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# Effects of Shelf Age Based on Types of Approval Marking on Passenger Car Tyres' Safety Performance

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**Abstract** – *Issues surrounding the use of aged tyres are one of the major concerns with regard to vehicle safety. The changes in rubber components due to the ageing process may cause changes in a tyre's mechanical and chemical properties which may lead to road crashes attributed to tyre failure. The main objective of this study is to discover the effects of tyre shelf age and approval markings on the performance of aftermarket passenger car tyres. This study involved conducting accelerated ageing on the randomly purchased tyres. By utilizing the Design of Experiment method, 48 passenger car tyres from four tyre manufacturers were used as test samples representing 'Marked' and 'Non-marked' tyres. Half of the samples were subjected to accelerated ageing process using an accelerated ageing chamber to simulate the desired age, to the maximum of 5-year old shelf aged. All new and aged tyres comprising both 'Marked' and 'Non-marked' groups were then tested under the Tyre Performance Test protocols stipulated in the Malaysian Standard (MS) 149:2008. All of the samples were tested in accordance with MS 149:2008 and the results were compared thoroughly by markings, age and type of failure. The study implied that age did have effects on safety performance of the tyres and significant difference in terms of safety performance was observed between 'Marked' and 'Non-marked' tyres. In overall 'Marked' tyres showed superior performance as compared to 'Non-marked' tyres for all of the tests conducted. The results had also provided crucial reference in terms of suggested age of tyre life span for proactive tyre replacement. The suggested tire life span for proactive tire replacement is 7.2 years-old for 'Marked' tyres and 2.3 years old for 'Non-marked' tyres. Since the Malaysian government has already gazetted the mandatory standard on tyre markings for the local market, relevant authorities need to take responsibility for the effective and efficient enforcement of compliance with the standard.*

**Keywords:** Passenger car tyres, accelerated ageing, Design of Experiment, performance test, shelf age

## 1.0 INTRODUCTION

From the public's perspective, passenger car tyres are replaced every 3 to 5 years. This is largely influenced by either the information provided by the tyre companies or from personal experience. From previous discussions held with tyre manufacturers, the majority recommend tyre replacements no later than 5 years from the manufacturing date, whilst some recommend service lives of up to 10 years (Bridgestone Motor Sport, 2018). Nevertheless, without scientifically proven evidence, road users face the risk of tyre failure due to unknown and unforeseen degradation of tyre performance resulting from ageing or wear.

Throughout the year 2007 to 2010, the National Automotive Sampling System-Crashworthiness Data System (NASS-CDS) data showed that 11,047 crashes had occurred due to tyre failure and 1.77% (195) of the crashes involved fatalities (NHTSA, 2014). In Malaysia, data from in-depth investigation by MIROS revealed that 37% of crashes related to tyre issues had caused more than three fatalities in one single crash (Zainal Abidin et al., 2012). Knowledge on causes of tyre ageing and its effects on safety performance of the tyres needs to be established in order to further understand the implications and provide the necessary precautionary measurements to avoid untoward incidents involving road users.

Theoretically, the ageing process of a passenger car tyre can be categorized into two types, namely chemical ageing and mechanical ageing. The chemical ageing process occurs due to the interaction between the material and oxygen in atmosphere, which is also commonly known as oxidation. On the other hand, mechanical ageing occurs when a material is subjected to mechanical stress and strain. Tyres used on roads suffer ageing from both these mechanisms, which aggravates the ageing process. Previous research noted that the ageing process affects the integrity of rubber which then could contribute to tyre failure on the roads (NHTSA, 2014). The ageing processes are also influenced by climate conditions such as temperature, rain or moisture, snow, and ultraviolet radiation (Campbell, 1969). It is known that tyres are significantly affected by increasing temperature (Tampere University of Technology, 2014).

The current limited knowledge and inadequate enforcement of the sales and usage of substandard tyres in Malaysia has been a cause for alarm. Knowledge on safety performance differences between tyres with different approval markings could help motorists in making wiser, safer decisions when buying new tyres.

## 2.0 METHODOLOGY

### 2.1 Accelerated Ageing

An ageing chamber shown in Figure 1 was used to simulate the environment with the desired climate conditions for accelerated tyre ageing process in this study. The protocols for the accelerated ageing tests were based on two available and relevant standards during the time which were as follows:

i. ISO 188:2011 Rubber, vulcanised and thermoplastic – Accelerated ageing and heat resistance tests
ii. ASTM D572 – 04(2010) Standard Test Method for Rubber – Deterioration by Heat and Oxygen

The ageing chamber was installed with multiple instruments to enable control of climatic conditions in the chamber. The concept for the chamber was developed by MIROS research team through numerous discussion sessions with tyre experts and academics in regards to polymer and vulcanized rubber products. The final technical specifications selected for the ageing chamber were as follows:

i. Machine Name: Accelerated Ageing Chamber
ii. Size (W x D x H): 1702mm x 2115mm x 3051mm
iii. Voltage (V) / Phases: 415±10% AC / 3 phase
iv. Frequency (Hz): 50/60
v. Mains Fused (A): 100
vi. Max Operating Temperature (ºC): 110
vii. Capability: 6 units of passenger car tyres per batch
viii. Safety Features: sensors with PLC control, siren & light tower signal

**Figure 1**: Accelerated ageing chamber

## 2.2 Ageing Correlation Model

The ageing correlation model is required to estimate accurately the ageing period in the ageing chamber for the tyres to reach the desired age. The ageing correlation model is based on Arrhenius theory, which relates to the chemical reaction rates of a material. It is important to note that in the case of tyre ageing, the chemical reaction occurs between the rubber and oxygen. The mathematical equation used was taken from ASTM F1980 – 07 based on Arrhenius theory and is shown below:

$$ta = td \,/\, [\, Q10^{\frac{T_1 - T_0}{10}} \,] \quad (1)$$

where:

*ta* – accelerated ageing time (t)
*td* – desired age (t)
$T_1$ – elevated temperature (°C)
$T_0$ – ambient temperature (°C)
*Q10* – material temperature coefficient

*ta* indicates the time required for the tyre to be heated in the ageing chamber. *ta* can be determined when values for *td*, $T_1$, $T_0$, and *Q10* are set. *td* is the desired age for the tyre sample. Based on equation 1, the chemical reaction rate is approximately doubled when temperature is elevated by 10°C. However, the rate depends on the exact value of *Q10*. For this study, the values selected for *td* were based on the findings of market surveillance of the average tyre age of Malaysian cars (1.83 years) (Zainal Abidin et al., 2012) and the baseline maximum tyre warranty period given by tyre manufacturers (5 years). A review of prior studies showed that rubber could not be heated to more than 70°C in an accelerated ageing process. It is known that the excessive heat stress may initiate rubber reversion problems (NHTSA 2014) and other types of rubber failures that do not take place in normal ageing. Thus, $T_1$ was set at 70°C to maximise the rate of acceleration of the ageing process without causing unintended effects to the ageing process. Malaysia's annual mean temperature (27±2°C) was used for $T_0$ in this study (Jabatan Metrologi Malaysia, 2014).

## 2.3 Specific Temperature Coefficient

*Q10* is the specific temperature coefficient for a specific type of material and is a constant for that material. The *Q10* value for rubber can be determined by modelling the kinetics of material deterioration. However, that process is very complex and was out of the scope of this study. Furthermore, tyre manufacturers keep the material compositions of their tyres confidential. Thus, a conservative estimate of 2 was used for *Q10* in this study the effect of $T_1$ and *Q10* on ageing is shown in Figures 2. By substituting the variable value into Equation 1, the equation is simplified (see Equation 2). The equation indicates that the time for the rubber ageing process can be reduced by a factor of 0.051.

$$ta = (0.051) \times td \qquad (2)$$

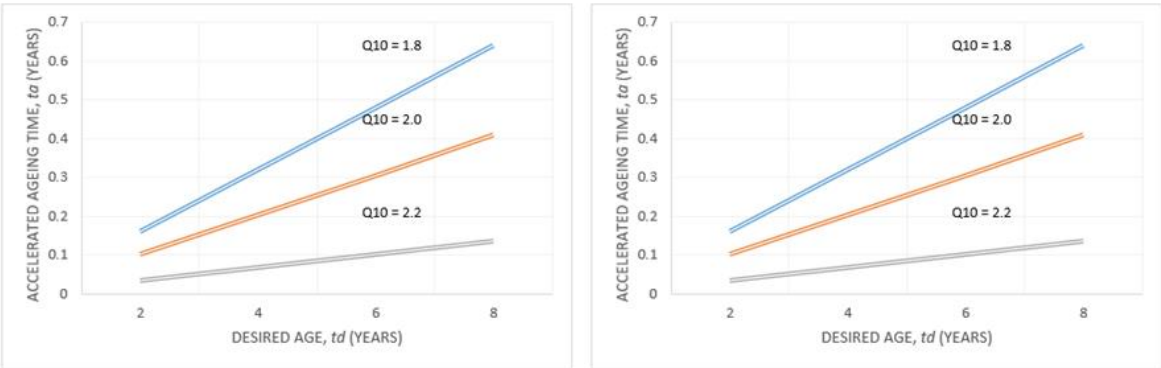


**Figure 2**: Effects of $T_1$ and Q10 on tyre ageing

## 2.4 Design of Experiment

To study the effects of multiple factors on a response, which for this study were the tyre age (A) and approval markings (M) towards the safety performance of the tyres, design of experiment (DOE) was been conducted. Description of the observed design factors is shown in Table 1. For the purpose of tyre group segregation, the tyres marked with the United States Department of Transport (DOT) markings were considered as 'Non-marked' tyres due to the self-declaration nature of the marking.

**Table 1**: Description of design factors

| Design Factor | Condition | Description |
|---|---|---|
| Tyre age | New | New tyre/tyres with no ageing effect |
| | Aged | thermal accelerated aged tyres (1.83 years) |
| Marking availability | 'Non-marked' | Tyres with DOT markings/ with no markings |
| | 'Marked' | Tyres with 'E' /'MS' markings |

As previously mentioned in the earlier chapter of the paper, the age of tyres (1.83 years) used was based on the findings obtained from a surveillance study conducted by MIROS (Zainal Abidin et al., 2012). The value represented the mean on-the-road passenger car tyres' age in Malaysia, obtained from the study. For the purpose of providing additional analysis and comparison, additional accelerated ageing tests were performed and supplementary tyre samples were obtained. These comprised tyres which underwent accelerated ageing process equivalent to five years (to represent manufacturers' typical warranty period) as well tyres which were aged naturally on-the-road of 8 and 10 years.

## 2.5 Design Factor Combination

The design factor combinations in this study are shown in Table 2. By using the design factor combination method, four levels of different combinations were developed and considered during the tests. In order to ensure the consistency of the output result, a total of three replicates were conducted for each design factor combination were conducted. In overall, forty-eight samples of tyres were used to complete the numbers for the said design factor combinations.

Although the initial planning of the DOE incorporated different manufacturers for both 'Marked' and 'Non-marked' tyres, due to a lack of availability of the 'Non-marked' tyres, samples from only one manufacturer were used in the testing.

**Table 2**: Design factor combination

| Design Factor | Age (A) | Mark (M) | Treatment | No of Samples |
|---|---|---|---|---|
| 1 | + | - | A | 12 |
| 2 | + | + | AM | 12 |
| 3 | - | - | - | 12 |
| 4 | - | + | M | 12 |

## 2.6 Tyre Performance Tests

All of the tyres involved in the study were tested by a series of performance tests as stipulated in the Malaysian Standard (MS) requirement for New Pneumatic Passenger Car Tyres (MS 149:2008). According to the Trade Descriptions Order 2012 with regards to marking of pneumatic tyres, all locally manufactured pneumatic passenger car tyres needs to be certified with MS 149 before it can be sold in the market. In general, the tyres need to be tested with four types of performance testing, as shown in Table 3.

**Table 3**: Performance Tests stipulated under MS 149

| | Type of Test | Test Category |
|---|---|---|
| 1 | Bead Unseating Test | Static |
| 2 | Plunger Test | Static |
| 3 | High Speed Test | Dynamic |
| 4 | Endurance Test | Dynamic |

Bead unseating tests are conducted to study a tyre's resistance to bead unseating. The breaking energy of a tyre was tested with the plunger test while the load and speed rating performance of the passenger car tyres were tested in the high speed and tyre endurance test. New and aged tyres utilized under the study were tested and the test results were assessed and compared as the tyres were divided into several groups according to the age of the tyres and availability of certification markings.

## 3.0 RESULTS AND DISCUSSION

First the study looked into the hardness of the tested tyres, represented by the Shore A value, as shown in Figure A. The study found an apparent different trend between the 'Marked' and 'Non-marked' tyres in terms of Shore A value for the new and aged tyres for both categories of tyres. Analysis on the test results have shown that tyre samples from the 'Marked' category showed constant hardness value for both new and aged tyres. Furthermore, even after eight years of on-the-road usage, tyres from the 'Marked' category still showed no significant change in terms of hardness, as reflected by their Shore (A) hardness of 74.

However, in contrary, tyres from the 'Non-marked' category was observed to have an increasing trend of hardness value by the increasing age of the tyres. The test revealed that the hardness of tyres in the 'Non-marked' category increased by 8.5% after accelerated ageing simulating 5 years of normal ageing. Meanwhile, the 'Non-marked' tyres with 8 and 10 years of on-the-road usage reached a Shore (A) hardness of 85, which was the highest among all tyre samples. In regards to tyre safety, previous literature has often related tyre hardness increase with the decrease of tyre grip and traction performance on the road (Rex Gauge, 2014; Malaysian Standard, 2008; Federal Government Gazette, 2012; Klein & Black, 1999). Thus, as shown by the test result in Figure 3, the increase in tyre age could play a contributing effect towards the may grip and traction performance of the 'Non-marked' tyres as compared to the 'Marked' tyres.

Bead unseat tests were conducted to study the tyre resistance to bead unseating. During the tests incremental forces were applied until the bead was unseated. The graph in Figure 4 shows the performance of 'Marked' and 'Non-marked' tyres during bead unseat tests in a quadratic polynomial trend, where Y-axis represents the percentage of clearance above minimum loading requirement (910 kgf) while the X-axis represents the year of the tyre. From the graph, the values of loading to unseat the bead for 'Marked' tyres were slightly higher than 'Non-marked' tyres, particularly for new and 2-year old tyres, as shown from the graph. The difference in terms of performance is found gradually increased throughout the years as shown from the trend line. This indicates that the 'Marked' tyres have superior performance than 'Mon-marked' tyres for bead unseating tests.

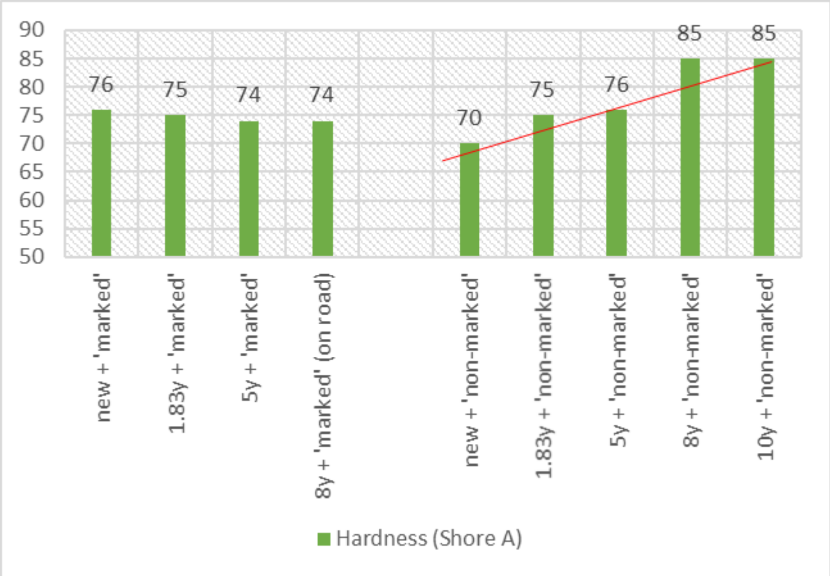


**Figure 3**: Changes in tyre hardness (Shore A) value with age

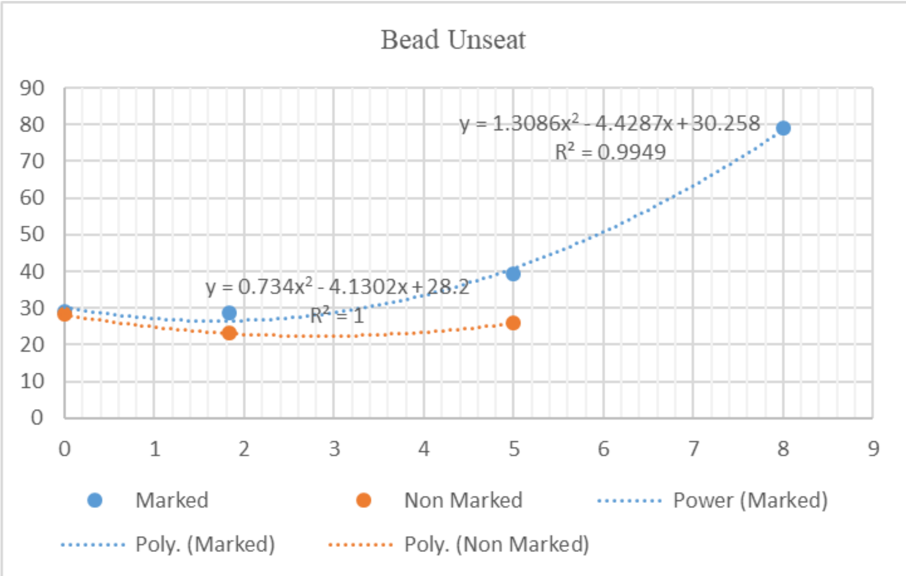


**Figure 4**: Bead Unseating Test result by tyre category

Plunger tests are conducted to study the tyre resistance to plunger force applied on the tyre treads. The graph in Figure 5 shows the performance of 'Marked' and 'Non-marked' tyres during plunger tests, where the 'Marked' tyres shows a Cubic Polynomial trend and 'Non-marked' tyres display a Quadratic Polynomial trend. The Y-axis represents the percentage of clearance above minimum loading requirement (3000 kgfcm) while the X-axis represents the year of the tyre. From the graph, the values of breaking energy applied on the tyre treads for marked tyres were significantly higher than 'Non marked' tyres (> 40% difference), starting from year 0 as shown from the graph. At year 5, 'Non marked' tyres produced breaking energy below minimum requirement of 3000 kgfcm as for the 'Marked' tyres, the performance for the 5$^{th}$ year further increased up to 114% from the minimum requirement stated in MS149. The performance of the 'Marked' tyres however decreased after year 5.

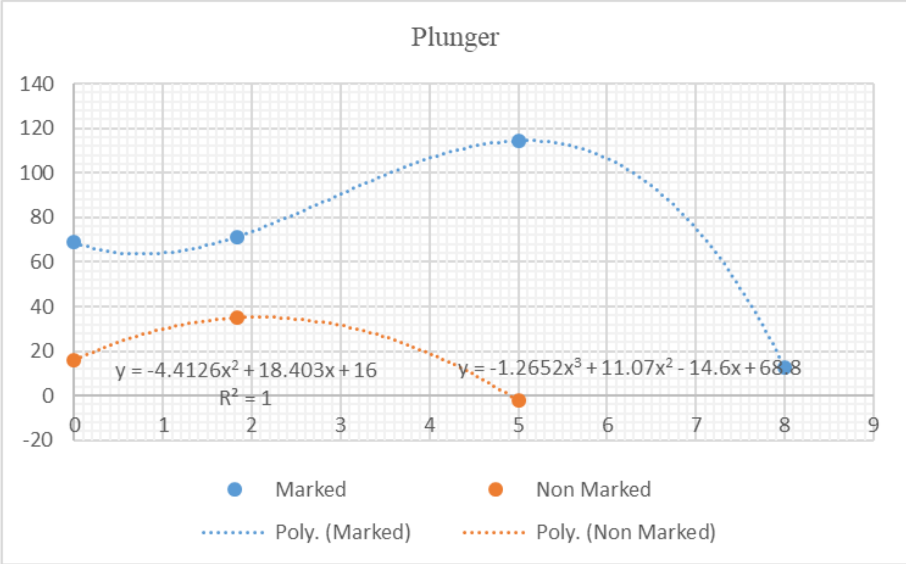


**Figure 5**: Plunger Test result by tyre category

It was noted that all aged ‘Non-marked’ tyres showed a similar type of failure- tread chunking (see Figure 6). One of the causes of tread chunking is the built-up of excessive heat on tyre during the ageing process (Malaysian Standard, 2008). Thus, tread chunking may indicate that ‘Non-marked’ tyres had poor heat build-up resistance as compared to ‘Marked’ tyres. However, the damage carried a minor weighting in the post-test evaluation and the tyre samples were still considered as having passed the plunger test based on the current practice at the testing facility and by the certification body. The results showed that 5-year old ‘Non-marked’ tyres failed the plunger test and possessed physical defects (tread chunking).

**Figure 6**: Tread chunking on ‘non-marked’, aged tyre samples

Meanwhile, with regard to physical inspection requirements, only the 10-year old tyres failed the requirements of MS 149:2998 due to existing pre-test physical damage. Thus, it can be said that the 10-year old tyres tended to have extreme physical defects and inferior roadworthiness, disabling the ability for them to be tested in accordance with MS 149:2008.

In the high speed tests, the tyres were subjected to high speed performance test and had to meet the following criteria; no visual evidence of physical defects and the pressure at the end of the test must not be lower the initial pressure of 220 kPa.g. From the Quadratic Polynomial graphs of both group of tyres, it can be seen that all tested tyres passed the minimum requirement (post-test pressure higher than initial pressure). 'Marked' tyres showed that degradation point occurred at tyres aged 3.6-year-old tyres while the 'Non-marked' tyres showed an earlier degradation point of approximately 1.2-year-old tyres (refer Figure 7). The degradation point is an indicator for air permeability of the tyres.

From the polynomial graphs, the slope of the graph where dy/dx = 0 points are being referred. These points signify the deflection point or in other words the Performance Degradation Indicator (d) of the tyres. Results from two tests, specifically the Plunger Test and High Speed Test were observed. As shown in Table 4, from both of the tests performed, 'Marked' tyres show higher test result which reflects a superior performance as compared to the 'Non-marked' tyres. 'Marked' tyres had a 5-year-old degradation point in Plunger Test compared to 'Non- marked' tyres which were found degraded at 2 years old in the similar test, while the 'Marked' tyres had a 3-year-old deflection point in High Speed Test compared to only a 1-year-old degradation point for 'Non-marked' tyres in the same test. In overall, the results show that 'Non-marked' tyres display faster degradation point in terms of the year of the tyres for both of the test results. Nonetheless these figures serves as key indicators of the tyre performance deflection point, which may serve as beneficial guidance for predictive maintenance.

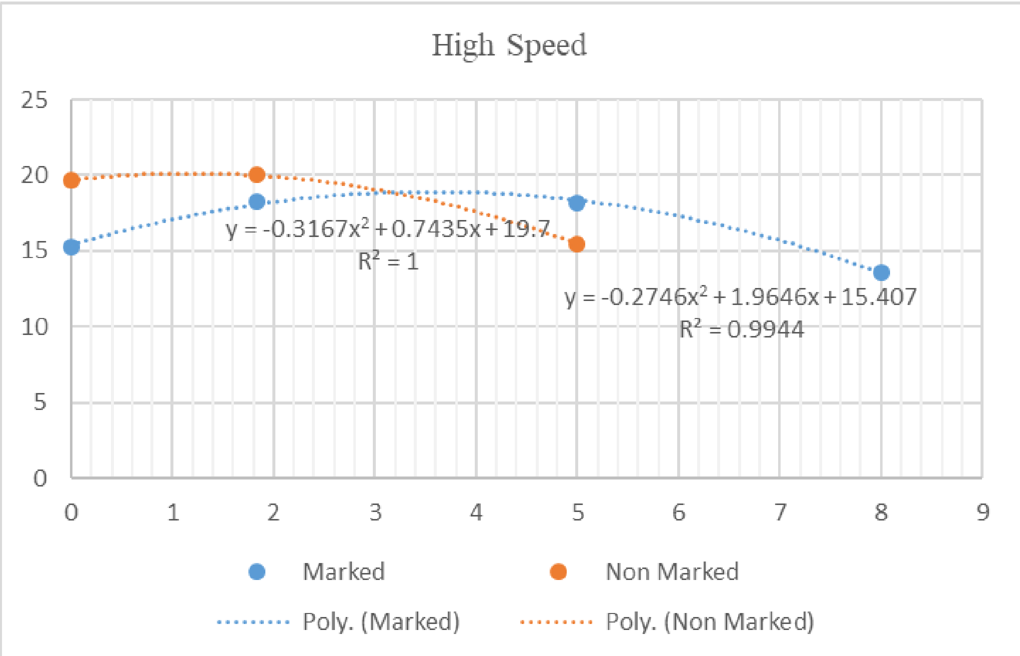


**Figure 7**: High Speed Test result by tyre category

Moreover, result from the Plunger Test which is a static type of test was found to be higher than the result in High Speed Test which is a dynamic test. The result shows that the tyres tend to have lower value of years for performance degradation when being tested in High Speed test which is a dynamic test as compared to Plunger Test which is a static test, as shown in Table 4.

**Table 4**: Tyre Performance Degradation Indicator (d)

| | Marked | Non Marked |
|---|---|---|
| Plunger | 5.1 years old | 2.1 years old |
| HS | 3.6 years old | 1.2 years old |

Next, the analysis looked into the Minimum Value of Tyre Performance Indicator (m) (refer Table 5). These indicator remarks the point of which the test results of the tyres are below the initial performance of the tyres during testing. From the table it can be seen that 'Marked' tyres shows (m) value of 7.2-year-old which means that the tyres display performance value below the initial value when the tyres reach 7.2-year- old. On the contrary, 'Non Marked' tyres had (m) value of 4.1 years old and 2.3 years old, in which the latter refers the value obtained from the dynamic typed of test. These result may act as crucial indicator for tyre replacement as it reflects the point where the performance of the tyres decreased below the initial value (new tyre condition).

**Table 5**: Minimum Tyre Performance Indicator (m)

| | Marked | Non Marked |
|---|---|---|
| Plunger | 7.2 years old | 4.1 years old |
| HS | 7.2 years old | 2.3 years old |

## 4.0 CONCLUSION

Summing up briefly, after undergoing accelerated ageing, the Shore A hardness of 'Non-marked' tyres was found to increase with age. This may indicate that 'Non-marked' tyres had lower resistance to heat build-up, thus having decreased high temperature performance. 'Marked' tyres displayed slightly improved performance in the bead unseating test. However, no significant association was observed between bead unseating performance and age. 'Non-marked' tyres did show an inferior result as compared to the 'Marked' tyres in the plunger test. Moreover, aged 'Non-marked' tyres suffered from tread chunking. On the same note, 5-year old 'Non-marked' tyres failed the requirements of MS 149:2008.

From the analysis done to correlate the tire performance and tire age, the result showed that the dynamic High Speed Test is more significant in determining tire performance as the test result yield a lower life span of the tyres. From the best fit trend line, two suggested indicators to reflect tire performance used in the study were the Tire Performance Degradation Indicator (d) and Minimum Tire Performance Indicator (m). In overall, the result for 'Marked' tyres showed superior performance as compared to 'Non-marked' tyres for all of the tests conducted. In both of the (d) and (m) result, 'Marked' tyres were found to be 3 fold in terms of tire age as compared to the result for 'Non-marked' tyres for dynamic test (High Speed) and

2 fold for static test (Plunger). Thus, it is safe to say that the suggested tire life span for proactive tyre replacement is 7.2 years-old for 'Marked' tyres and 2.3 years old for 'Non-marked' tyres.

To conclude, this study found that age did affect the safety performance of passenger car tyres and there were significant differences in performance between 'Marked' and 'Non-marked' aftermarket passenger car tyres. It should be noted that the accelerated ageing process conducted only accounted for the chemical ageing of the tyres. On-the-road conditions are far harsher for tyres due to cyclic loading, abrasion caused by traction and weathering due to humidity.

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