 2001), while the standard laboratory design samples are classified as poor.

The data indicate that laboratory prepared samples should at least be aged to resemble the type of rut performance obtained from field samples using the TWTT.

Table 3: TWTT results for laboratory compacted HMA versus field compacted HMA.

Sample	**Thickness [mm]**	**Load [kPa]**	**Temperature [℃]**	**Repetitions**	**Rut depth [mm]**	
					Field compacted sample	**Laboratory compacted sample**
Laboratory compacted sample	40	600	60℃	4 000		18.24
	40	600	60℃	4 000		13.84
Laboratory compacted short-term aged (SA) sample	40	600	60℃	4 000		9.93
Field compacted samples	40	600	60℃	4 000	4.99	
	40	600	60℃	4 000	4.01	

<u>Hamburg Wheel Track Test (HWTT)</u>

The samples were tested at 60℃ and at a constant load of 705 N, as prescribed by the standard test protocol for HWTT (AASHTO: T 324-04). The Gyratory Superpave compactor was used to prepare 60 mm thick standard laboratory design mix and short-term aged (SA) samples, while a smooth drum roller was used for field compaction.

Figure 3 shows a big difference between the test results of the gyratory prepared samples for standard laboratory design mix and the field prepared samples, while the short-term aged (SA) sample shows similar rut rates to the field compacted samples. Early failure was evident after 2 000 wheel passes for the short-term aged (SA) samples. This necessitated the inclusion of long-term aged samples to determine whether they would provide a better match to the field sample performance than the short-term aged samples. The long-term aged samples (LA) were kept in an oven for 4 hours at 135℃ and then kept in the oven for five days at 85℃ (Bell *et al,* 1994). This is perceived to simulate the field performance after more than 1 year. However, the rut rate obtained for the long-term aged samples (LA) were much less than that obtained for the field and short-term aged samples, indicating the impact of binder viscosity on permanent deformation. Long-term ageing is deemed too severe ageing for the purposes of this experiment.

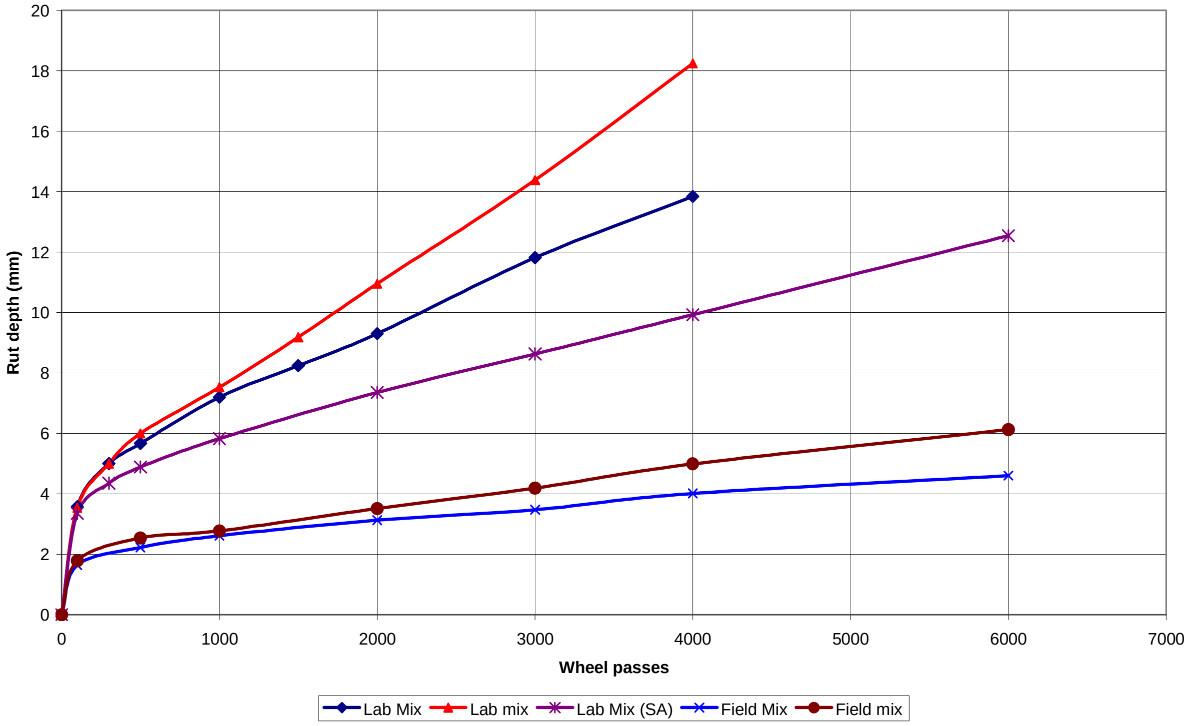

Figure 2: **TWTT test results for field compacted and laboratory compacted HMA samples.**

The laboratory (design, short- and long-term aged) and field compacted samples were classified as poor, indicating that the asphalt mix design rate poor in this case (Aschenbrener, 1995). The good relationship obtained between rut rates for the short-term aged (SA) sample and the field compacted sample (up to 2 000 repetitions) (Figure 3) is promising, and should be further investigated as a potential indicator for rut performance.

HWTT vs TWTT

Figure 4 shows a summary of the average rut development of the HWTT and TWTT tests for similar environmental conditions. The rut values differed after 500 wheel passes with the HWTT showing a higher rut rate than the TWTT. The different stresses applied on the two samples may be the primary reason for the difference in rut development between the two samples. The TWTT uses a solid rubber wheel (400 mm diameter, 100 mm wide) while the HWTT uses a steel wheel (196 mm diameter, 47 mm wide) for loading. In the HWTT the sample is also submerged during loading and this further contributes to the difference in rut development of the two samples.

Dynamic Creep

Samples were tested at 40℃, and varied in thickness (Table 4). The different samples thicknesses complicated the comparison of the data. The Dynamic Creep data did not show good relationships between any of the laboratory compacted samples and the field compacted samples, and relatively wide scatter was also evident in some of the results (Table 4 and Figure 5). Although cases were found where better comparisons were visible (i.e. Gyratory and Marshall compaction – 1 test each) the repeat tests for these samples showed very different moduli (Figure 5). Based on the data summarised in Table 4 and shown in Figure 5 it is concluded that the Dynamic Creep test does not provide a good indicator of potential field rut performance as the scatter in data obtained is too wide.

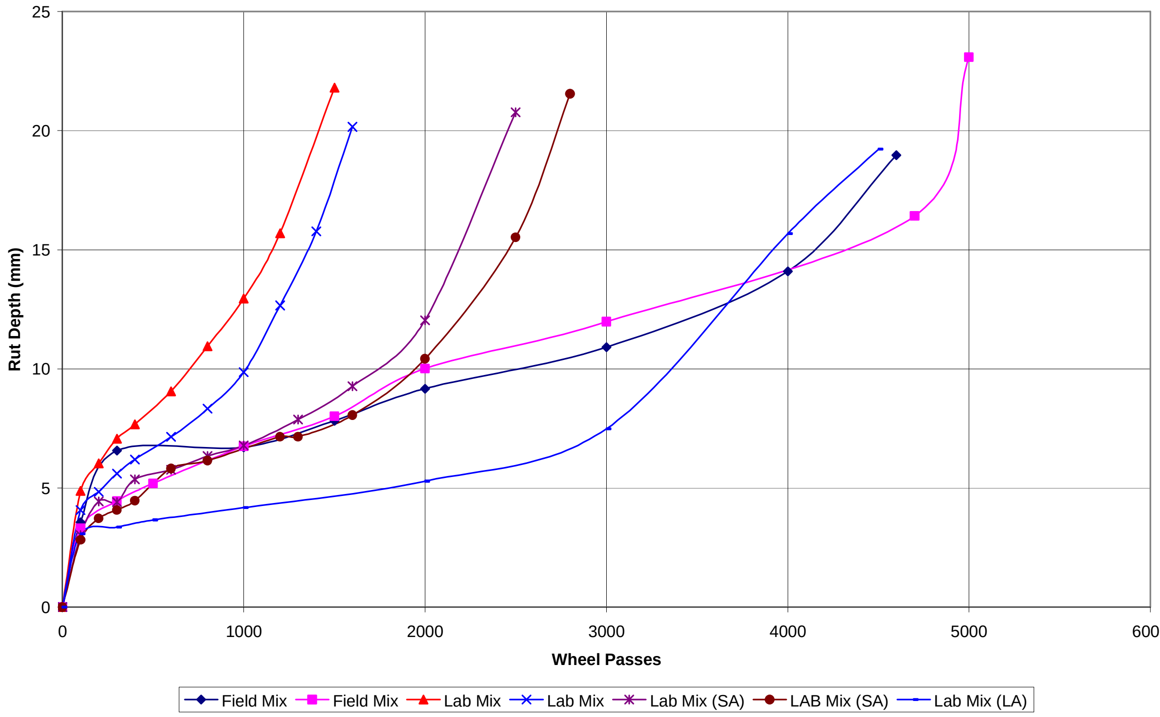

Figure 3: **HWTT test results for field and laboratory compacted samples.**

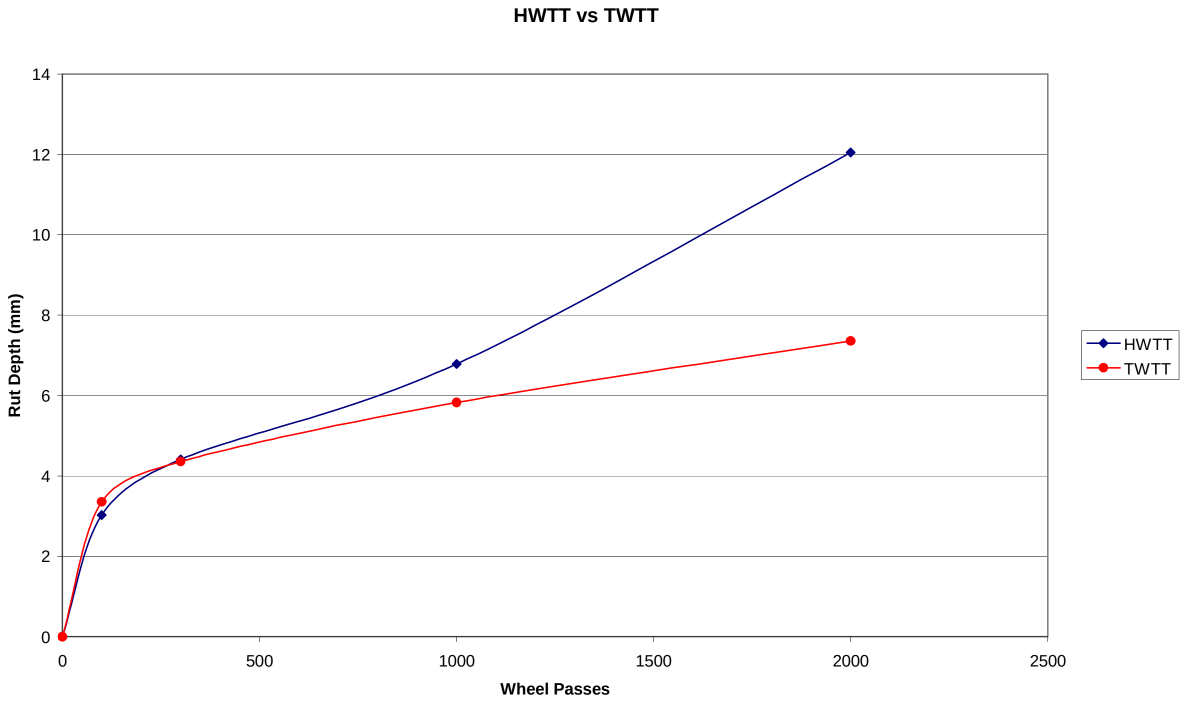

Figure 4: **HWTT vs TWTT rut development.**

Table 4: Dynamic Creep results for different compaction methods.

Condition	Thickness [mm]	Temperature [ºC]	Dynamic Creep Modulus E [MPa]		
			Average	SD	CoV [%]
Gyratory Lab design voids (LDV)	100	40	26.50	6.5	24.5
Gyratory Plant design voids (PDV)			30.51	1.4	4.6
Gyratory Plan field voids (PFV)			15.53	2.5	15.8
Gyratory short aged (SA)			48.05	3.7	7.8
Gyratory High binder content (HB)			5.35	0.5	9.3
Marshall lab design voids(LDV)	63		18.00	2.7	14.9
Marshall Plant design voids (PDV)			16.42	6.2	37.6
Marshall Plant field voids (PFV)			10.85	0.0	0.2
Marshall short aged (SA)			40.85	12.0	29.3
Marshall Long aged (LA)			19.80	5.7	28.6
Marshall high binder content (HB)			43.95	4.5	10.1
Slab Lab design voids (LDV)	57		4.60	0.3	6.1
Slab Plant design voids (PDV)			5.32	0.6	11.2
Slab Short aged (SA)			7.95	2.9	36.5
Slab High binder content (HB)			2.15	0.5	23.0
Field core	64		30	0.3	1.0

Indirect Tensile Strength (ITS)

The ITS is used to determine the tensile strength of HMA materials, and in practice the ITT and ITS tests are usually conducted on the same samples. The samples evaluated again differed in thickness due to the different compaction methods used.

The data (Table 5 and Figure 6) showed less scatter than the Dynamic creep results. Most of the data from the laboratory compacted samples are scattered around the field compacted samples. One point of concern is the fact that the Gyratory short-term aged samples showed a decrease in tensile strength (against the non-aged sample) while the Marshall compacted and slab compacted samples both showed increases in tensile strength (against the non-aged sample). Further evaluation of these results is required. The overall relationships between the laboratory and field compacted sample tensile strengths is promising, and further evaluation of the ITS on laboratory compacted samples for predicting field compacted sample performance should be evaluated. The best match between tensile strength from the field compacted sample and the laboratory compacted samples was found for the Gyratory compacted design sample.

Indirect Tensile Test (ITT)

The ITT results showed slightly higher scatter than the ITS results (Table 6 and Figure 7). The majority of the laboratory compacted samples had resilient moduli lower than the field compacted samples with only the slab compacted samples showing consistently higher resilient moduli than the field compacted samples. There is not a major difference between the results for the design and the short-term aged samples for any of the samples. The Gyratory and slab compacted samples showed less scatter for the short-term aged samples while the Marshall compacted samples showed more scatter for the short-term aged samples.

No conclusive recommendation regarding a preferred laboratory compaction method can be made based on these sets of ITT data, as none of the methods really stands out as being much more effective than any of the others.

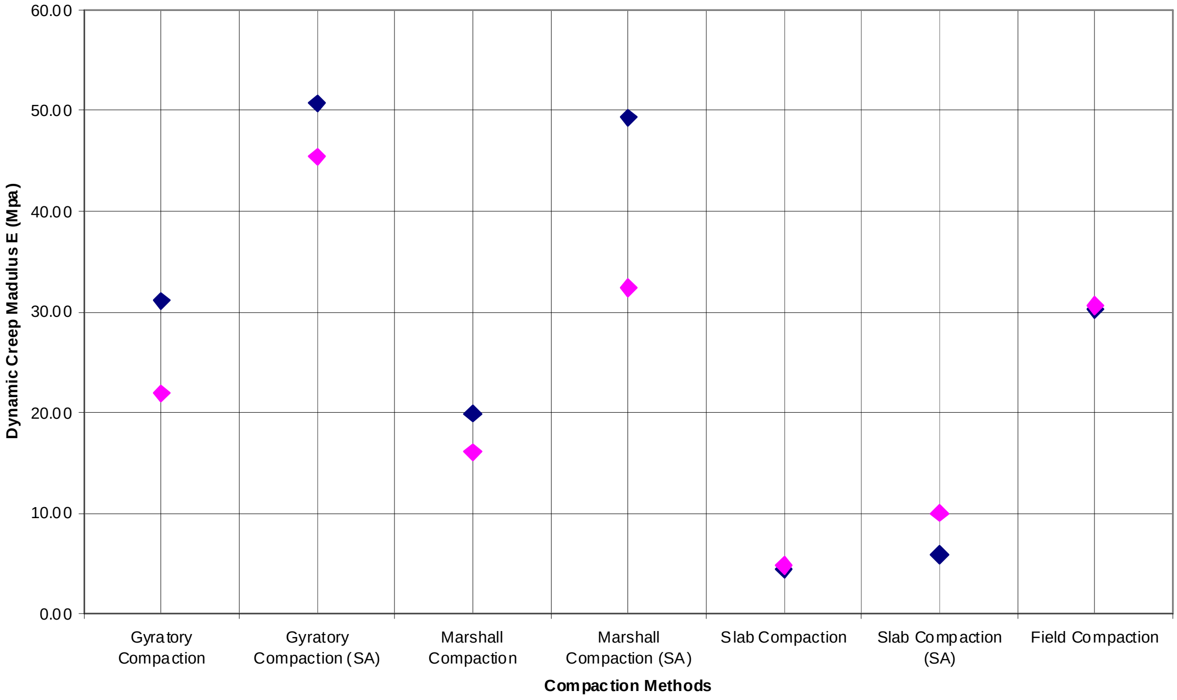

Figure 5: Dynamic Creep results using different compaction methods.

Table 5: ITS results for different compaction methods.

Condition	Thickness [mm]	Temperature [ºC]	Tensile strength [kPa]		
			Average	SD	CoV [%]
Gyratory(design voids)	100	25	1 262	20.8	1.7
Gyratory (short-term aged) (SA)			911	14.3	1.6
Marshall (design voids)	62		1 067	86.8	8.1
Marshall (short-term aged) (SA)			1 429	89.4	6.3
Slab (design voids)	57		909	46.4	5.1
Slab (short-term aged) (SA)			1 309	89.0	6.8
Field core	64		1 189	35.4	3.0

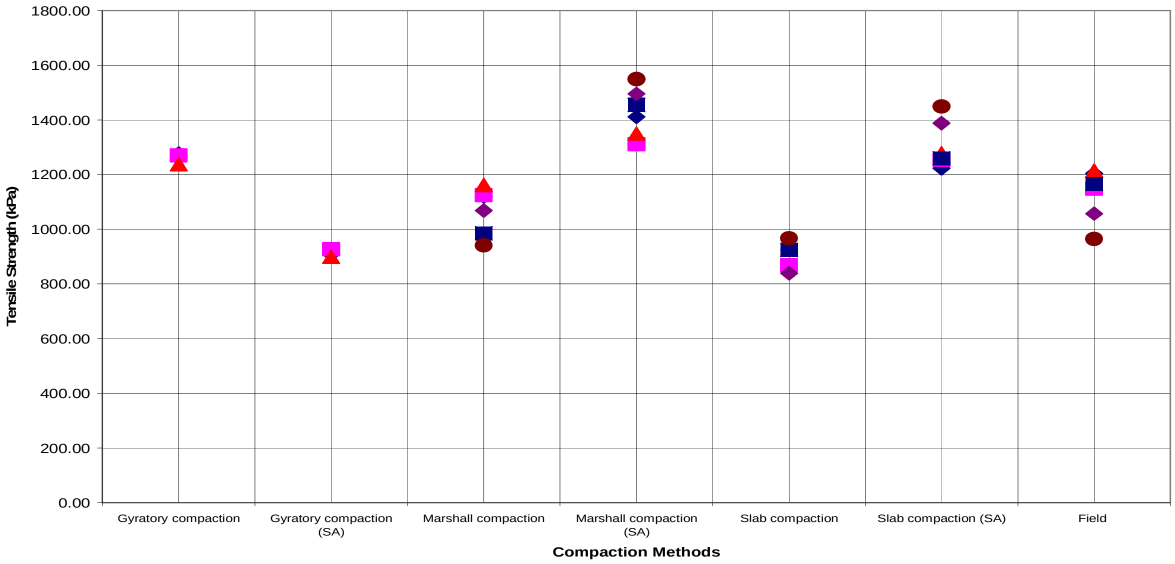

Figure 6: ITS results for samples with different compaction methods.

Table 6: ITT results for different compaction methods.

Condition	Thickness [mm]	Temperature [ºC]	Resilient Modulus [MPa]		
			Average	SD	CoV [%]
Gyratory(design voids)	100	25	3 125	462.6	14.8
Gyratory (short-term aged) (SA)			3 560	176.0	4.9
Marshall (design voids)	62		3 605	203.7	5.7
Marshall (short-term aged) (SA)			3 265	477.3	14.6
Slab (design voids)	57		4 886	1064.7	21.8
Slab (short-term aged) (SA)			4 370	324.3	7.4
Field core	64		3 839	247.9	6.5

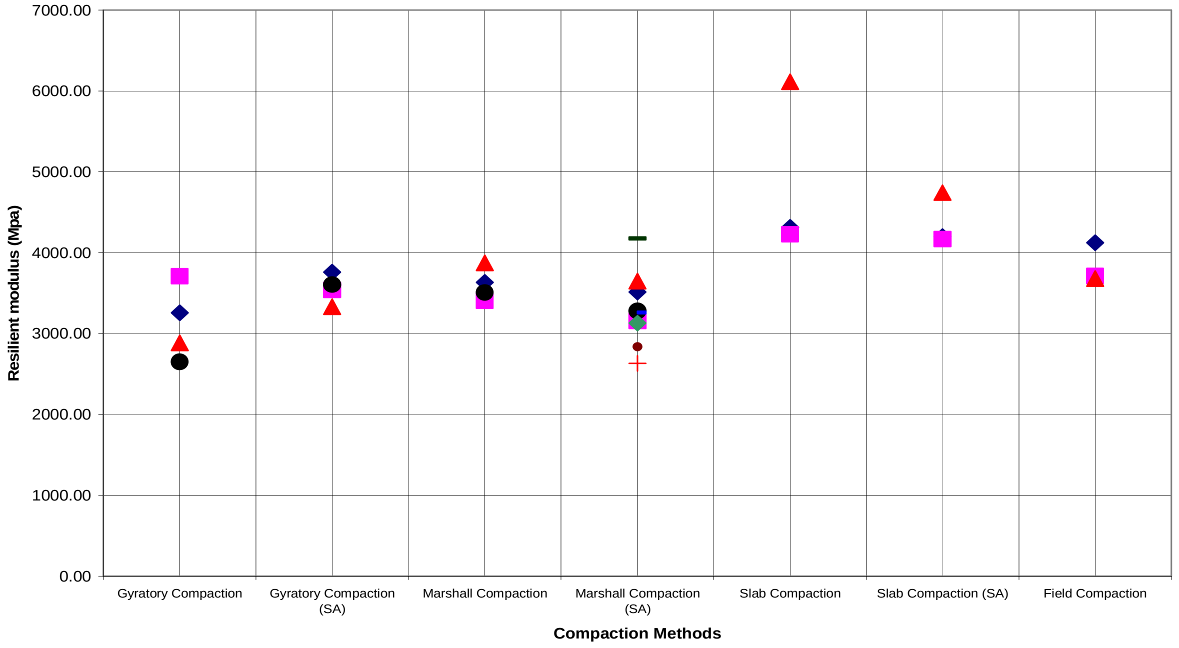

Figure 7: ITT results for samples with different compaction methods.

5 CONCLUSIONS

Based on the information discussed in this paper, the following conclusions are drawn:

- The laboratory (short-term aged) prepared samples classified as medium rut performance using the TWTT, while the laboratory prepared samples (un-aged) are classified as poor;
- Laboratory (design, short- and long-term aged) and field prepared samples classified as poor rut performance using the HWTT;
- A good relationship was obtained between HWTT rut rates for the short-term aged (gyratory compacted) and field compacted samples;
- The Dynamic Creep test does not provide a good indicator for permanent deformation;

- The overall relationship between the tensile strengths (ITS test) of laboratory- and field-compacted samples is promising;
- The closest resemblance between tensile strength from the field-compacted and laboratory-compacted samples was found for the Gyratory compacted design sample;
- The Dynamic creep data showed high scatter, while the ITS and ITT data showed less scatter;
- No conclusive recommendation regarding a preferred laboratory compaction method can be made for the ITT data as none of the methods really stands out as being much more effective than any of the others, and
- The Gyratory compaction method appears to most often provide samples that relate relatively close in performance to the field compacted samples (although the effect of ageing is not always clear and requires further analysis).

6 RECOMMENDATIONS

Based on the information discussed in this paper, the following recommendations are made:

- Laboratory prepared samples for the TWTT should at least be short-term aged to have resemblance to the type of rut performance obtained from field samples;
- Relationships between actual field rut performance and the laboratory test performance for those tests that shows promise should be evaluated as a next step;
- The Dynamic Creep test should not be further evaluated as a potential indicator of field rut performance;
- Further evaluation of the ITS as a reliable performance indicator should be conducted, although the relationships between ITS and permanent deformation is not as yet clear, and
- Further analysis of the data (including volumetric property effects) should be focused on the most promising test (HWTT and TWTT) to obtain clarity regarding proposed laboratory compaction methods and tests to predict field rut performance.

7 ACKNOWLEDGEMENTS

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