Characterisation of Some Candidate Surfacing Materials for Orthotropic Steel Bridge Decks

T. Medani, M.Huurman & A.A.A.Molenaar
Department of Road and Railway Engineering, Faculty of Civil Engineering and Geo- Sciences, Delft University of Technology, the Netherlands

ABSTRACT: To study the distress phenomena of orthotropic steel deck bridges, and in particular the rather short lifespans of surfacing materials, a research project has started at the Technical University of Delft. The main goal of the research is to suggest new design techniques for the structure. To achieve this goal, it is important to characterise some candidate surfacing materials for orthotropic steel deck bridges. In this paper, results of an extensive experimental program on three surfacing materials will be presented. The mixes which were tested in this program are: SBS modified mastic asphalt, guss asphalt and open synthetic wearing course. The tests carried out included: fatigue tests, frequency sweep tests, uniaxial monotonic compression and tension tests and static indirect tensile tests. Several properties/phenomena have been quantified and modeled e.g. dependency of mix stiffness on strain levels, dependency of compressive/tensile strength on temperature and strain rate.

KEY WORDS: Orthotropic bridges, mastic asphalt, monotonic tension and compression tests, strain dependency

1 INTRODUCTION

Modern steel bridge decks consist of a 10-14 mm thick plate stiffened by 6 mm closed longitudinal stiffeners spanning in the direction of the traffic flow. The stiffeners are supported by transverse girders, spaced at 3.0-4.5 m. Usually, the deck plate is surfaced with a 30-70 mm thick surfacing material e.g. mastic asphalt [Kolstein and Wardenier, 1997]. A typical cross-section is shown in Figure 1.

The life spans of surfacing materials on orthotropic steel deck bridges e.g. mastic asphalt are quite short when compared with those of ordinary road pavements. Also due to changes in traffic in terms of number of trucks, heavier wheel loads, introduction of wide-base tires etc., prevailing design methods have a very limited success, especially since the interaction between the structural components, the different materials involved and the vehicles is poorly understood. As a result of these factors, high strain levels (1000-1400 μm/m) have been measured at the top of the surfacings [Medani, 2001]. Such strain levels are quite high compared to those generally encountered in ordinary road pavements (120-200 μm/m). Furthermore, several problems have been reported, in many countries, including rutting and cracking e.g. Ewijk Bridge in the Netherlands [NPC, 1996] and the Popular-Street Bridge in the USA [Gopalaratnam, 1989] and several bridges in Japan [Nishizawa et al. 2004].

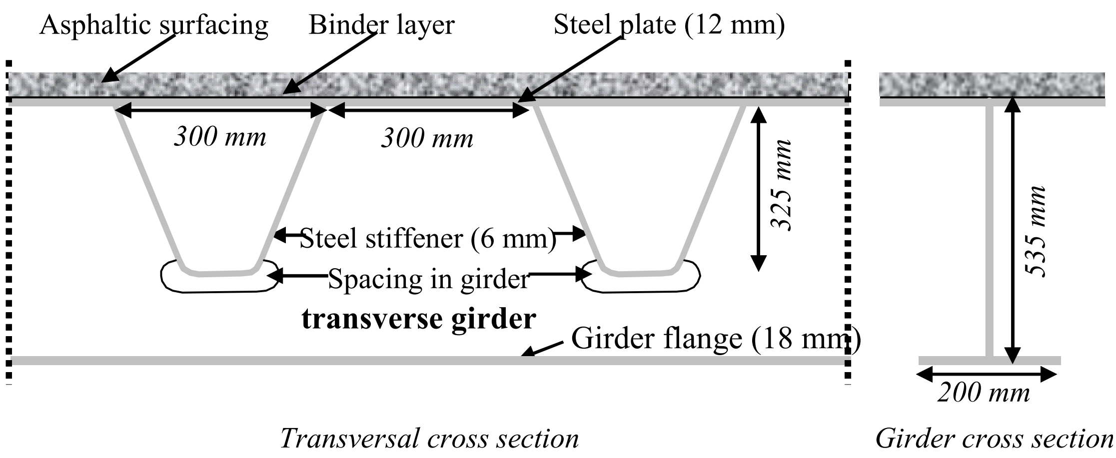

Figure 1: Typical geometry of an orthotropic steel bridge deck

2 TESTING PROGRAM

The testing program was carried out at the laboratory of the Road and Rail Engineering Department of the Technical University of Delft, and consisted of:

- Fatigue testing: to determine the fatigue characteristics of the candidate materials. For that purpose two fatigue tests have been used: the four-point bending fatigue test and the indirect tensile fatigue test. The four-point bending fatigue apparatus was also used for the determination of the mix stiffness and the compliance characteristics of the mixes for several temperatures, frequencies and strain levels.
- Static indirect tensile test: to determine the tensile strength and the fracture energy of the different mixes.
- Uniaxial compression and tension tests were used to characterize the response of the candidate surfacing materials to temperature and strain rate and to estimate the parameters of the ACRe material model [Erkens, 2002].

2.1 Mix Composition

The volumetric composition of the mastic asphalt [MA] and the guss asphalt [GA] mixes is shown in Table 1 [Bosch, 2001]. The volumetric composition of the open synthetic wearing course [OS] is not known. However, the mix consists of aggregates, sand, small fractions and a binder. The binder is a one-component solvent-free polyisociante MDI based prepolymer.

Table 1. Volumetric mix composition of mastic asphalt and guss asphalt

Component	Percentage by volume	
	Mastic asphalt	Guss asphalt
Aggregate	63	61.7
Filler	17.5	20.6
Air	1.5	2
Bitumen	18	15.7

3 TESTING RESULTS

3.1 Fatigue characteristics

The four-point bending fatigue apparatus was used for the characterization of the fatigue resistance of the mixes. Tests were conducted at a temperature of 10 ºC and a frequency of 5 Hz. The number of load repetitions to failure is determined when the initial stiffness is halved. The fatigue resistance of the mastic asphalt and guss asphalt is compared to some surfacing mixes tested by Kolstein (1989), and to the F1 and F2 lines of the Shell Pavement Design Manual (SPDM 1978). The results are shown in Figure 2.

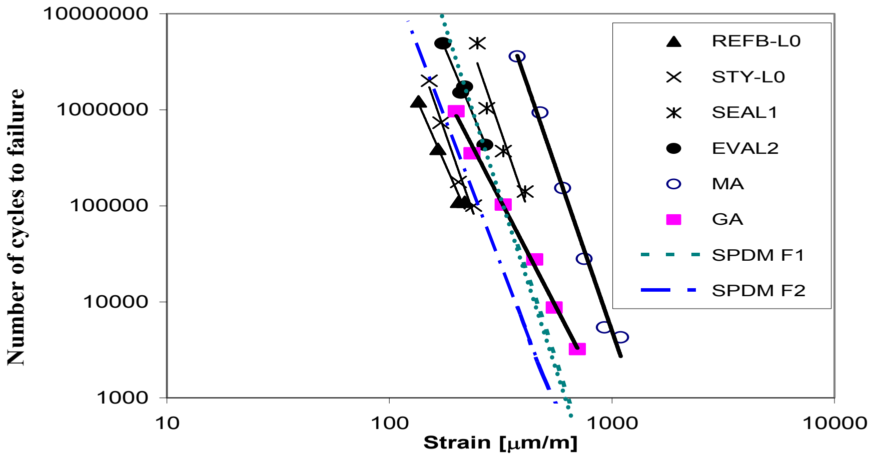

Figure 2: Results of fatigue tests for different mixes

From Figure 2 it can be observed that the MA mix performed better than all the other mixes. Due, to the limitation of the capacity of the actuator of the fatigue apparatus (5kN), it was not possible to obtain a fatigue line for the OS mix. It was then decided to estimate the fatigue resistance of the mix by using the indirect tensile fatigue test. The specimens (diameter =100 mm and thickness =25mm) were tested at a temperature of 10 ºC and a frequency of 5. The results of the tests carried out for the MA and OS mixes are shown in Figure 3.

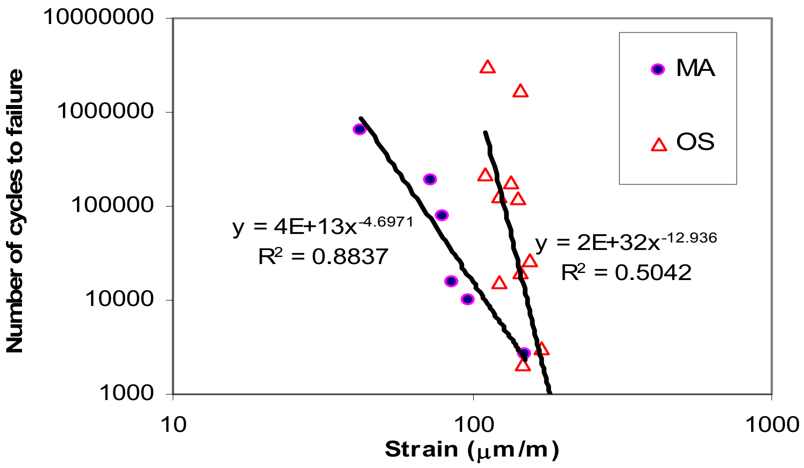

Figure 3: Results of indirect tensile fatigue tests for the MA and the OS mixes

From Figure 3 it can be noticed that the slope of the fatigue line of the OS mix is quite high. This suggests that the OS mix shows brittle behaviour.

3.2 Strain dependency of flexural stiffness

Because surfacing materials are subjected to high strain levels in practice, it was decided to determine the flexural stiffness of the candidate mixes at different temperatures, frequencies and strain levels. This was done using the four-point fatigue bending apparatus. Due to the space limitations, the test results will be presented in a form of stiffness master curves of the mixes at different strain levels, at a reference temperature of 20°C. The sigmoidal model suggested by Medani and Huurman [2003, 2004] and briefly described below, was used to determine the master curves. The results are shown in Figures 4-6.

$$S = 1 - \exp\left[-\left(\frac{10 + \log f_{fict}}{\beta}\right)^{\gamma}\right] \quad (1)$$

$$\log(S_{mix}) = \log(S_{\min}) + [\log(S_{\max}) - \log(S_{\min})].S \quad (2)$$

where:

- S_{mix} : flexural stiffness [MPa]
- $S_{\min}$, $S_{\max}$: minimum and maximum flexural stiffness, respectively [MPa]
- f_{fict} : reduced frequency
- ß, γ : shape parameters

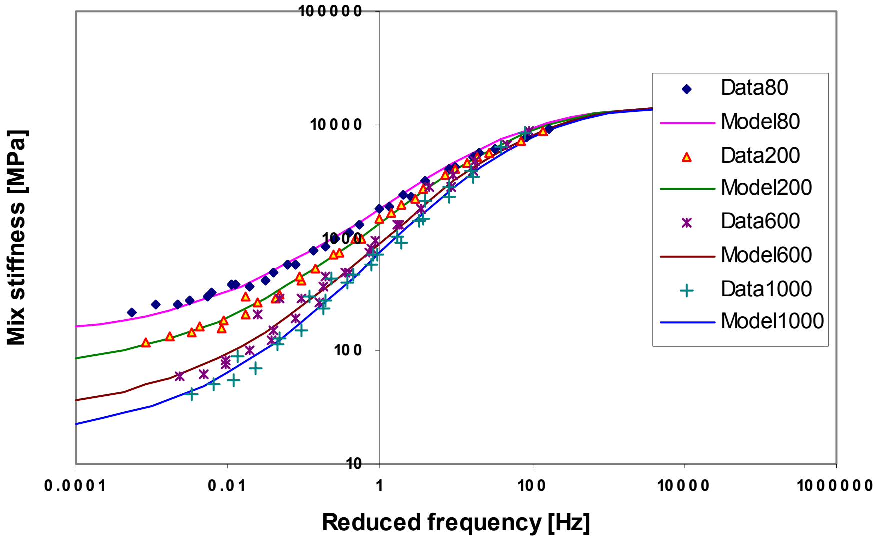

Figure 4. Relationship between mix stiffness, frequency and strain level for the MA mix

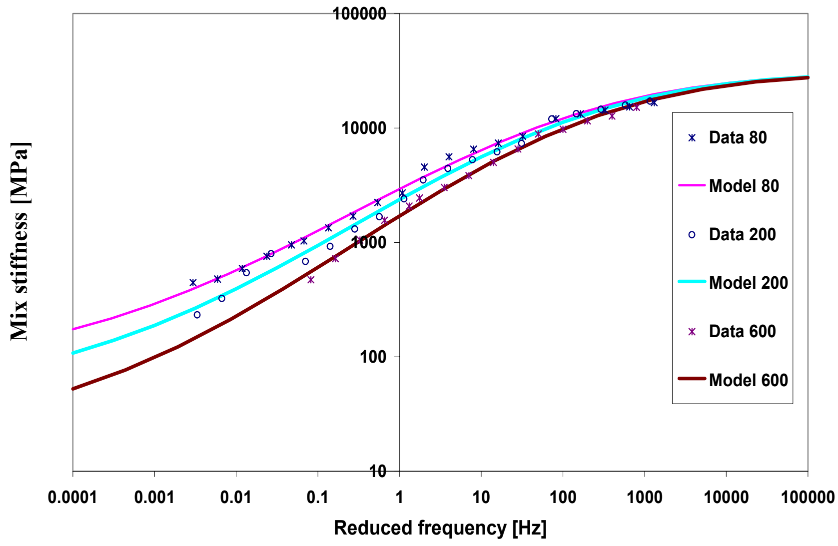

Figure 5. Relationship between mix stiffness, frequency and strain level for the GA mix

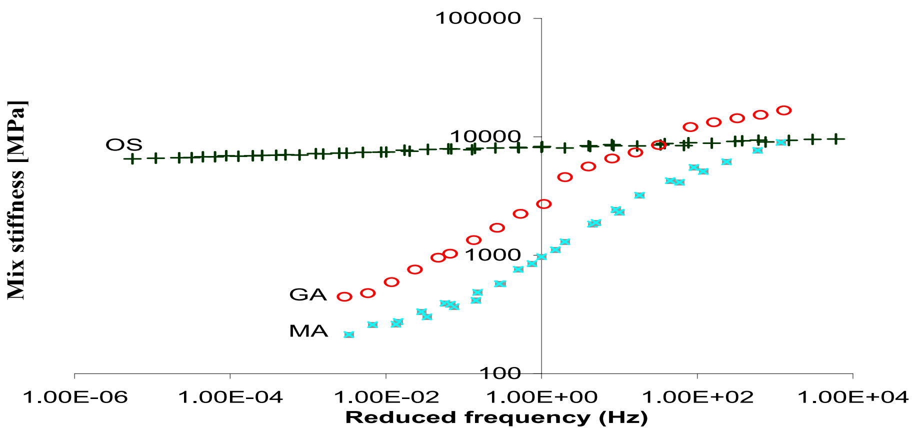

Figure 6. Master curves for the three mixes a reference temperature of 20°C and a strain level of 80 μm/m

From Figures 4-6 the following can be concluded:

- Especially for the asphaltic mixes, the flexural stiffness does not depend only on temperature and loading frequency, but also on strain level. In fact, the flexural stiffness reduces with the increase of the strain level.
- Ignoring this phenomenon can partially explain the overestimation of the lifespans of surfacings.
- Compared to the asphaltic mixes, the flexural stiffness of the OS mix hardly depends on loading frequency, and to a less extent on temperature and strain level.

3.3 Static indirect tensile test

The static indirect tensile test was used to estimate the tensile strength and the fracture energy of the different mixes. The tests were carried out at a temperature of (≈25°C). The test conditions and results are shown in Figure 7-9.

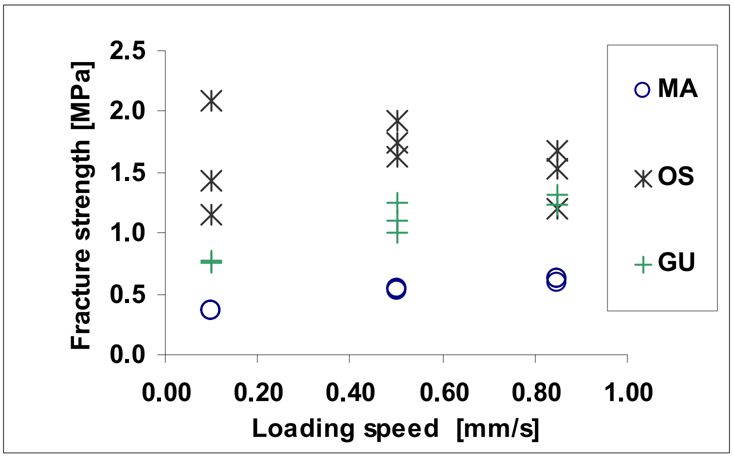

Figure 7. Results of static indirect tensile test: fracture tensile strength

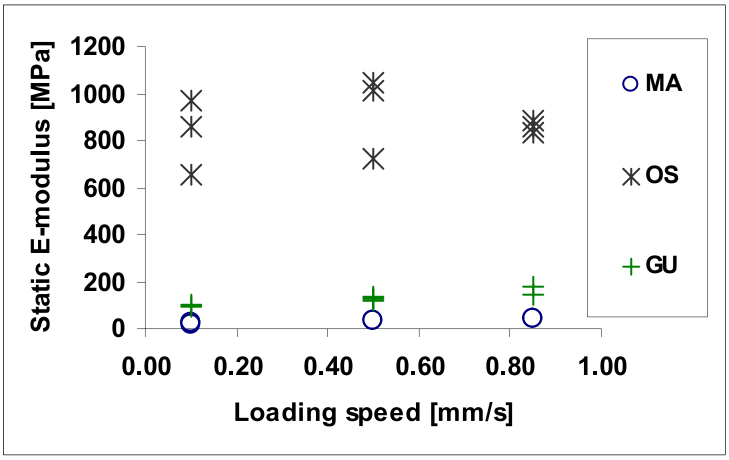

Figure 8. Results of static indirect tensile test: static E-modulus

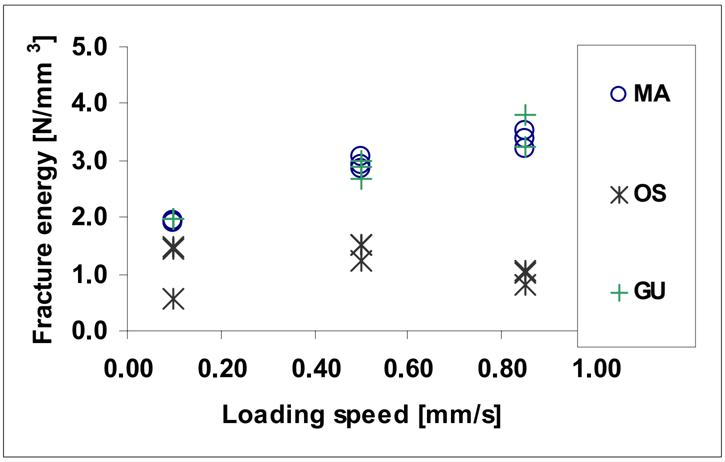

Figure 9. Results of static indirect tensile test: fracture energy

From Figures 7-9 the following can be concluded:

- For the MA and GA mixes: the fracture tensile strength, the static E-modulus and the fracture energy increases with the increase of loading speed. That is not the case for the OS where no such trend can be noticed.

- The fracture strength and the static modulus of the OS mix are remarkably higher than those of the asphaltic mix. This suggests that the OS mix is much stiffer than the MA and GA mixes.
- With regard to the fracture energy: the MA and GA mixes scored much better than the OS mix. This suggests that the OS mix is rather brittle, and hence, its capacity to take damage after initial damage takes place is rather limited.

3.4 Uniaxial monotonic compression and tension tests

Uniaxial compression and tension set-ups developed in a previous project (Erkens, 2002), were used to characterize the response of the candidate surfacing materials to temperature and strain rate. Due to the large amount of experiments involved in this project, it was decided to make use of statistical-based techniques for the optimization of the testing program. The technique which was chosen in this program is often referred to as "experimental design techniques" [Robinson, 2000]. An example of the test conditions is shown in Table 2.

Table 2. Test conditions for the monotonic compression test for the GA mix

Test #	Speed [mm/s]	Temperature [°C]
1	4.005	0
2	1.180	5.9
3	6.830	5.9
4	0.010	20
5	8	20
6	1.180	34.1
7	6.830	34.1
8	4.005	40
9 -13	4.005	20

Typical results of the compression and tension tests are shown in Figures 10 and 11, respectively.

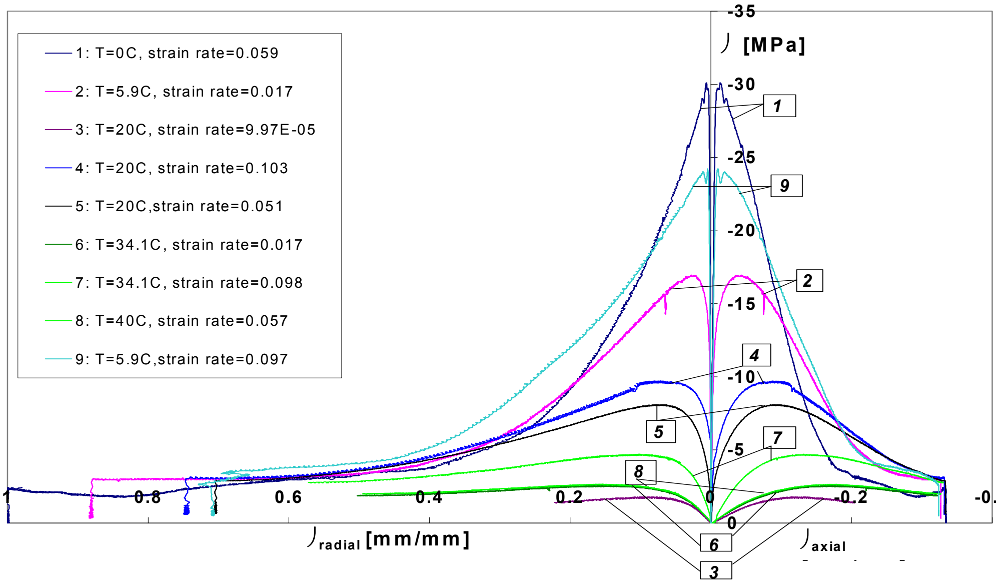

Figure 10: Results of the monotonic compression tests for the MA mix

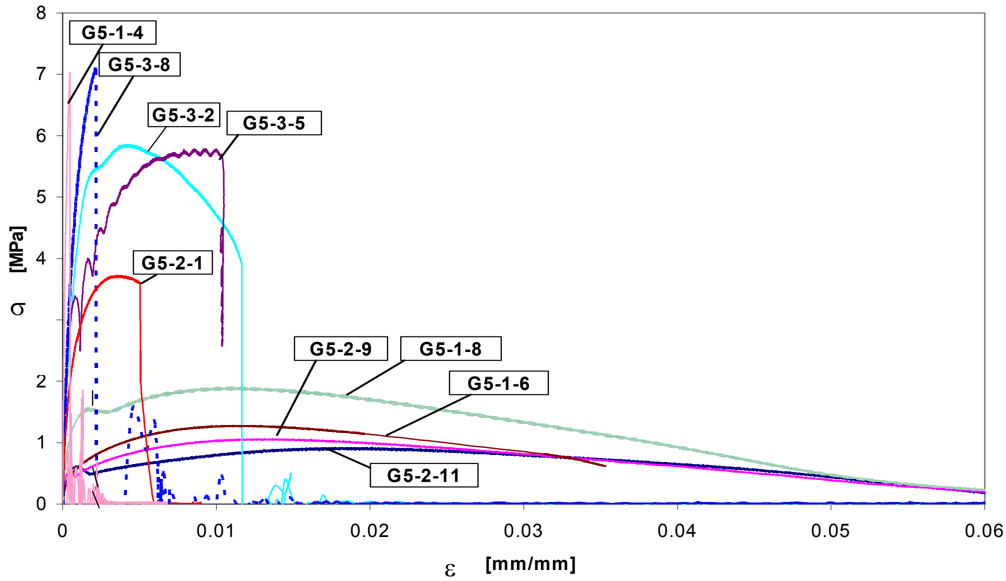

Figure 11: Results of the monotonic tension tests for the GA mix

From Figure 10, it can be noticed, as expected, that the compressive strength of the materials increases with the increase of strain rate and decreases with the increase of temperature. The same trends hold for the tensile strength.

To get an impression of the response of the three candidate materials, it is convenient to construct master curves of the properties of interest. The model suggested by Medani and Huurman [2004] is used to produce master curves at a reference temperature of 20^{o}C. Due to the space limitations, only master curves of selected properties will be shown in Figures 12-14.

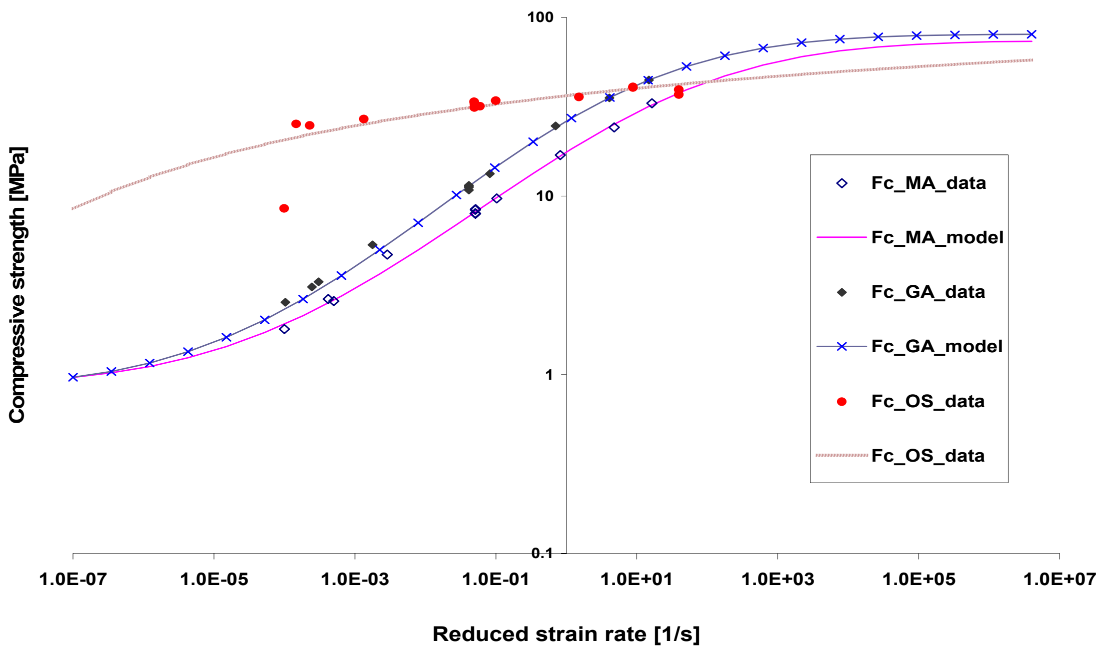

Figure 12: Master curve of the compressive strength for the three mixes

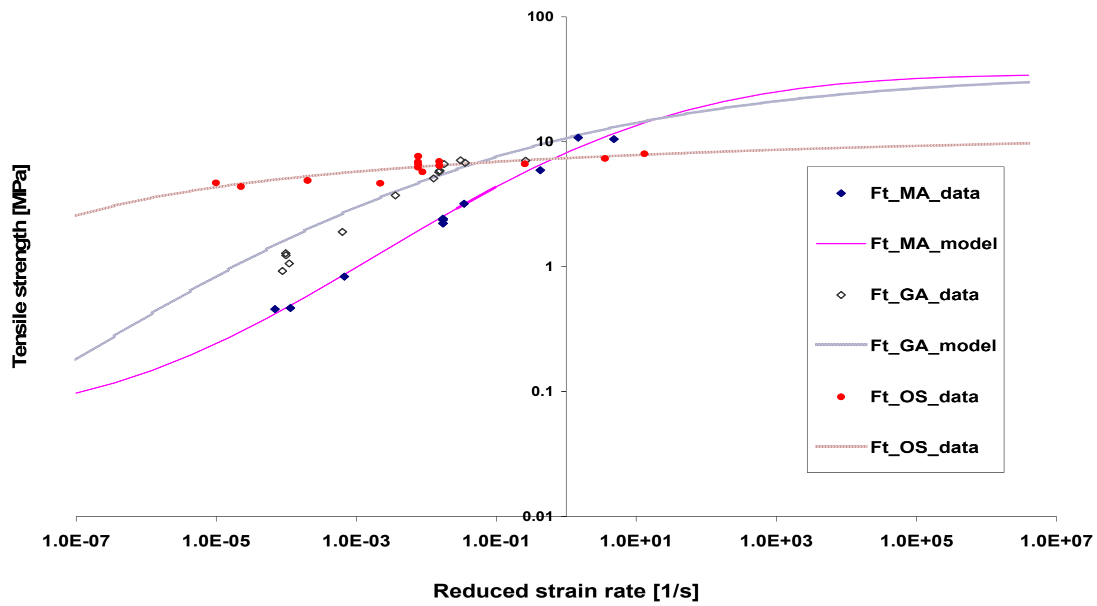

Figure 13: Master curve of the tensile strength for the three mixes

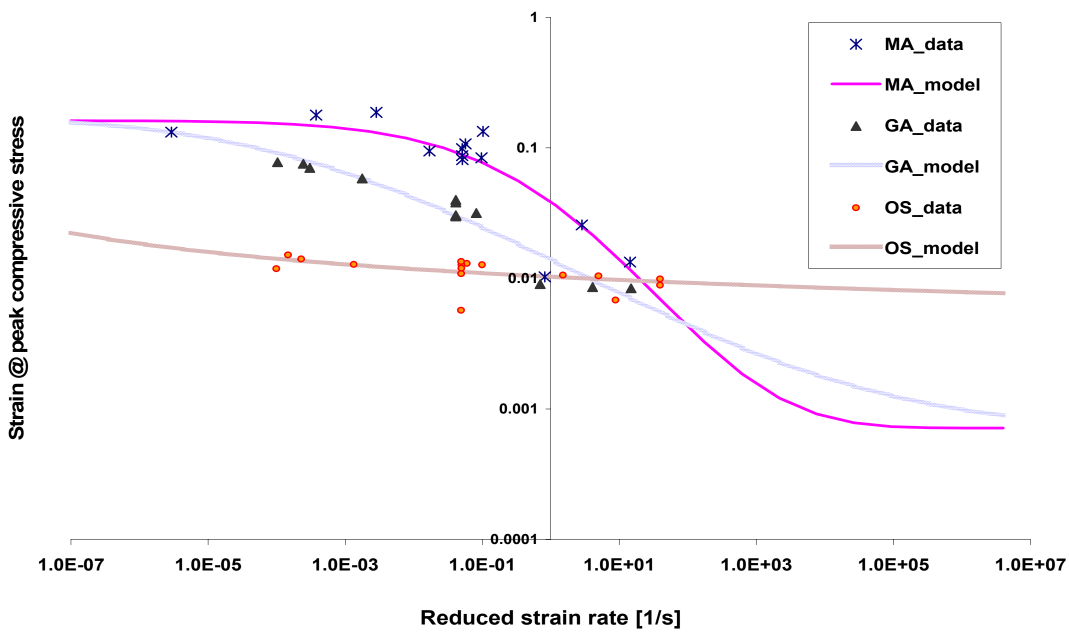

Figure 14: Master curve of the strain at peak compressive strength for the three mixes

4 CONCLUSIONS

Based on the material presented in this paper, the following conclusions and remarks can been drawn:

- Especially for the asphaltic mixes, the flexural stiffness does not depend only on temperature and loading frequency, but also on strain level. The stiffness reduces with the increase of the strain level.
- Ignoring this phenomenon can partially explain the overestimation of the lifespans of surfacings.

- Compared to the asphaltic mixes, the flexural stiffness of the OS mix hardly depends on loading frequency, and to a less extent on temperature and strain level.
- For the MA and GA mixes: the fracture tensile strength, the static E-modulus and the fracture energy increases with the increase of loading speed. That is not the case for the OS where no such trend can be noticed.
- The fracture strength and the static modulus of the OS mix are remarkably higher than those of the asphaltic mix. This suggests that the OS mix is much stiffer than the MA and GA mixes.
- With regard to the fracture energy: the MA and GA mixes scored much better than the OS mix. This suggests that the OS mix is rather brittle, and hence, its capacity to take damage after initial damage takes place is rather limited.
- While the compressive/tensile strength increases with the increase of strain rate and decreases with the increase of temperature, the strain at failure shows exactly opposite trends.
- When compared to the asphaltic materials, the properties of the OS mix are, less dependant on strain rate/frequency and hardly dependant on temperature.
- The high slope of fatigue line, high fracture strength and low fracture energy suggest that the OS mix is a brittle material.

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