A COMPARISON BETWEEN THE PERMANENT DEFORMATION BEHAVIOUR OF A STANDARD AND A RUT RESISTANT HMA MIX

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ABSTRACT

Efficient road transport is dependent upon construction of high quality roads. It is important that Hot-Mix Asphalt (HMA) surfaced roads resist permanent deformation (or rutting) in order to provide a high level of service to the road user. In order to improve the resistance of HMA layers against permanent deformation, the Gauteng Department of Public Transport, Roads and Works (GDPTRW) has commissioned a multi-phase study into the behaviour of different types of HMA under typical traffic and environmental loading conditions. The study includes laboratory and field evaluation of a standard HMA mix, as well as different HMA mixes that were designed to be rut resistant.

In this paper the focus is on the comparison between the permanent deformation behaviour of the standard HMA mix and one rut resistant HMA mix of which the grading differs from that of the standard HMA mix. The permanent deformation has been monitored under traffic loading with the Heavy Vehicle Simulator (HVS), and the temperature under which the loading was applied was varied. Other parameters such as the binder type (of the HMA) and load levels (of the HVS) were kept constant to focus the attention on the effect of the change in grading of the HMA mix.

The data presented in this paper indicate that the grading of the HMA mix can play a major role in the resistance to permanent deformation of the mix, even under severe temperature conditions. The potential rut resistant benefit of coarser grading for HMA mixes have been supported through HVS tests. Further tests are required (both in the laboratory and field) to evaluate the durability and fatigue properties of the coarser HMA mix against the standard reference mix.

This paper forms part of studies towards a Masters degree in Technology at Tshwane University of Technology (TUT) of the third author. The outcome of the overall research will contribute to road owners and design engineers' better understanding the deformation mechanism and being able to plan, design and construct HMA pavements that are resistant to it. These results will also be incorporated into updated Guidelines for the Design of Hot-Mix Asphalt in South Africa.

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1. INTRODUCTION

Permanent deformation is a type of distress associated with Hot-Mix Asphalt (HMA). It is influenced, among others, by factors that include vehicle loading, climatic conditions and mix design. Permanent deformation typically occurs in two stages, the first being consolidation, which is densification associated with volume change and the second being shear deformation, which is plastic flow and is not related to volume change. Permanent deformation leads to the formation of ruts in the wheel tracks in which water may collect, creating dangerous riding conditions for the motorists. The Interim Guidelines for the Design of Hot-Mix Asphalt in South Africa (ASAC, 2001) made an effort to address some of the aspects that contribute to the cause of the permanent deformation of HMA. During the 8th Conference on Asphalt Pavements for Southern Africa (CAPSA), concern was raised that although these interim guidelines is a helpful tool, the design of HMA that will resist permanent deformation is not addressed satisfactorily, specifically when evaluating roads with high traffic volumes and intersections. This is evident based on the development of premature permanent deformation on many of these roads and specifically interchanges (Figure 1). Based on this the Gauteng Department of Public Transport, Roads and Works (GDPTRW) has embarked on a multi-year study to investigate and improve the HMA design guideline, based on improved information regarding the permanent deformation and durability behaviour of HMA. As part of the process, several studies are conducted. This includes a forensic study, laboratory evaluation and Accelerated Pavement Testing (APT) aspect (Steyn & Verhaeghe, 2006). The information discussed in this paper covers only one aspect of this broader study.

Figure 1 Typical permanent deformation development at an intersection

The forensic investigation indicated a need for mixes that depend less on the binder and more on coarse aggregate interlock for permanent resistance, especially in high demand situations such as intersections and steep inclines (Denneman and Sadzik, 2008).

The focus of his paper is to evaluate the permanent deformation response of two HMA mixes (a standard (STD) HMA mix and a rut resistant (RR) HMA mix) under similar loading conditions and determine whether or not the change in grading of the rut resistant mix provided an improvement in the rut resistant properties of the standard HMA.

In order to obtain a realistic indication of the expected behaviour of the two HMA mixes, the Heavy Vehicle Simulator (HVS) was used to subject the two HMA sections to a series of loads at different surface temperatures. The objective of this was to determine whether the rut resistant HMA (which only had a different grading to that of the standard HMA) would provide superior response to the standard HMA when subjected to similar loading conditions.

The HVS tests discussed in this paper were all performed using a standard dual set of truck tyres with a load of 40 kN and tyre inflation pressure of 620 kPa on HMA sections of 40 mm thick. The three tests were conducted using a channelised, uni-directional loading pattern. The HMA was approximately one month old when each of the tests started, and thus ageing of the mix was eliminated as a factor in the comparison of the data for this paper.

2. DESRIPTION OF HMA MATERIAL, TEST SITE, AND APT EQUIPMENT

The grading of the standard (STD) HMA and the rut resistant mix (RR) can be compared visually in Figure 2. The percentage aggregate passing is plotted against the sieve size raised to the power 0.45. The grading of a planned and even coarser mix (RRP) which will be tested in the next phase of the project is also shown. The standard mix has 9.5 mm Nominal Maximum Particle Size (NMPS) while both rut resistant mixes have 13.2 mm NMPS. A 60/70 Pen grade bitumen (satisfying the SUPERPAVE Performance Grade (PG) 64 binder requirements) was used for both the STD and RR mixes. The material properties for the STD and RR HMA mixes are shown in Table 1.

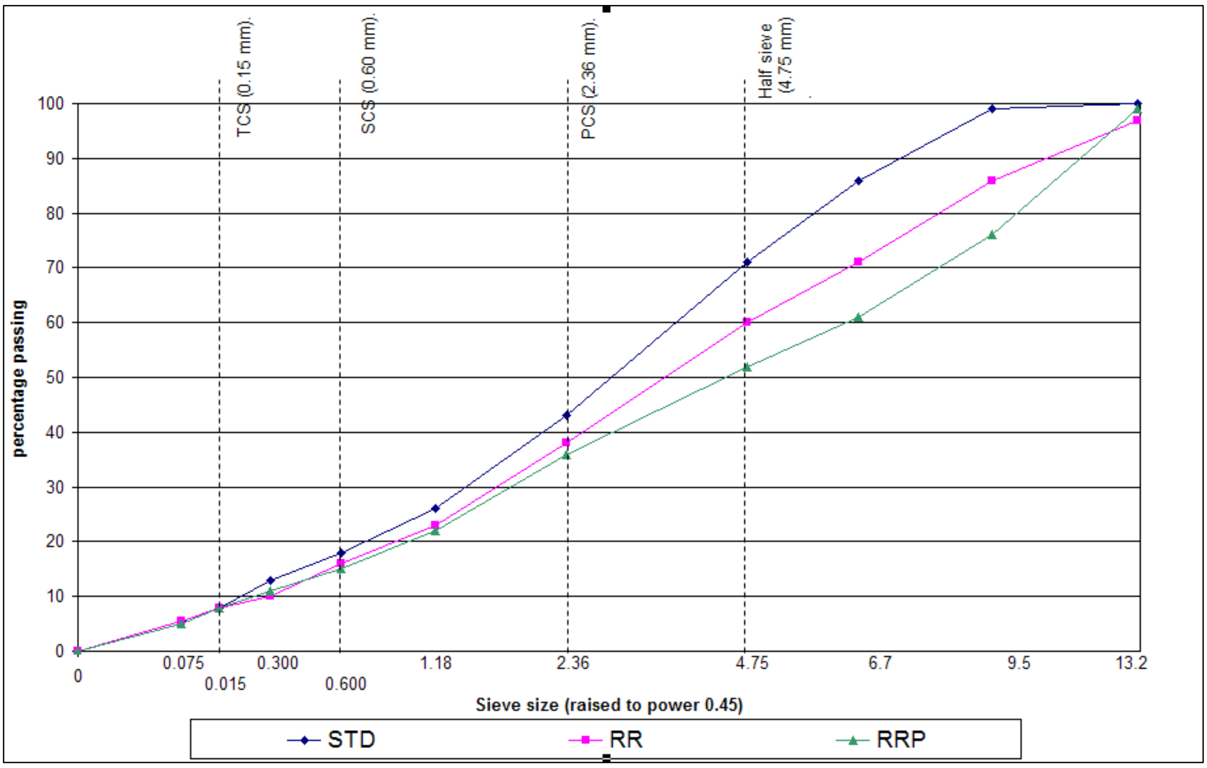

Figure 2 Grading of the standard HMA (STD) and two rut resistant HMA (RR and RRP) designs

Table 1 Properties of STD and RR HMA mixes

Mix	STD mix	RR mix
Binder content [%]	5.0	4.5
Air voids in mix (design) [%]	4.3	4.8
Air voids in mix (constructed) [%]	6.4	7.2
Voids in mineral aggregate [%]	15	15
Voids filled with binder [%]	72	68
Marshall stability [kN]	10.7	10.2
Flow [mm]	3.0	3.7
Indirect tensile strength [kPa]	1187	949
Filler bitumen ratio	1.1	1.23
Film thickness [µm]	8.2	7.8
Binder absorption [%]	0.5	0.5
Gyratory refusal voids (N=300) [%]	2.4	2.1

The intention of the study is to compare the permanent deformation performance of the fine graded STD mix with HMA mixes that possess a coarse aggregate skeleton. Figure 2 provides an indication that the RR and RRP mixes are coarser than the STD mix, as they contain more coarse particles, but that in itself does not guarantee that a coarse aggregate skeleton exists in these mixes. As part of the HMA project aggregate grading analysis methods are used to assess the characteristics of the mixes. Denneman et al (2007) used the Bailey method and a related concept of aggregate porosity to identify characteristics of poor and good performing mixes. These methods were applied in this paper to assess whether a coarse aggregate skeleton exists in the mixes. The results of aggregate grading analysis for the rut challenge mixes are shown in Table 2.

Table 2 Aggregate packing analysis

Mix	Bailey Coarse Aggregate Chosen Unit Weight (CA CUW)	Dominant Aggregate Size Range (DASR) porosity
STD	74 % (fine)	52 % (fine)
RR	99 % (coarse)	48.3 % (coarse)
RRP	105 % (coarse)	46.9 % (coarse)

- The standard mix (STD) has a Bailey method Coarse Aggregate Chosen Unit Weight (CA CUW) of 74 per cent of the coarse aggregate loose unit weight condition. The porosity of the Dominant Aggregate Size Range (DASR) is 52 per cent. Both parameters indicate that this is a fine graded mix;
- The RR mix (which is compared under the HVS to the standard mix in this paper) has a CA CUW of 99 per cent and the porosity of the DASR is 48.3 per cent indicating that the mix has a coarse aggregate skeleton, and
- The RRP mix (which has yet to be constructed) has a CA CUW of 105 per cent, which is the upper limit of what is recommended for coarse graded mixes. The DASR also indicates that this mix is significantly coarser than the East Rand mix. The mix has a high volume of particles of the largest aggregate size portion.

Based on this evaluation of the grading of the STD and RR HMA mixes, it is expected that the RR mix should be more rut resistant based on the coarser grading and potentially improved packing of the aggregate in the HMA.

The site on which the HVS tests were conducted was located on road P159/1 west of Pretoria (Figure 3). Construction of the standard HMA mix took place during October 2006 while the rut resistant mix was constructed during April 2008. The existing pavement structure was cleaned and primed, after which the HMA layer was paved. The HMA sections discussed in this paper were all 40 mm thick. The original pavement structure was constructed more than 20 years ago, as part of the original planning for the extension of the N4 west. Detailed as-built plans for the road structure could not be found, and thus a test pit was opened to sample material from all the layers in the pavement structure and test this material at a soils laboratory. The pavement consists of 4 layers (Steyn and Fisher, 2008). The base consisted of a 150 mm G4 layer, the subbase of a 100 mm G8 layer, the upper selected layer of a 150 mm G9 and the lower selected layer of a 200 mm G9. The in situ material appears to be a G9 material (Figure 4). Analysis of the base layer material indicates that it may well have been a G1 layer, as the grading fits the grading envelope of a G1 and the other material parameters are also all within the G1 requirement. It is a concern that the classification for the layers indicate these low quality materials, as the structural strength of the pavement appears to be relatively high with an average elastic surface deflection (FWD-measured) of between 134 and 149 micron.

Figure 3 Location of HVS site on Road P159/1

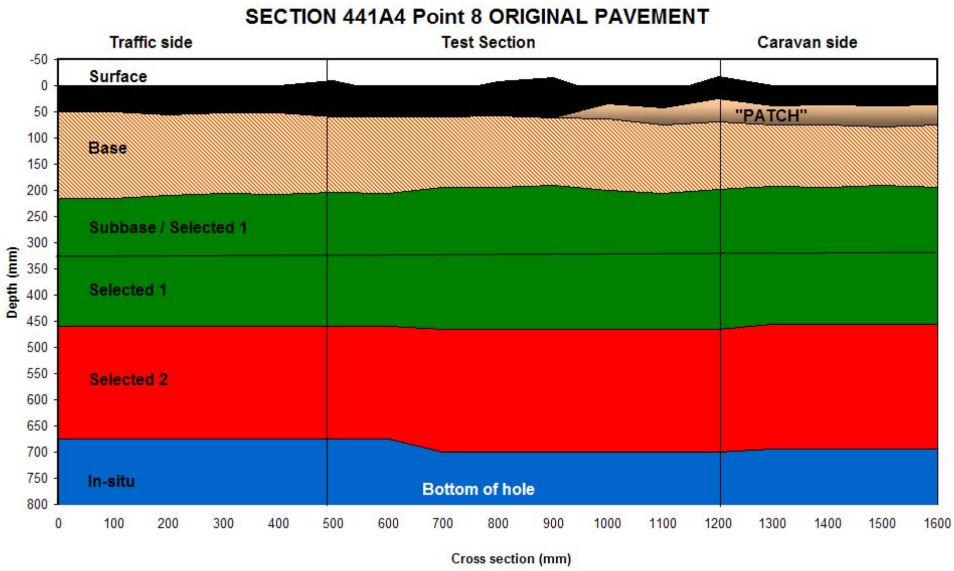

Figure 4 Pavement structure for HVS sections on Road P159/1

The Heavy Vehicle Simulator (HVS) is an Accelerated Pavement Testing (APT) device that has been used extensively nationally and internationally for the controlled evaluation of pavement behaviour under real loads (Du Plessis et al, 2006). The HVS is typically used to apply a controlled wheel load to a test section while the behaviour of the pavement is monitored using instruments such as a laser profilometer (surface profile) and Road Surface Deflectometer (RSD) (elastic surface deflection). The conditions under which the loads are applied are well controlled, and through the use of an environmental chamber the temperature of the pavement can be controlled (Steyn and Denneman, 2008).

3. TEST METHODOLOGY AND DATA

There are three HVS tests of which the data are used in this paper. The nominal test methodology for each of the three tests is shown in Table 3.

Table 3 Nominal HVS test methodology for three HVS tests discussed in this paper

<table>
<tr><th>Test number</th><th>Test load [kN]</th><th>Tyre Inflation Pressure [kPa]</th><th>Channelised / Wandering</th><th>Uni- / Bi-directional</th><th>Surface temperature [°C]</th></tr>
<tr><td>STD1</td><td rowspan="3">40</td><td rowspan="3">620</td><td rowspan="3">Channelised</td><td rowspan="3">Uni</td><td rowspan="2">60</td></tr>
<tr><td>RR1</td></tr>
<tr><td>RR2</td><td>70</td></tr>
</table>

The data obtained from the three HVS sites include permanent surface deformation, pavement temperatures, elastic surface deflection and visual condition. In this paper the focus is on the permanent surface deformation data and the pavement temperature data. In Figure 5 the permanent surface deformation for tests STD1, RR1 and RR2 are shown. The data indicates the measured permanent surface deformation of the two 40 mm thick HMA layers, loaded with similar loads using a dual set of truck tyres at surface temperatures of 60°C and 70°C. In Table 4 the rut rates for the constant portions of rut development for each of the HVS tests are shown, together with the measured surface temperature data for each of the tests. The data for the two tyres (designated caravan side and traffic side – Figure 6) of the channelised tests are shown separately, as the temperatures for HVS test STD1 differed and different responses were observed.

Table 4 Rut rates for steady-state rut development and temperature data for three HVS tests

Test number	Rut rate [mm/million repetitions]		Surface temperature [°C]					
			Average		Standard deviation		Coefficient of Variation [%]	
	CS*	TS*	CS*	TS*	CS*	TS*	CS*	TS*
STD1	163	92	60.9	58.5	1.6	4.1	3.0	0.1
RR1	14	14	59.9	62.9	3.5	3.9	5.8	6.2
RR2	17	15	71.2	70.4	6.6	6.9	9.3	9.8

*CS – Caravan side; TS – Traffic side

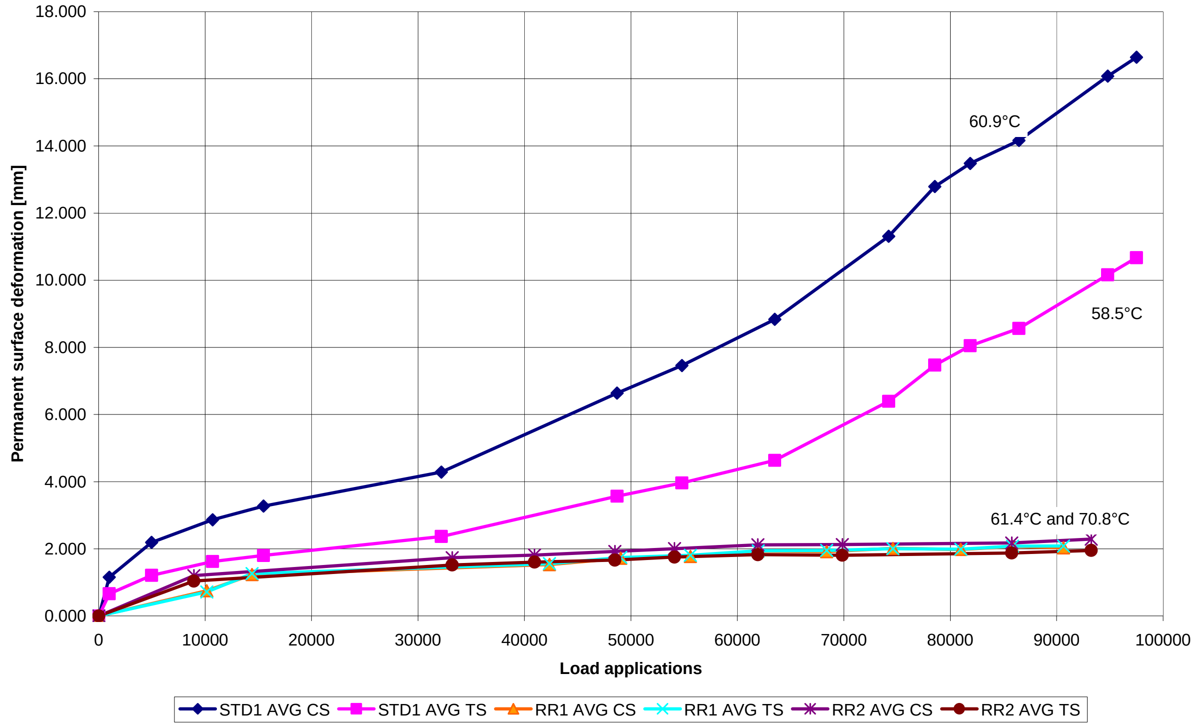

Figure 5 Permanent surface deformation for HVS tests STD1, RR1 and RR2

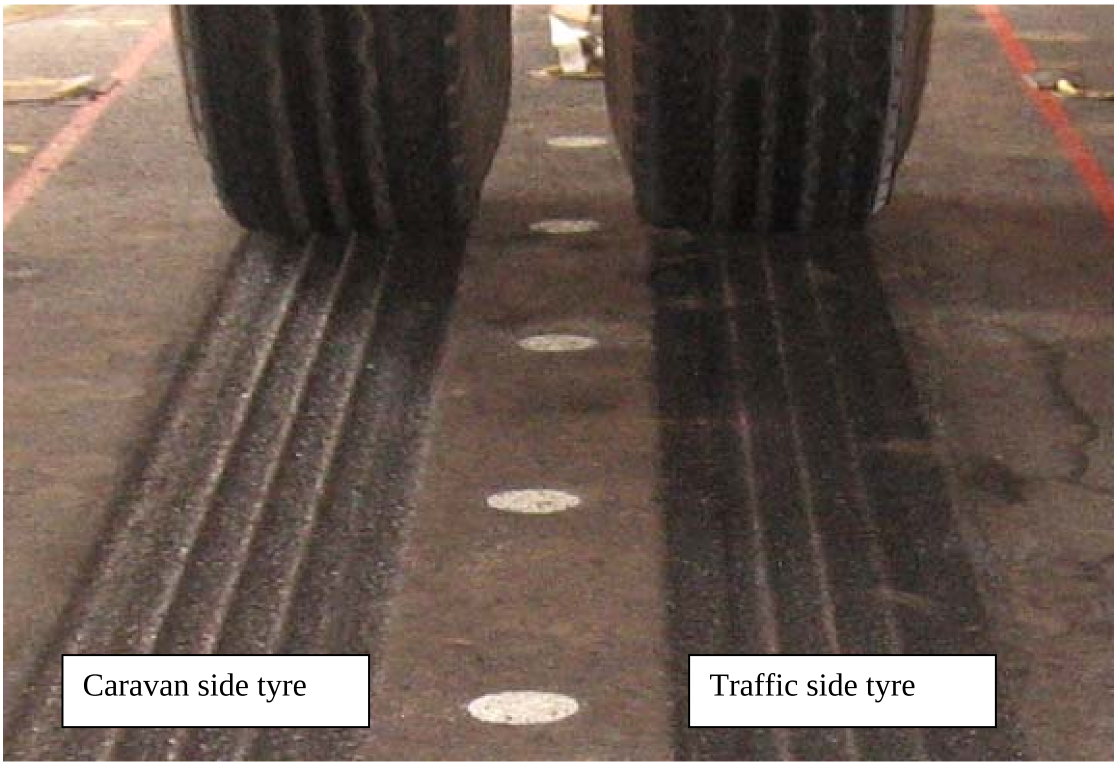

Figure 6 HVS tyres indicating caravan and traffic side wheel tracks formed during channelised test

4. DATA ANALYSIS

Analysis of the data in Figure 5 and Table 4 indicates that the standard HMA mix (STD1) is significantly more sensitive to the loading at a surface temperature of 60°C than the rut resistant HMA mix (RR1) at the same surface temperature. The initial HVS tests and laboratory tests on the standard HMA mix indicated that the mix is very sensitive to increases of the surface temperature above the softening point of the binder (50°C) (Denneman, 2008; Steyn and Fisher, 2008). This is also visible when evaluating the Hamburg Wheel Track tests (HWTT) conducted as part of the laboratory evaluation of the STD HMA mix (Figure 7). The clear increase in permanent deformation observed with increased temperature is related to the STD HMA mix being dependent on the binder stiffness for providing resistance to permanent deformation.

In order to evaluate whether this sensitivity still exists with the RR HMA mix (which used the same binder as the STD HMA mix), a second HVS test was conducted on the RR HMA mix at a nominal surface temperature of 70°C (RR2). The response of the HMA under these conditions is similar to that obtained under the 60°C surface temperature (Figure 5 and Table 4). This insensitivity of the RR HMA mix towards changes in surface temperature is indicative of the permanent deformation behaviour of the RR HMA mix being governed by the aggregate packing rather than the binder conditions.

This further supports the recommendation from the forensic investigation that was conducted during the initial phases of the HMA project (Denneman et al, 2007) that, because of the high pavement temperatures in South Africa, the use of mixes with a coarse aggregate skeleton that rely less on the binder for rutting resistance should be encouraged. This is especially relevant in situations with slow moving heavy traffic, such as inclines and intersections.

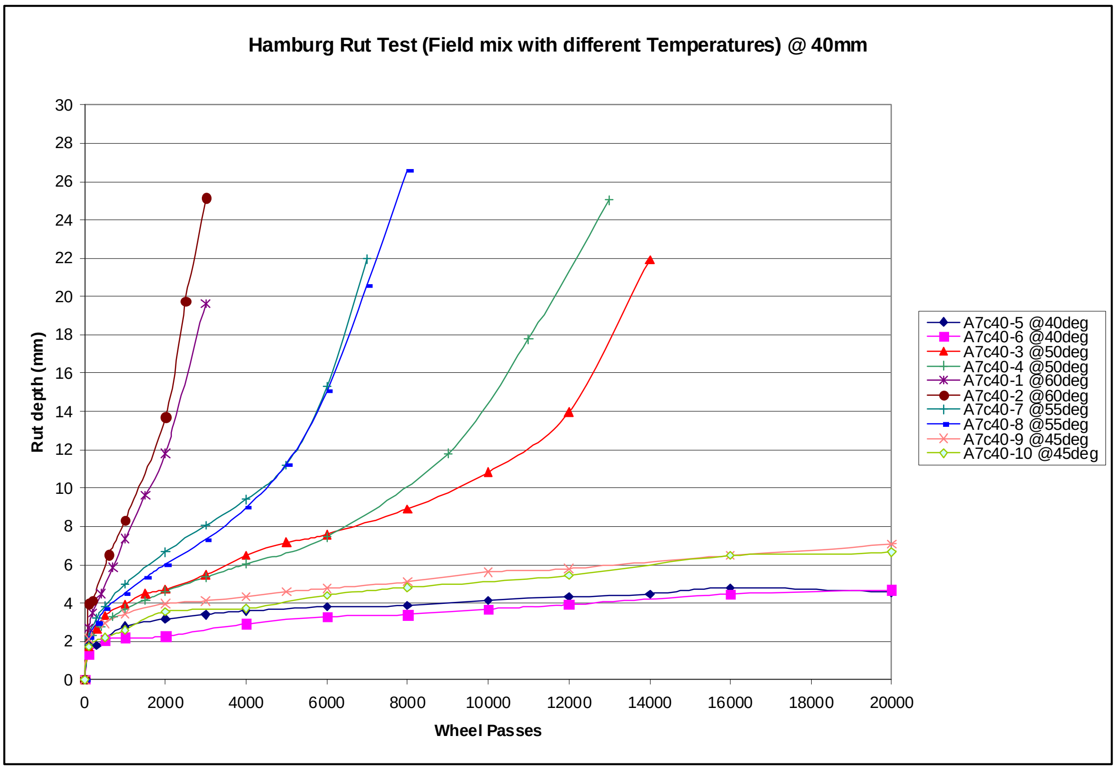

Figure 7 Hamburg Wheel Track Test developed permanent deformation for STD HMA mix at different temperatures

5. CONCLUSIONS AND RECOMMENDATIONS

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

- The RR mix was designed to have a coarse aggregate skeleton in the hope that this would provide it with superior rutting performance compared to the fine graded STD mix,
- HVS testing confirms that the RR mix has a higher resistance against rutting than the STD mix, even under elevated temperatures, and
- The potential benefit of using coarser HMA mixes in order to benefit from the improved packing and interlock of the aggregate during traffic loading mixes is supported by the HMA rut data presented in the present paper.

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

- The use of coarser HMA mixes for improvement of rut resistance properties of HMA (especially on inclines, intersections and areas with high truck traffic) should be promoted;

- The durability and fatigue properties of the coarser HMA mixes should be investigated, and
- The RRP HMA mix should be constructed to obtain a practical upper limit for the benefit obtained from coarse graded HMA mixes.

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