THE EFFECTS OF AGE ON THE STIFFNESS PROPERTIES OF A SUV TYRE

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Abstract

The pneumatic tyre is a difficult component to model accurately in all natural vehicle environments. Proposed tyre models should be validated with real test data collected on the specific tyre being modelled under the specified application conditions. The rubber in a tyre oxidises with the oxygen in the air used to inflate it as well as the oxygen in the air surrounding it. The effects of a tyre‘s age on the performance characteristics of a tyre such as vertical, longitudinal and lateral stiffness, are not well researched. In this study, the effects of a tyre's age on stiffness parameters were determined. A tyre was artifically aged and tested periodically during the aging process. Simplified methods of quantifying the age of the tyre were investigated and used to update a validated FTire model. The results indicate that the vertical and longitudinal stiffnesses of the tyre have convincing dependencies on the age of the tyre. The use of the Shore A hardness of the tyre tread to update the FTire model was found to have good potential in accounting for the age of the tyre.

Keywords: tyre, age, model, FTire

1. Introduction

The use of simulation models to lower the cost of the design process and shorten the time required to find an optimal design has become standard practise for Original Equipment Manufacturers (OEMs). Due to its high degree of non-linearity, the pneumatic tyre has always been a difficult component of a full vehicle to accurately model. As a result, extensive research has been placed on the modelling of a full tyre capable of simulation in all natural vehicle environments. These efforts involve validating a proposed tyre model with real test data collected on the specific tyre being modelled. Test data is almost exclusively obtained from new tyres after a short run-in period. Tyres do wear during testing which may affect results.

During normal use a tyre's tread wears down and although less well-known, the rubber in a tyre also oxidises with the oxygen in the air used to inflate it as well as the oxygen in the air surrounding it (Baldwin, et al. 2008). The effects of tyre age on the characteristics of a tyre (e.g. vertical, longitudinal and lateral stiffness) are not well understood.

All tyre models used in vehicle dynamics analysis require stiffness parameters in some form. FTire is a good example of a tyre model that relies heavily on these stiffness parameters. The parameterisation of this model involves the use of test data acquired from the subject tyre to identify specific model parameters. Specific tests are recommended for the FTire parameterisation process by Gipser and Hoffmann (2016). These tests include vertical, lateral and longitudinal stiffness as well as the footprint, carcass geometry and Shore A hardness of the tyre.

This paper investigates the extent of the changes in tyre stiffness parameters due to aging, as well as updating the model parameters to compensate for these effects.

2. Test Setup and Testing Procedure

2.1 Tests Conducted

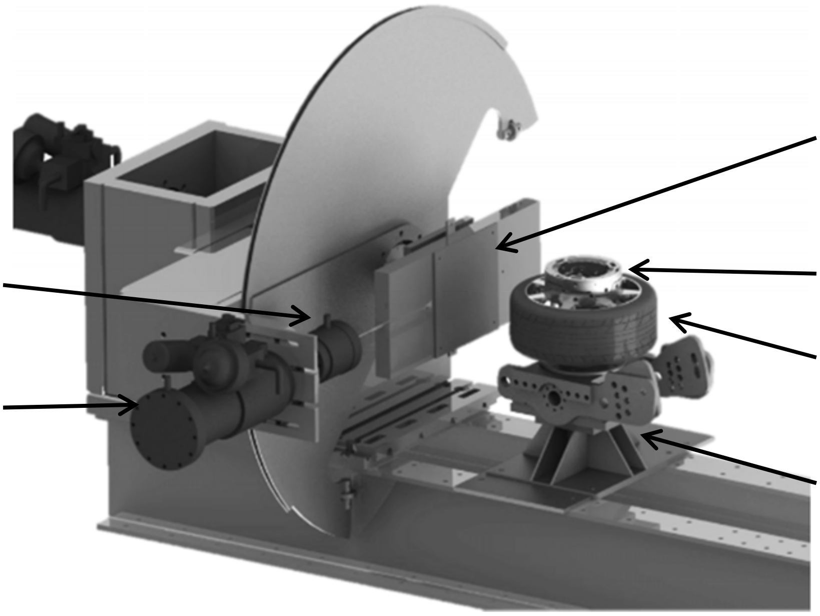

Figure 1 - Isometric view of STTR in position for vertical and longitudinal stiffness test

For the current study, quasi static stiffness tests were conducted on a Static Tyre Test Rig (STTR) (Figure 1). Figure 2 illustrates how the STTR operates when testing the vertical and longitudinal stiffnesses of the tyre. The dotted arrow indicates the direction of travel when only testing the vertical stiffness. The crosses and circles indicate all the components of the STTR that move in the vertical direction of the tyre. When testing the longitudinal stiffness, the tyre is vertically loaded and then held at a specific load whilst the sliding longitudinal assembly, indicated by all those components connected with the circles, moves in the direction of the dashed arrow. The tyre displacement is measured with road profiling laser transducers (Acuity, 2016), indicated by plus signs. They are accurate displacement transducers with a resolution of 0.01*mm* across a span of 200*mm.* All tyre forces and moments are measured using a 6-component Wheel Force Transducer (WFT). In addition, single component longitudinal and vertical load cells measure these two force components directly.

The STTR makes use of two hydraulic actuators, namely a 100*kN* actuator for actuating in the vertical direction and a 40*kN* actuator for actuating in the lateral or longitudinal direction depending on the orientation. Each actuator is fitted with a Linear Variable Differential Transformer (LVDT) displacement transducer and coupled with a Universal Low Profile (ULP) load cell (labelled as the vertical and lateral/longitudinal load cell in Figure 1 and Figure 2) of equivalent force range to that of the actuator used. Tests are performed on a flat surface as well as a variety of cleats.

The repeatability of the STTR was investigated by the comparison of several cycles of the various tests and it was found to be better than ±1% of the vertical deflection at 50% of the Load Index (LI) of the subject tyre. Any variation in test results of less than ±1% is therefore deemed insignificant and attributed to the repeatability of the test equipment.

The aging analyses produced a significant number of tyre stiffness curves. An easily interpretable and relevant method is needed to quantify the changes in these stiffnesses. In this study, the percentage change in the deflection of the tyre required to reach 50% of the tyre's LI is used to compare the different test results. This produces a quantifiable value which is easily interpreted as it is a physical dimension. Furthermore, it uses a load that is representative of the normal operating load experienced by the tyre.

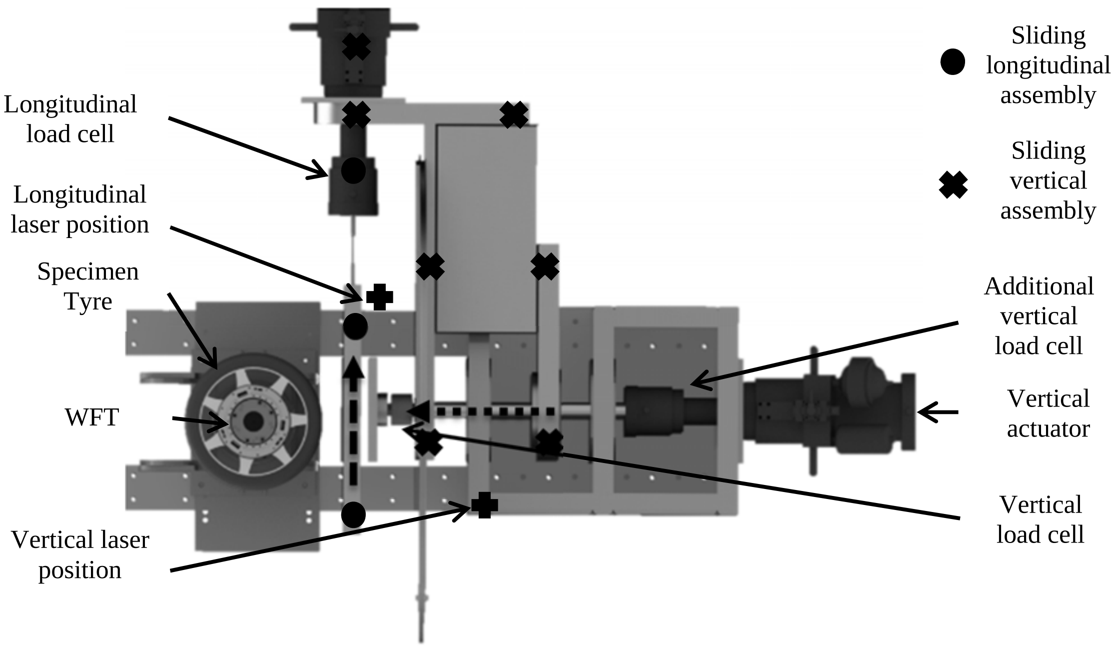

Figure 2 - Plan view of STTR in position for vertical and longitudinal stiffness test

2.2 Subject Tyre

The subject tyre used to capture all the test data for the current study was a Pirelli Scorpion Verde 235/55 R19 105V all-season tyre with a nominal inflation pressure of 2.5*Bar*. Due to the variety of tests completed four tyres were used. One was used as a control tyre, one for aging only and two for wearing. The tyres were all manufactured in the 10^{th} week of 2015 at the Pirelli manufacturing facility in Carlisle, United Kingdom as part of batch number L598. The tyre is directional and has an asymmetric tread pattern. The tyre mass was 13.6*kg* and together with the rim weighed 23.8*kg.* The load index of the tyre was 9.1*kN*. All comparisons were performed at 50% of the LI i.e. 4.55*kN.*

2.3 Aging Procedure

Baldwin (2003), Baldwin et al. (2005a, 2005b, 2008), Bauer et al. (2005) and Ellwood et al. (2004) have published several papers on the artificial aging of tyres using static oven aging. Their research effort is significant and includes the testing of a large number of passenger car tyres aged in the field from different regions and in different climates. Baldwin et al. (2005a, 2005b) describe methods of artificially aging tyres using the same evaluation method compared to the naturally aged tyres in Baldwin et al. (2005c, 2005d). This comprehensive method for accelerating the age of a tyre was methodically followed in order to acquire aged tyres as similar as possible to those aged in the field.

Based on the recommendation, the tyre in this study was artificially aged in an oven at 65°C for approximately 8 weeks. This procedure ensured the tyre of concern would have approximately equivalent rubber properties to that of a 4 year old tyre used in the field in Phoenix, Arizona in the USA according to Baldwin et al. (2005a). During the aging process the tyre was tested periodically on the STTR after 1, 2.5, 4 and 8 weeks of aging. The tyre was allowed sufficient time to cool down and was deflated and re-inflated after each removal from the oven before any testing was performed.

The Shore A hardness is one of the easily updatable parameters in a FTire model and was also anticipated to be a property of the tyre that would change with the aging of the tyre. This is based on results discussed in Kataoka et al. (2003) where the Shore A hardness of the tread rubber on a specific spare tyre was observed to increase by 10 over a period of approximately 250 weeks. The Shore A hardness was measured using a Bondetec BS-392A Shore A Hardness tester. The hardness was measured at 10 marked locations around the tyre, 5 on the tread and 5 on the sidewall. The measurements were repeated approximately 15 times at each location. This process was repeated each time the tyre was removed from the oven for testing.

3. Results

3.1 Shore A Hardness

The average Shore A values for the sidewall and tread measurements were used from each round of tests after the tyre had been removed from the oven and allowed to cool down to room temperature.

Figure 3 illustrates a distinct difference in rubber hardness between the sidewall and the tread. Where the sidewall gives clear indications of a change in hardness after the first round of aging, the tread hardness does not change by any noticeable amount until after approximately 2 weeks of aging.

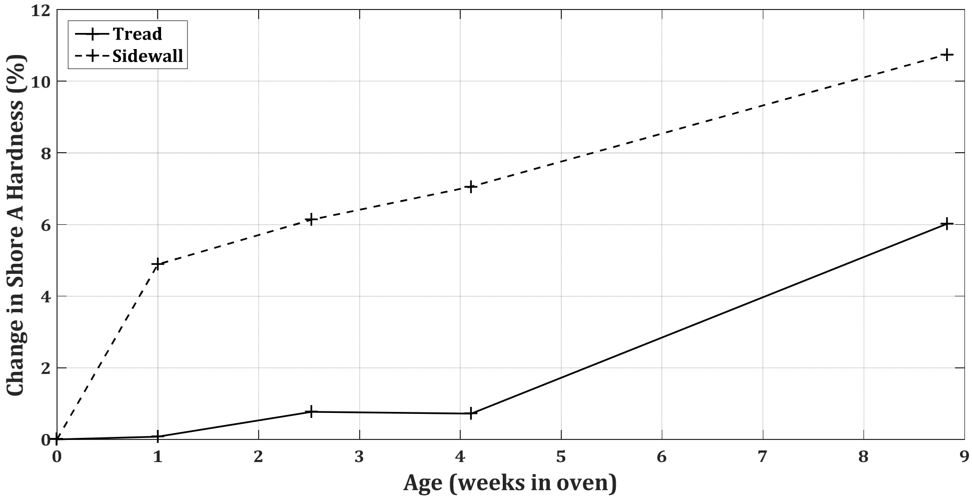

Figure 3 - Percentile change in Shore A hardness at the tread and sidewall whilst aging

3.2 Vertical Stiffness

Figure 4 shows the various vertical stiffnesses on a flat surface with zero camber angle as the tyre was aged. The change in stiffness is not consistent. The tyre appears to get softer after the first week of aging before it starts getting stiffer in the weeks that follow. Figure 5 shows the actual changes in deflection at 50% and 100% of the LI compared to the results of the tests of the new tyre.

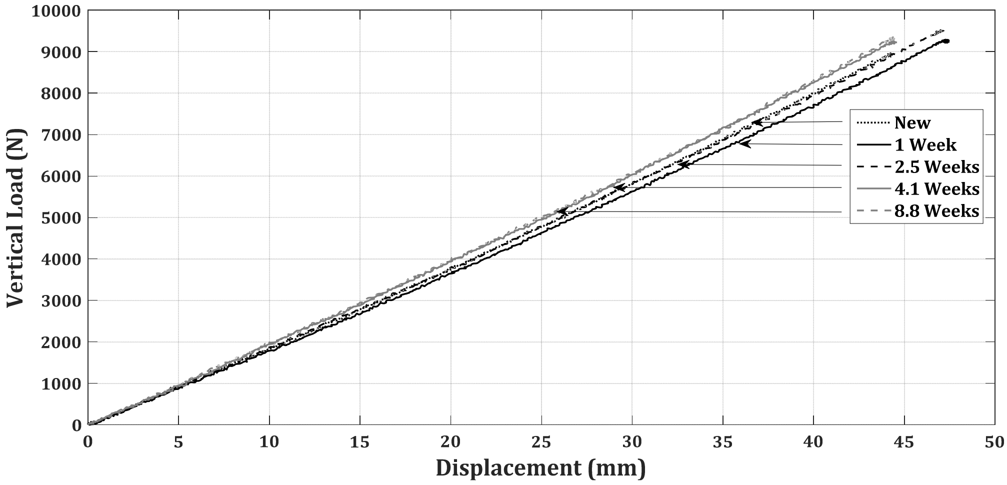

Figure 4 - Vertical stiffness changes on a flat surface as the tyre ages

Figure 5 indicates changes in deflection at the two load cases considered. Relative to the deflection required to reach the same load with the new tyre, the percentage change is more significant at the lower load than at the higher load. Despite the initial ‘softening’ of the tyre the stiffness appears to consistently increase for an additional three weeks of aging after which the 1% threshold is exceeded after 4 weeks. Thereafter the rate drops significantly, almost as if it had stopped changing completely.

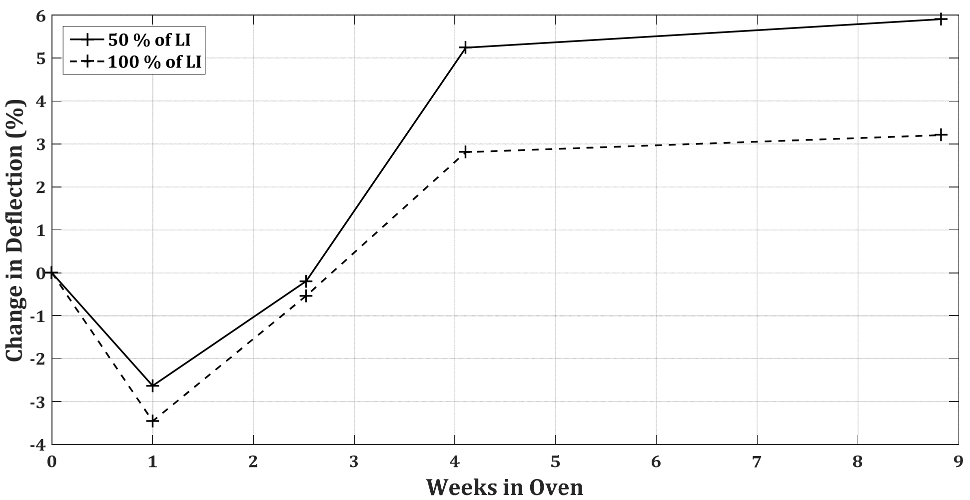

Figure 5 - Percentile change in deflection of aged tyre on a flat surface

3.3 Longitudinal Stiffness

Results of the longitudinal stiffness tests are shown in Figure 6. A P80 Corundum contact surface was used for all tests to create a high friction coefficient and thus a large longitudinal displacement prior to the tyre slipping. The maximum change in deflection was 4.16% at 1000*N* of longitudinal force. Again, an initial softening is observed after which the stiffness increases above the value for the new tyre.

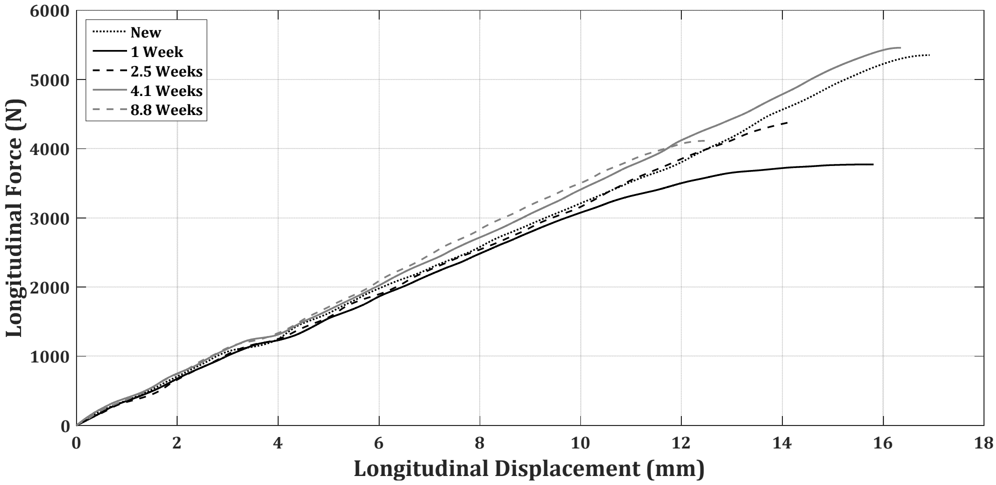

Figure 6 - Changes in longitudinal stiffness as the tyre ages

3.4 Summary of Aging Effects

The results of the tyre stiffness tests illustrate a variety of changes in the characteristics of the tyre as it ages. The comparison between the stiffnesses was conducted through the relative change in the deflection detected at loads of 50% and 100% of the LI. Results for all tests conducted are summarised in Figure 7. The average change in deflection at each interval is also plotted. The dash-dotted lines were added for the equipment measuring thresholds of ±1%. There is a clear upward trend in all the measured parameters with changes varying from 2% to 8%. The changes exceed the equipment threshold in all tests after approximately 4 weeks of aging, indicating that the changes are induced due to the tyres aging and not due to the experimental repeatability.

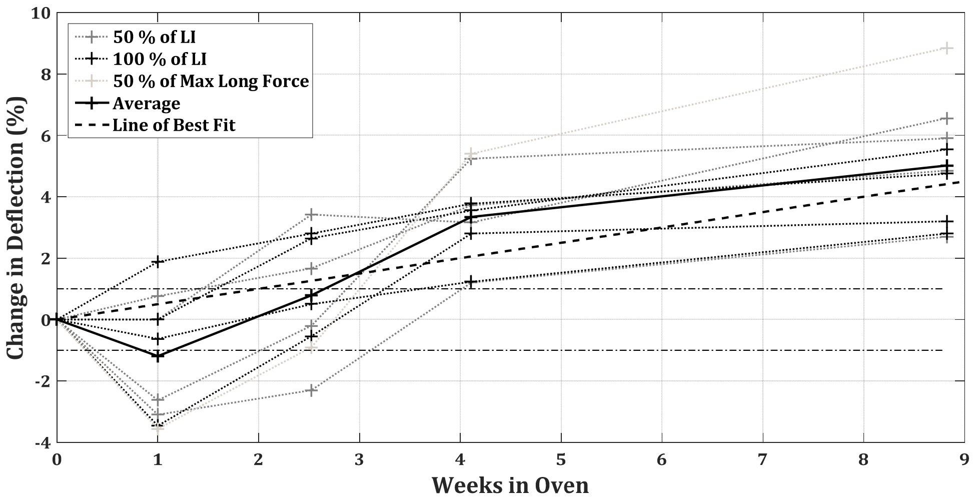

Figure 7 - Percentile change in deflection of all test data with averages and a line of best fit

Of all the parameters measured, the Shore A hardness indicated a clear and significant trend and since this parameter is very simple and quick to measure, as well as to change in the model, it is a good candidate to be considered for the FTire model updating.

4. Conclusion

The investigations carried out in this paper quantified the effects of aging on the stiffnesses of a tyre. In general the testing equipment threshold of ±1% was commonly exceeded by the aging effects presented. The largest reported error between a severely aged tyre and a tyre model based on a new tyre is approximately 5%. The changes in tyre properties due to aging are generally small but not insignificant.

5. Acknowledgements

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