Characterisation of low-noise tyres for the roads of Hong Kong

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ABSTRACT

This study on low noise tyres started with a survey on commonly used tyres on 941 light duty vehicles. Subsequently, most common brands of tyre with a carefully selected size and tread block patterns were selected for testing on one commonly laid road surface, namely wearing course (WC), and one low noise road surface, namely polymer modified friction course (PMFC). Over 30 new and old tyres with varying properties of rubber hardness, depth and sizes were tested; tyre/road noise, air and road surface temperature, tyre pressure and vibration data were recorded. In order to identify the tyre properties on tyre/road noise, over 500 runs on the roads were made. It was found that the bi-directional & asynchronous (Michelin) was the quietest and the symmetrical tyre pattern (SRTT) was the noisiest on WC. The asymmetric pattern (Yokohama C.drive) became noisiest on PMFC. The change of driving speed from 50 to 70 km/h changed the noise order of bi-directional tyre (Yokohama A.drive) and the directional tyre (Dunlop Direzza). Tyre/road noise increased as the tyre rubber hardness increased owing to aging. The effects of the tyre tread depth and the tyre size on the level of noise are uncertain and minor.

Keywords: Type/road noise, Rubber hardness I-INCE Classification of Subjects Number(s): 11.7.1

1. INTRODUCTION

In order to abate the road traffic noise, in particular the tyre/road noise, it is imperative to have a thorough understanding of the tyre properties on tyre/road noise emissions. This study tried to identify the characteristics of low-noise tyres. Previous studies (1,2) found that the key tyre characteristics that have major impacts on tyre/road noise are: a) the tyre tread pattern, b) the tyre tread depth and c) the tyre rubber hardness. For the tyre tread pattern, we have adopted the criterion proposed by Sandberg and Ejsmont (1), i.e., randomization, symmetry and directionality. The tread depth and tyre rubber hardness were simply assessed by their measurements with the respective standard methods and equipment. Local surveys on commonly used tyres were conducted to identify the tyres to be selected for tyre/noise tests on one dense asphalt surface and one porous asphalt surface. The tyre/road noise was measured by a CPX vehicle developed at the Hong Kong Polytechnic University (3).

2. TEST TYRES AND ROAD SURFACES

2.1 Local Tyre Survey

According to the Transport Department's Annual Transport Digest 2011, up until 31 December 2010, there were 449,400 registered private cars, 18138 taxis and 3,340 heavy goods vehicles (HGV) in Hong Kong. In November 2011, a pilot survey on tyre brand was carried out covering 100 samples. The variance was found to be 48.3. The number of samples required for the tyre survey was calculated by applying the equation expressed below.

$$number \quad of \quad samples = \frac{\sigma^2 N}{(N-1)D + \sigma^2}$$

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A tyre survey was conducted to study the in-use tyre brand and tread depth of vehicles in the public car parks, both on-street and off-street, in Hong Kong. Data of the vehicle registration number, vehicle tyre, vehicle manufacturer, tyre name, tyre brand, tyre code together with the tread depth were collected for each sample. To collect the tread depth data, four points from the left front tyre of each sampled vehicle were measured, and the average tread depth was calculated.

2.2 Results of the Tyre Survey

941 private cars, 175 HGV, and 37 taxies were surveyed (Figure 1). For private cars, the most popular tyre brands were Dunlop and Bridgestone. Detailed distribution of tyre brand for private cars is shown in Figure 2. The most popular tyre brands for HGV (Figure 3) and taxis are Michelin and Yokohama respectively (Figure 4). The tread depths are measured for each sampled vehicle, and it is found that the average tread depths for private cars, HGV and taxis are 5.62 mm, 8.25 mm, and 4.00 mm, respectively (Figure 5).

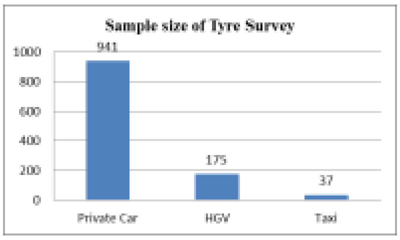

Figure 1: Sample size of tyre survey

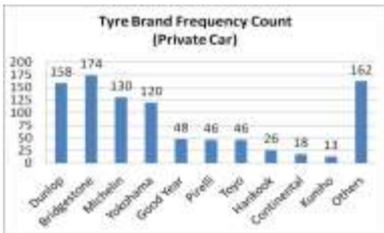

Figure 2: Tyre Brand Frequency Count (Private Car)

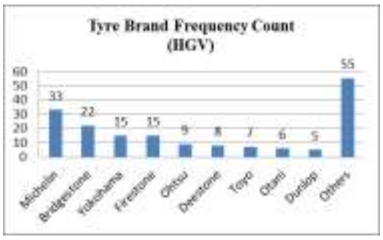

Figure 3: Tyre Brand Frequency Count (Heavy Goods Vehicles)

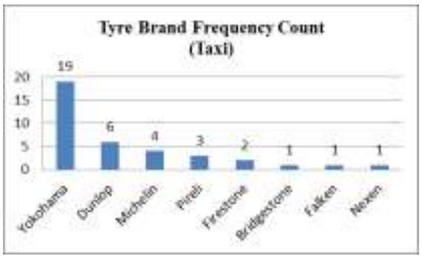

Figure 4: Tyre Brand Frequency Count (Taxi)

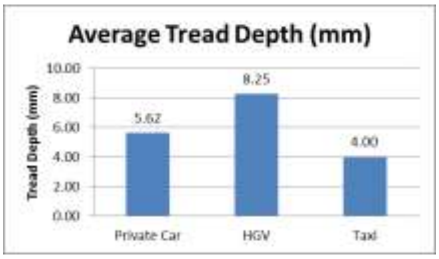

Figure 5: Average Tread Depth for Tyre Survey

2.3 Selected Test Tyres

Based on the tyre utilization survey and variety of tyre patterns of the commonly available tyres, the following six tyres were selected for tyre/road noise assessment as shown in Figure 6 below. SRTT is a reference and Michelin Primacy was claimed to be the quietest tyre. These two tyres were included for comparison although they were not a common tyre in Hong Kong.

2.4 Test Road Surfaces

One dense asphalt road surface, i.e. wearing course (WC) and one porous surface i.e. polymer modified friction course (PMFC) were selected as reference surfaces for tyre/road noise testing. Based on road surface conditions, speed limit as well as practicability and safety concerns for conducting tyre/road noise measurement with our Close-Proximity (CPX) vehicle, the two road sections as shown in Figure 7 were selected. Both road sections had a speed limit of 70 km/h which enabled the CPX measurements to be conducted at 50 km/h and 70 km/h.

2.5 Tyre rubber hardness preparation

We have to prepare tyres of the same batch (same brand and size) to have varying rubber hardness for testing (i.e., tyre/road noise test runs on the reference road surfaces) in order to assess the impact of rubber hardness on tyre/road noise. To achieve this, we employed natural hardening method and oven hardening method. In the former method, we exposed the tyres under strong sunlight or raining conditions while in the later method, we put the tyres in a temperature controlled oven for periods of time so as to achieve the marked differences in tyre rubber hardness.

Figure 6: Selected tyres for tyre/road noise tests

Figure 7: Selected test road surfaces

3. FINDINGS

3.1 Impacts of tyre tread patterns on tyre/road noise

The rubber hardness and tread depth of the selected tyres are measured as shown in Table 1. The rubber hardness of all six models is in round 61 -67 Shore A as they are all new tyres while the rubber hardness of SRTT is 70.1 Shore A as it is relatively old. The tread depth of tyres ranges from 7.0 to 7.7 mm. As both the tread rubber hardness and depth are in a narrow range, it is reasonable to assume that the differences in tyre noise level is mainly attributed to the different tread pattern.

Table 1: Tyre Tread rubber hardness and depth of test tyres

Tyre Model	Tread Rubber Hardness (Shore A)	Tread Depth (mm)
Uniroyal Tigerpaw (225/60R16)	70.1	7.0
Michelin Primacy LC (205/60R15)	61.4	7.2
Dunlop SP Sport LM703 (205/55R16)	62.5	7.3
Yokohama A.drive AA01 (185/60R14)	66.5	7.1
Dunlop Direzza DZ101 (195/50R15)	67.4	7.7
Yokohama C.drive AC01 (185/65R15)	66.0	7.4
Pirellii P4 (175/80R14)	63.2	9.0

L_{CPX} noise levels

Figures 8 and 9 show the measured noise levels corrected according to the ISO/DIS 11819-2. Michelin Primacy LC is consistently the quietest while SRTT and Yokohama C drive are the nosiest on both WC and PMFC at 50 and 70 km/hr, indicating that bi-directional/ synchronous/ asynchronous tyre tread pattern is the quietest. Michelin claims that its "silent rib" technology reduces tread pattern noise; the shape and distribution of the grooves, gives the intermediate ribs consistent rigidity around the circumference of the tyre and thus minimizes vibrations and noise. Dunlop on the other hand claims its variable pitch of larger tread blocks and effective groove arrangement manage to minimize noise. The figures also show the tyre and road surface coupling effect. For example, Yokohama A. drive is among the nosiest on WC but becomes quieter on PMFC.

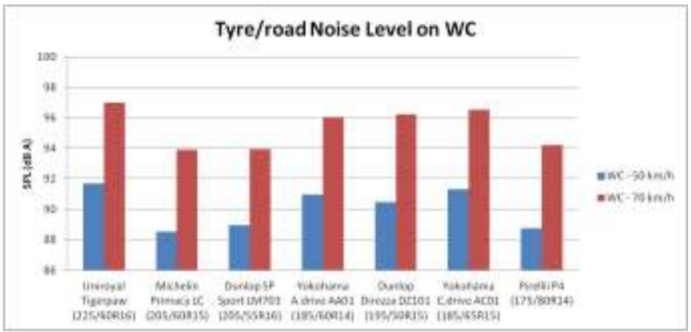

Figure 8 - Measured tyre/road noise levels on wearing course

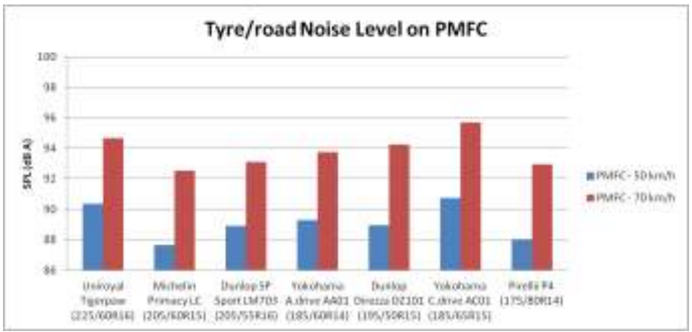

Figure 9 - Measured tyre/road noise levels on polymer modified friction course

CPX noise spectra

The noise spectra on wearing course at 50 km/hr (Figure 10) and 70 km/hr (Figure 11) show typical tyre/road noise pattern on the wearing course peaking at 1000 Hz band.

The spectra on the polymer modified friction course (Figures 12 and 13) clearly demonstrate a shift of the peak from 1000 Hz even down to 500 Hz band depending on the tyres. On the wearing course, the differences of noise level across each frequency band from 400 Hz to 5000 Hz are random. However, on the polymer modified friction course, the differences lie mainly between 500 Hz and 2000 Hz which signifies noises generated by tread impact, air pumping and stick-slip operation (1).

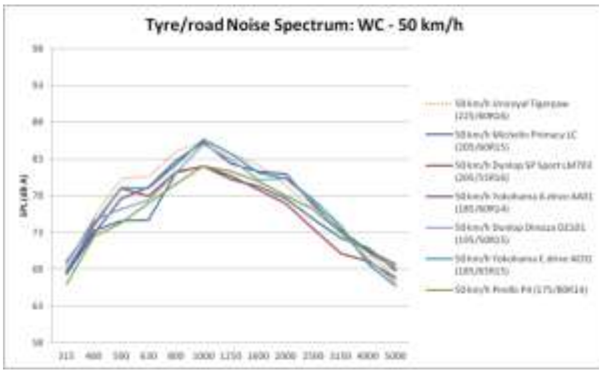

Figure 10 - Spectrum of tyre/road noise on wearing course at 50 km/h

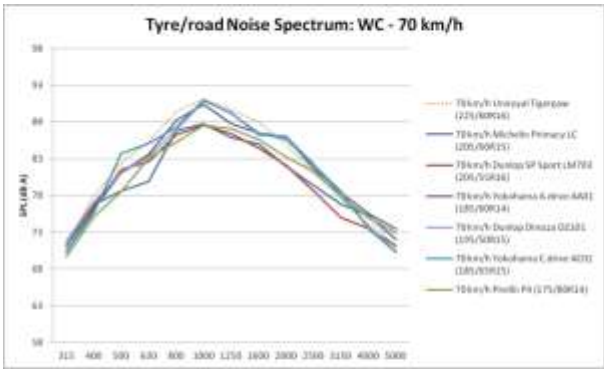

Figure 11 - Spectrum of tyre/road noise on wearing course at 70 km/h

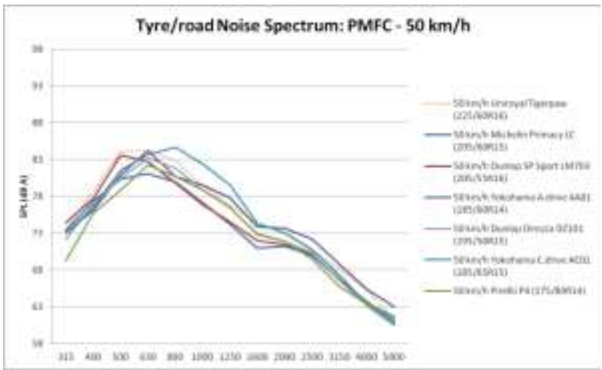

Figure 12 - Spectrum of tyre/road noise on polymer modified friction course at 50 km/h

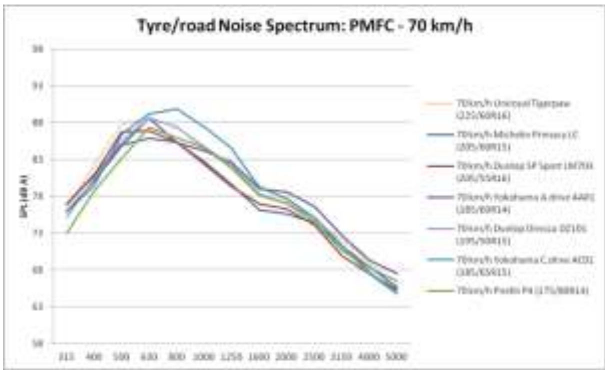

Figure 13 - Spectrum of tyre/road noise on polymer modified friction course at 70 km/h

3.2 Impacts of tyre hardness on tyre/road noise

Three pairs of **Dunlop Direzza DZ101 195/50R15 tyres**, one new pair and two aged pairs, were selected to perform the CPX tests. Table 2 shows the measured tread rubber hardness and depth. Figure 14 shows the L_{CPX} results. The L_{CPX} measured on PMFC exhibits a logical result in which the more aged the tyre, the more noise emitted. The phenomenon on WC, however, is not the same. The less aged tyre is nosiest.

Table 2: Tyre tread properties of Dunlop Direzza DZ101

Tyre	Tread Rubber Hardness (Shore A)	Tread Depth (mm)
D195N1	65.83	7.53
D195N2	66.96	7.23
D195A	80.92	5.30
D195B	80.17	5.41
D195C	83.38	3.40
D195D	83.75	3.07

T-test results show significant differences (at 0.05 level) in L_{CPX} between the new tyres and the aged tyres on the two surfaces for both driving speeds. The two aged tyre pairs demonstrate significant difference for the two following surface–speed combinations: WC–70 km/h and PMFC–50 km/h.

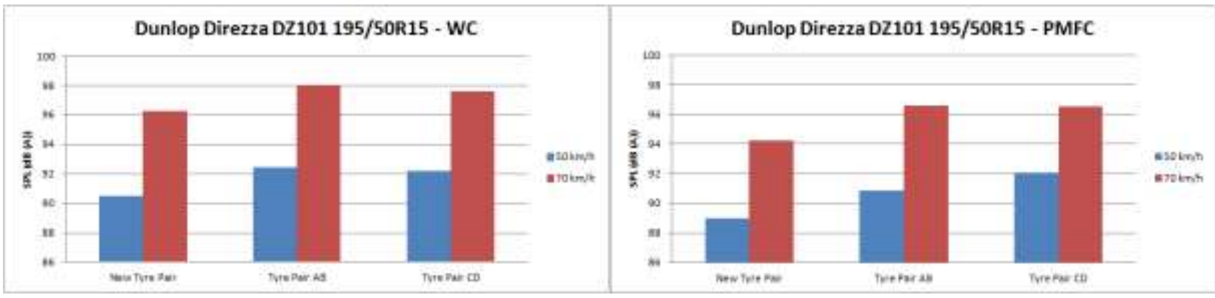

Figure 14 - L_{CPX} results of new and aged directional patterned tyres

Four Yokohama C.drive tyres of asymmetric tyre block pattern for light duty vehicle of the same batch, size 185/65R15 88H produced in week 31 of 2007, were also tested. The tread hardness and depth as well as the speed-corrected tyre/road noise measurements are shown in Table 3 below.

Table 3: Tyre properties and mean L_{CPX} for four Yokohama tyres (dB(A))

	Speed (km/h)	Tyre A	Tyre B	Tyre C	Tyre F
Hardness (Shore A)		73.67	68.42	69.00	70.17
Depth(mm)		5.77	7.39	5.78	7.42
WC	50	91.3	91.2	90.7	91.5
	70	96.6	96.4	96.0	96.6
PMFC	50	91.4	90.4	90.5	91.0
	70	96.3	95.4	95.5	96.0

The results show that there are very small differences (within 1 dB(A)) in the measured tyre/road noise with the four tyres at the two reference driving speeds of 50 and 70 km/h on the wearing course. The differences of the measured tyre/road noise levels on the porous asphalt surface remain small, albeit the difference between the highest and the lowest level is marginally bigger.

The tread depth of tyre A and C is nearly the same, the difference of tyre/road noise level between these two tyres can be considered as mainly attributed to the difference in rubber hardness. Indeed, the measured noise levels using tyre A is constantly higher than that using tyre C (0.6 dB(A) at 50 km/h and 0.8 - 0.9 dB(A) at 70 km/h), indicating that the measured noise level increases as the tyre rubber hardness increases.

In summary, Table 4 quantifies the changes of L_{CPX} per unit increase of rubber hardness.

Table 4: Changes of L_{CPX} per unit rubber hardness increase (dB(A)/shore A)

Road	Speed (km/h)	Yokohama C.drive Tyre B & F	Yokohama C.drive Tyre A & C	Dunlop Direzza DZ101
WC	50	0.1772	0.1265	0.1091
	70	0.1108	0.1291	0.0928
PMFC	50	0.3681	0.2014	0.1612
	70	0.3518	0.1663	0.1417

Sandberg and Glaeser (2008) found that the effect of tyre wear on tyre/road noise emission very much depends on the road surface type. The noise changes due to tread wear may amount to a decrease of 3-4 dB on very smooth-textured surfaces and an increase of 4-5 dB on rough-textured road surface (4). Rubber ageing adds one extra dB to the smooth-surface and two extra dB to the rough-surface. They reckoned that the air pumping and vibration excitation by tread blocks are dominating on smooth surface. On a rough surface, the texture-induced vibrations will dominate in all conditions. Our study found less than one dB difference for ageing tyres on both smooth (WC) and rough (PMFC) surfaces. Probably both our surfaces are not perfectly smooth or rough; the air pumping and vibration excitation caused by tread blocks are not high.

We further examined the change of L_{CPX} per unit change of rubber hardness for each frequency band for each of the tyres. Table 5 shows a case of Dunlop DZ101 tyres on PMFC. The increase in sound level is highest at 1000 - 2500 Hz relating largely to the air-displacement mechanism while there is decrease in sound level at very low frequency. Other studies have found that tire vibration mainly influences the tire/road noise below 1000Hz (5) and the air displacement mechanism relates to the high frequency noise while impact mechanism relates to the low frequency noise (6).

Table 5: Changes of L_{CPX} per unit rubber hardness for each frequency band for Dunlop DZ101 tyre

Frequency (Hz)	dB(A)/Shore(A)	
	70 km/h	50 km/h
20	-0.013938179	-0.178331144
25	0.100813859	-0.078954899
32	-0.060467391	-0.17482337
40	0.060278533	-0.020304574
50	0.094334239	0.005905193
63	0.137849864	0.091012002
80	0.108999321	0.016013587
100	-0.033159647	0.127822803
125	0.246773098	0.175692746
160	0.164033967	0.159038383
200	0.127936141	0.112269814
250	0.199771739	0.097696105
315	0.149629076	0.074538081
400	0.069060462	0.106576615
500	-0.01060462	0.025283175
630	0.009165082	0.033693539
800	0.158610054	0.108587485
1000	0.213326087	0.145246339
1250	0.256743207	0.195710107
1600	0.280684103	0.266496905
2000	0.268826087	0.242029552
2500	0.200445652	0.139874472
3150	0.182988451	0.104282835
4000	0.165150815	0.073622811
5000	0.195550272	0.106875038
6300	0.163188179	0.054903382
8000	0.133177989	0.04495671
10000	0.18282269	0.048991168
12500	0.188651495	0.085460069
16000	0.164982337	0.062811217
20000	0.169696332	0.083477959

3.3 Impacts of tyre tread depth on tyre/road noise

Table 3 that the rubber hardness of tyre B, C and F is nearly the same, the difference of measured noise level between these three tyres can be considered as mainly attributed to the difference in tread depth. The measured noise levels using the B and F tyres are always higher than that using the C tyre at 50 km/h and 70 km/h) on WC surface indicating that the shallower the tread depth, the quieter is the tyre on the WC surface. This phenomenon is unclear on the PMFC surface.

Three pairs of **Pirelli P4 - 175/80R14 of symmetric tread pattern,** one new and two aged, have been tested. The tread rubber hardness and tread depths of these tyres are shown in Table 6. The tread depth of the aged tyres reduced 1.21 to 2.24 mm compared to the brand new condition of 8.97 mm while the change in tread hardness is very small.

Table 6: Tyre tread properties of Pirelli P4 - 175/80R14

Tyre	**Tread Rubber Hardness (Shore A)**	**Tread Depth (mm)**
New Tyre 1	63.96	8.97
New Tyre 2	62.42	8.97
Used Tyre A	63.96	7.69
Used Tyre B	63.25	7.76
Used Tyre C	64.71	6.80
Used Tyre D	61.29	6.73

Table 7 quantifies the changes of L_{CPX} per unit of drop of tread depth in terms of per unit mm. The noise increases with the decrease of tread depth for all three tyre groups on the WC. The phenomenon is not that clear on the PMFC as the Yokohama tyre shows an opposite sign. There is a big limitation with these tests as it is nearly impossible to keep the rubber hardness unchanged while the tread depth reduces in real life driving conditions. And thus, the range of tread depth is very small with minor change of rubber hardness. With these limitations, the level of confidence of this observed trend is low. The increases in L_{CPX} may as well be partly due to rubber hardness variations.

Table 7 – Changes of L_{CPX} per unit of tread depth (mm) drop - dB(A)/mm

Road	Speed	Pirelli P4 - 175/80R14		Yokohama C.drive
	(km/h)	Tyre Pair AB	Tyre Pair CD	
WC	50	0.2366	0.1363	0.2152
	70	0.2146	0.1161	0.1227
PMFC	50	0.0157	0.8050	-0.1517
	70	0.4855	0.6932	-0.1208

3.4 Impacts of tyre size on tyre/road noise

Three new pairs of Dunlop tyres with same pattern but different sizes were studied. The interactions of these tyres on WC and PMFC differ as shown in Figure 16. The L_{CPX} levels on WC have very little difference, i.e., within 1dB(A) for both 50 and 70 km/h but L_{CPX} levels on PMFC indicate the smallest tyres are the nosiest in both speeds. T-test confirms the significant difference in the case of PMFC.

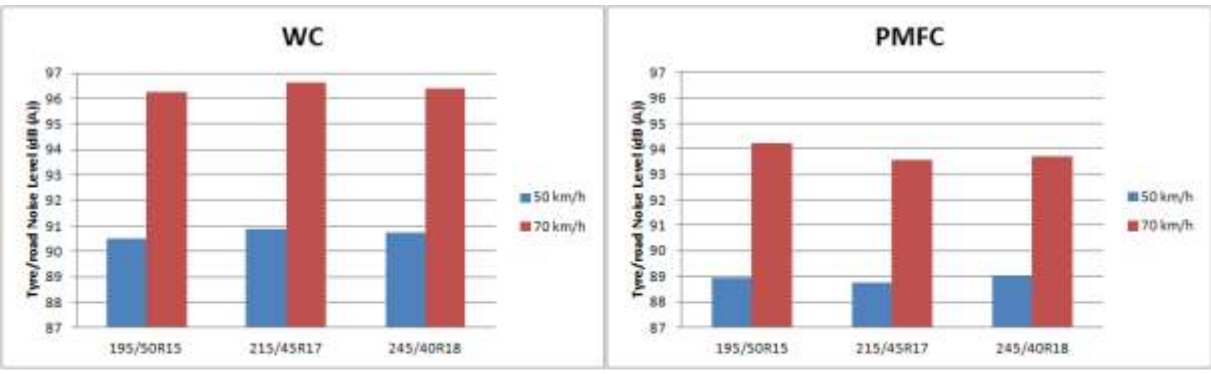

Figure 16 - L_{CPX} results of new directional patterned tyres of different sizes

4. CONCLUSIONS

We tried to identify low-noise tyres in this study on both dense asphalt and porous asphalt surfaces. We found that the bidirectional asynchronous tyre, i.e, Michelin Primacy LC tyre is consistently the quietest one. The noise level increases with the tyre rubber hardening. The rate of noise increase per unit rubber hardness increase ranges from 0.1091 to 0.1772 on WC but 0.1612 to 0.3681 on PMFC at 50 km/h. The change of speed to 70 km/h does not have significant impact on the rates. The highest rate of noise increase is found at the range of 1000 to 2500 Hz indicating the dominance of the air displacement mechanism. The noise level changes with the tyre tread depth or the tyre size are very small and un-certain.

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