# On the Irregular Wear Over Tread Belt Separations

John W. Daws, Ph.D., P.E.
Daws Engineering, LLC

## Abstract

The present analysis uses data on irregular wear over artificially-created tread separations presented in ITEC 2004 [1]. These data are separated into groups by tire inflation pressure. It was found that tires inflated to full inflation pressure had irregular tread wear over the separation that varied exponentially as the size of the separation. A mathematical model is developed for predicting the relative wear over a separation based on the base rate of wear of the tire.

## Introduction

The wear rate of tread rubber over internal tread belt separations has long been a point of contention among tire experts. In litigation, plaintiffs routinely allege that a “bald spot” in the tread is a clear indication that the tire had a developing tread belt separation, and that this visible indication was present for a “long” time prior to the actual separation and failure of the tire in the case. The term “long” will invariably be at least as long as the time period between the last service and the incident, even if this time period is months. Hence, the rate at which this irregular wear develops in the tread becomes the key point of discussion, especially when there are only a few hundred miles between the time the tire was inspected by a service provider and the time of the accident.

## Background

Until recently, there has been no data upon which to base opinions about the rate of tread wear over a tread belt separation. There have been attempts to cut tires between the steel belts and measure the wear as the tires are driven. This approach suffers from the problems that the separation size is only known approximately, the tread often chunks out, and the tread is not attached along the shoulder as it would be in a tire in service. However, at the ITEC 2004 meeting, Brico [1] published data that was obtained by measuring wear over separations that were created in tires by building in (prior to vulcanization) thin plastic films between the steel belts. This method clearly addresses the complaints about previous methods in that the tread edge is not cut and the separation is of a known size. Separations of 4 square inches (2x2) and 16 square inches (4x4) were built into the tires. These tires were run over distances of up to 2500 miles, and the most worn point over the separations as well as the wear over regions without separations were carefully measured. The actual tread depths measured for all test conditions are shown on Page 9 of the 2004 paper.

In the study, tires were run under two separate pressure conditions. Some of the tires were run at the vehicle's recommended operating pressure, and others were run at half the vehicle's operating pressure. A statistical analysis on the wear rates of all the tires was performed and it was concluded that there was a difference in the wear rate associated with separation size, but that this difference was not statistically significant.

**Present Analysis**

In the present analysis, the same data is analyzed in a different manner to attempt to discern whether the data shows more significant results. If the original data is segregated by the pressure condition, two data sets can be developed for analysis. These sets are: (1) tires run at the recommended vehicle pressure, and (2) tires run at half the recommended vehicle pressure. In the 2004 study, there were two tires that were run at full pressure, and these tires were run on the left and right rear tire positions, respectively. Plotting the data for the right rear tire results in the curves shown in **Figure 1**.

Note that there are three sets of points corresponding to no separation, the 2x2 separation, and the 4x4 separation. A regression line is fitted through each of the data sets. Straight line regression is used because the mileages are relatively short and the separation sizes, following the original analysis, remained essentially fixed. The slopes of these lines represent the instantaneous wear rate over the separation of the given size with essentially full tread depth. This is significant because the tread thickness can be expected to increase the stiffness of the tread and outer steel belt. The stiffer this tread and outer steel belt is, the less distortion is expected on it while entering and leaving the contact patch area. It is this distortion in the contact patch area that gives rise to the irregular wear, so the wear data may be considered to represent a <u>minimum</u> wear rate over the separation of a given size. When the same plot is generated for the left rear tire, again at full pressure, the result is shown in **Figure 2**.

It is significant that each of the two tires shows a different wear rate for each of the separation conditions. The 2004 data was developed by driving the test tires around a closed-loop course. It is not explicitly stated in that paper whether or not the direction of travel was alternated periodically during the test. However, outside versus inside cornering could yield very different results on the left and right side tires if all the driving was in the same direction.

The data for the tires inflated to half the recommended vehicle pressure is shown in **Figures 3, 4, and 5**. These charts show a different characteristic in that while the wear rate is different for the case of no separation versus the case of a separation, there was no significant difference observed with separation size. That is, separations of 2x2 and 4x4 yielded almost identical wear rates. This suggests that the contact patch is being loaded in a very different fashion at half the recommended operating pressure. One visual clue that a tire is being operated in an under-inflated state is excessive wear of the outer tread ribs of the sculpture. This results from the contact pressure shifting to the outer ribs as pressure is reduced in the tire. This pressure shift had a significant effect on the 2004 study, and suggests that analyzing the tires' wear data as one population was misleading. This is because the two pressure groups do not exhibit the same behavior relative to the independent variable (separation size in this case). There was no apparent correlation of separation size to wear rate for tires that were run at half the vehicle recommended pressure.

However, from **Figures 1 and 2**, there is a distinct relationship in the data between the separation size and the wear rate for tires run at the full recommended operating pressure. **Figure 6** shows a plot of the wear rate in mm/Kmile versus separation size for both the right and left rear tires at full vehicle pressure. This chart also shows the average data obtained at each separation size. In creating this "average" data set, it was assumed that normal road driving would wear real-world tires in a manner similar to the average of the left and the right tires in the 2004 data because the road curves would tend to be distributed evenly to the right and the left. Linear curves were fit through these data, yielding a relationship between the average wear rate and the separation size. This relationship is

$$R_w = 0.5058 + 0.0591S \qquad (1)$$

Where S is the size of the separation in square inches and $R_w$ is the wear rate in mm/Kmile. The underlying data, and therefore this relationship, apply only to tires that are inflated to the vehicle's recommended pressure. Also, since these data were taken beginning with full-depth tread, this relationship likely represents a lower bound to the wear rate. The reason for this is that the stiffer the tread and outer steel belt, the more resistant it will be to distortion in the contact patch. In tires that have failed due to tread belt separation, the tread over the separation will typically be worn below the wear bar height in some cases, and into the subtread in others. It is distortion of the tread and outer steel belt over the casing and inner steel belt that gives rise to the irregular wear. Equation 1 is made up of two parts. The constant 0.5058 represents the base wear rate, i.e., with no tread separation, in mm/Kmile for the test tires. The 0.0591S term represents the differential wear rate due to tread separation.

**Figure 7** shows a similar plot for the tires run at half the recommended pressure. As noted above, there is no relationship between wear rate and separation size. The presence of the separation is significant, but its size is not.

**Figure 8** shows the relationship described by **Equation 1** for full-pressure tires in a graphical format. This figure shows both the total wear rate and the differential wear rate expressed in $32^{nd}$Inch/Kmile. The differential wear rate is an indication of how much wear would occur at the most worn spot over a separation relative to some adjacent area where there was no separation. The total wear rate gives an idea of the amount of material that would be removed at the spot immediately over the separation area. Again, these data likely define a lower bound to the wear rate over a separation between the two steel belts of a tire.

Larger separations are frequently found in tires that have failed due to tread belt separations. These separations are generally thumbnail-shaped, as described by Daws [2]. The actual separation size generally can be estimated as the area of a parabola with a height dimension, h, equal to the excursion of the separation radially into the tread area, and a chord dimension, c, equal to the length of the separation in the circumferential direction. The separation area can then be estimated as

$$S = (2/3)ch \qquad (2)$$

Most fatigue-related tread separations grow at increasing rates as the separation increases in size. Daws [2] described growth rates in fatigue-related edge cracking as starting at a constant of about 0.1 nm/rev until the crack depth exceeds 5-20 mm, and then accelerating as the crack size increases. Growth rates of 0.1 mm/rev were measured at crack depths of 50 mm, which would yield a conservative rate of 50-70 mm/mile. Ultimate growth rates of that order indicate that the separation grows dramatically in the final few miles of travel, so the total area of the fatigue thumbnail corresponds to the final relative wear rate prior to separation. Polished regions in the fatigue crack occur due to long-term rubbing of the torn surfaces, and so represent minimum areas of the fatigue crack that were present for a more extended period of time. These polished areas, then, probably represent the area that would be appropriate for use in estimating the longer-term wear rate over the initial separation.

The actual data taken in the 2004 study were for separations of 4 and 16 square inches. Extrapolation of the data outside this range has certain risks, but tread belt separation rarely occurs over separations this small. Another issue is the relative abrasion resistance of a particular tire's tread rubber in comparison to the tires used in that study. Passenger tires of nearly the same tread depth are available in mileage classes from 20,000 to 80,000 miles, indicating a factor of four spread in potential wear rates. **Figure 9**, then, recasts the present analysis in terms of the percentage increase in wear rate expected for a given separation size. The base wear rate would be the average wear rate on the tire over areas having no tread separation present. This can be estimated from the expected tread life of the tire and the tread depth when the tire was new using a simple straight-line relationship. The expected wear rate over a separation can then be estimated as a percentage increase in the base wear rate. Mathematically, then, this relative wear ratio would be given by

$$R'_w = 1 + 0.117S \qquad (3)$$

The relative wear ratio would then be multiplied by the expected linear wear rate of the tire in question to obtain an estimated rate of wear over the separation found in the tire during the forensic examination. As with all simple models, the analyst may need to consider increasing or decreasing the wear rate from that predicted when dealing with high or low pressure tires, very aggressive wear surfaces, and so on.

**Conclusions**

The present study reviewed the data presented in 2004 [1]. These data were analyzed by separating the full-pressure and half-pressure tires into two data sets. The following conclusions were drawn:

1. The data in the two data sets demonstrated different wear behavior.
2. For tires inflated to half the recommended pressure, the presence of a tread separation was significant to the instantaneous wear rate, but the size of the separation was not.
3. For tires inflated to the recommended pressure, the size of the separation was significant to the instantaneous wear rate.
4. The instantaneous wear rate over a tread separation was shown to vary linearly with the size of the separation.
5. The instantaneous irregular wear rate over a tread separation can be estimated from the present analysis if the base wear rate of a given tire can be obtained.

**References**

[1] Brico, J.C., “Irregular Wear Over Tread-Belt Separations”, International Tire Exhibition and Conference 2004, Paper No. 20, Akron, Ohio, Sept., 21-23, 2004.

[2] Daws, J.W., “The Fractography of Tire Tread Separations”, Paper Presented at a meeting of the Rubber Division, American Chemical Society, April 28-30, 2003, San Francisco, CA., Paper No. 67.

**Author Contact Information**

Dr. John W. Daws holds a Ph.D. in Mechanical Engineering from Virginia Polytechnic Institute. He has over twenty years experience in the tire industry, having worked for Michelin Tire Corp. in a number of technical roles. He also worked at Exponent Failure Analysis Associates in the areas of tire forensics and vehicle handling. He is currently Principle Engineer of Daws Engineering, and consults routinely on tire forensics and vehicle handling. He can be contacted at jdaws@dawsengineering.com

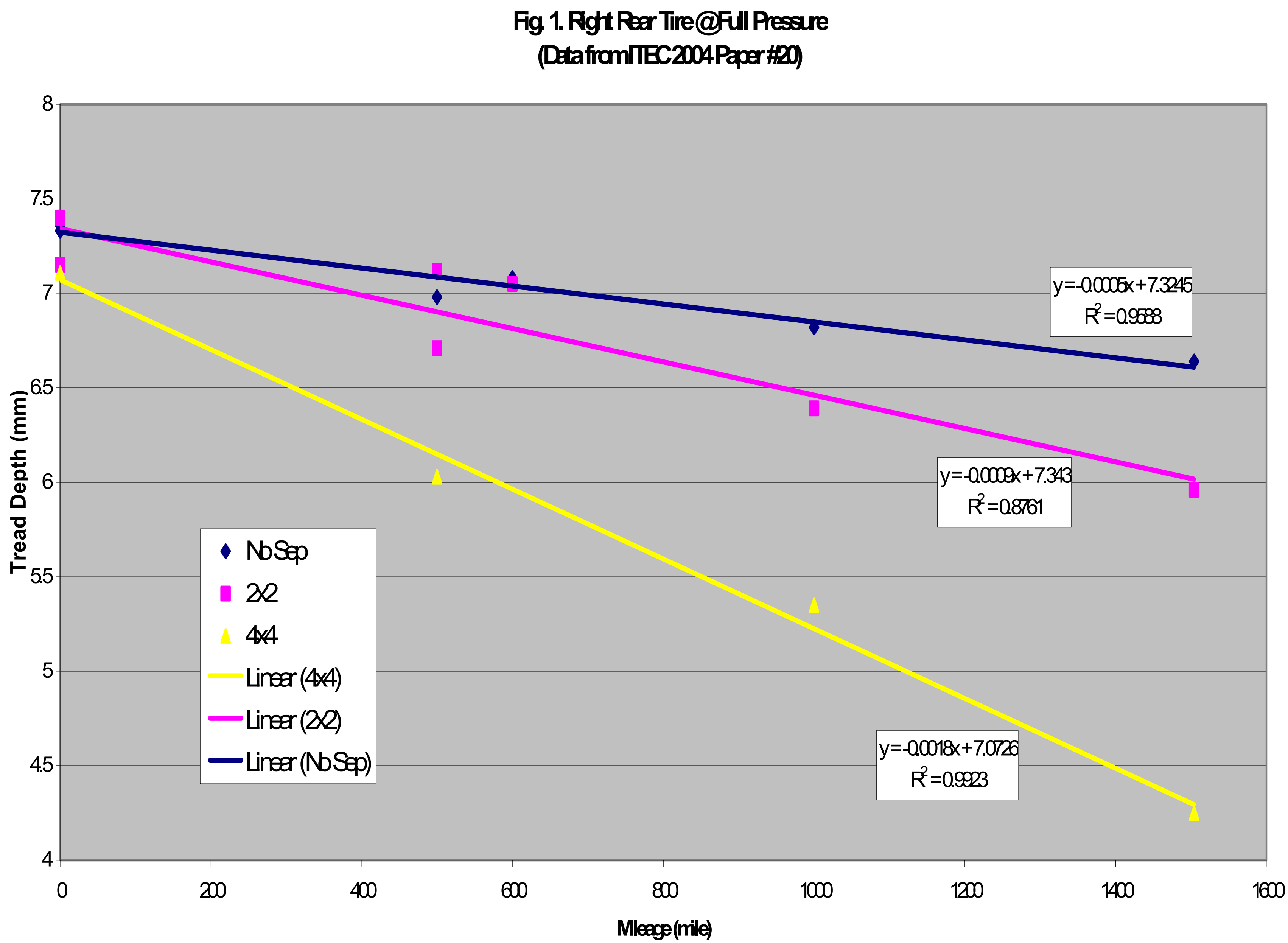
Fig. 1. Right Rear Tire @Full Pressure
(Data from ITEC 2004 Paper #20)
Tread Depth (mm)
Mileage (mile)
8
7.5
7
6.5
6
5.5
5
4.5
4
0
200
400
600
800
1000
1200
1400
1600
y=-0.0005x+7.3245
R2=0.9588
y=-0.0009x+7.343
R2=0.8761
y=-0.0018x+7.0726
R2=0.9923
No Sep
2x2
4x4
Linear (4x4)
Linear (2x2)
Linear (No Sep)

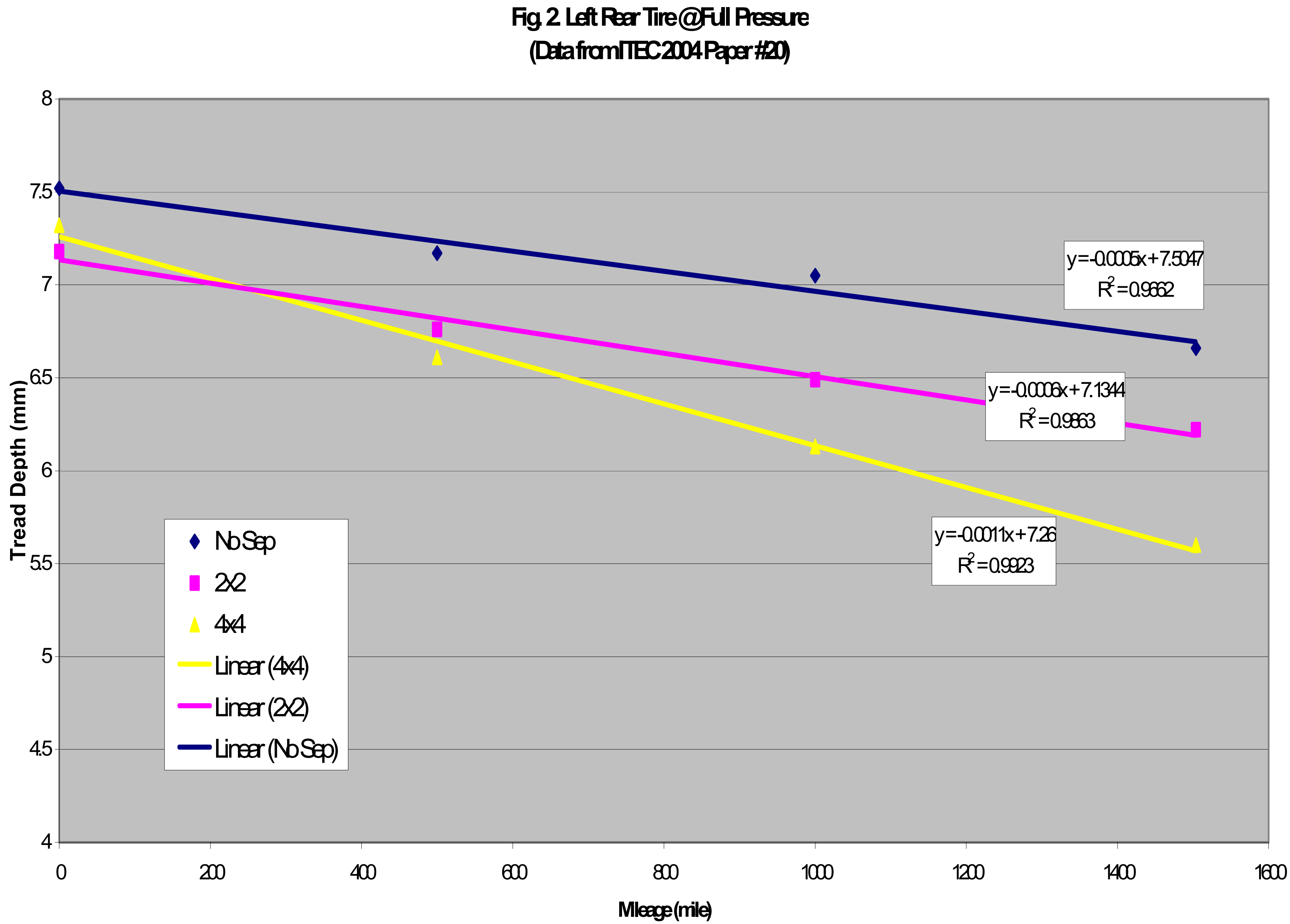
Fig. 2 Left Rear Tire @Full Pressure
(Data from ITEC 2004 Paper #20)
Tread Depth (mm)
Mileage (mile)
8
7.5
7
6.5
6
5.5
5
4.5
4
0
200
400
600
800
1000
1200
1400
1600
y = -0.0005x + 7.5047
R2 = 0.9662
y = -0.0006x + 7.1344
R2 = 0.9863
y = -0.0011x + 7.26
R2 = 0.9923
No Sep
2x2
4x4
Linear (4x4)
Linear (2x2)
Linear (No Sep)

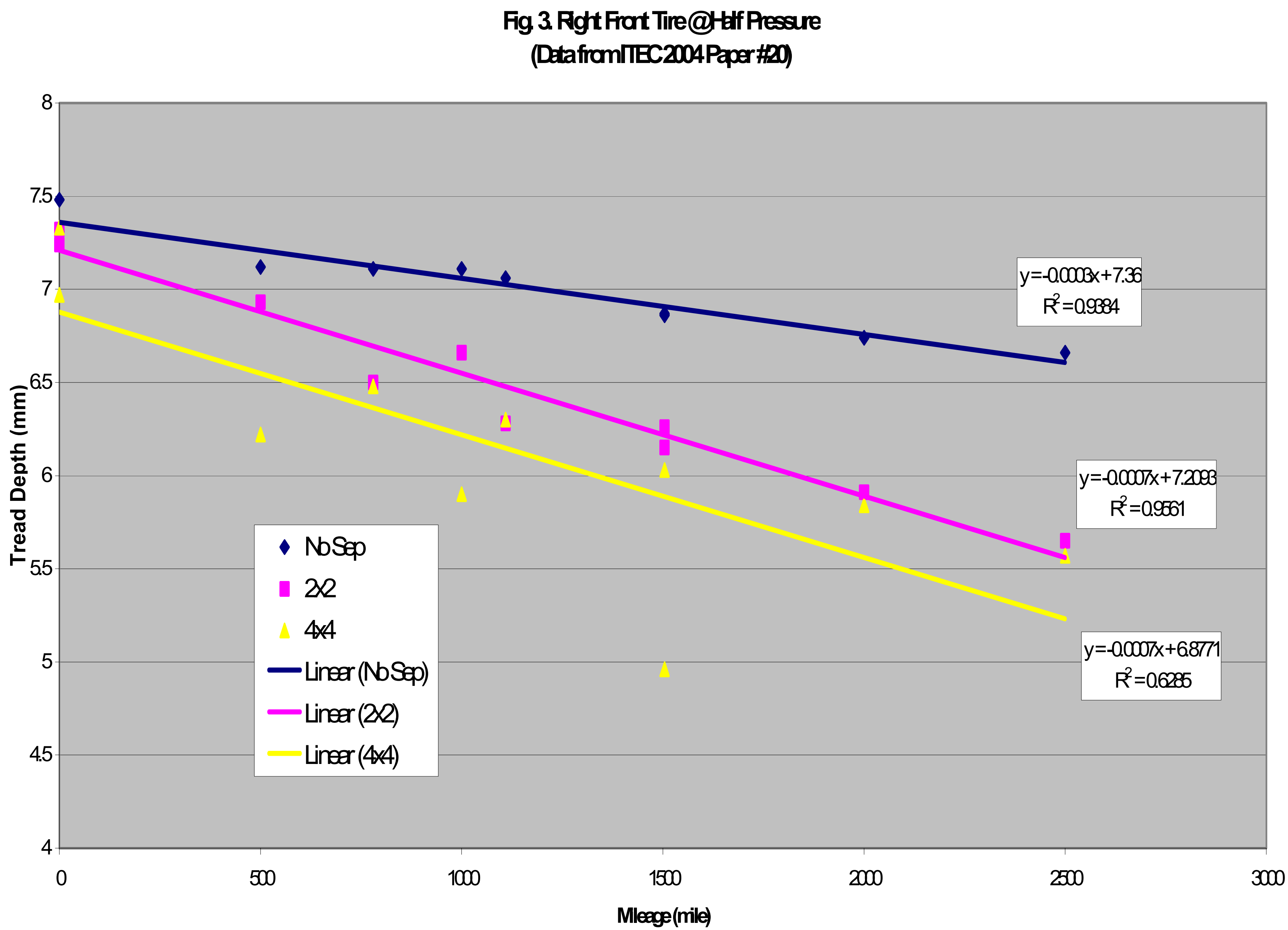
Fig. 3. Right Front Tire @ Half Pressure
(Data from ITEC 2004 Paper #20)
8
7.5
7
6.5
6
5.5
5
4.5
4
Tread Depth (mm)
0
500
1000
1500
2000
2500
3000
Mileage (mile)
No Sep
2x2
4x4
Linear (No Sep)
Linear (2x2)
Linear (4x4)
y = -0.0003x + 7.36
R2 = 0.9384
y = -0.0007x + 7.2093
R2 = 0.9561
y = -0.0007x + 6.8771
R2 = 0.6285

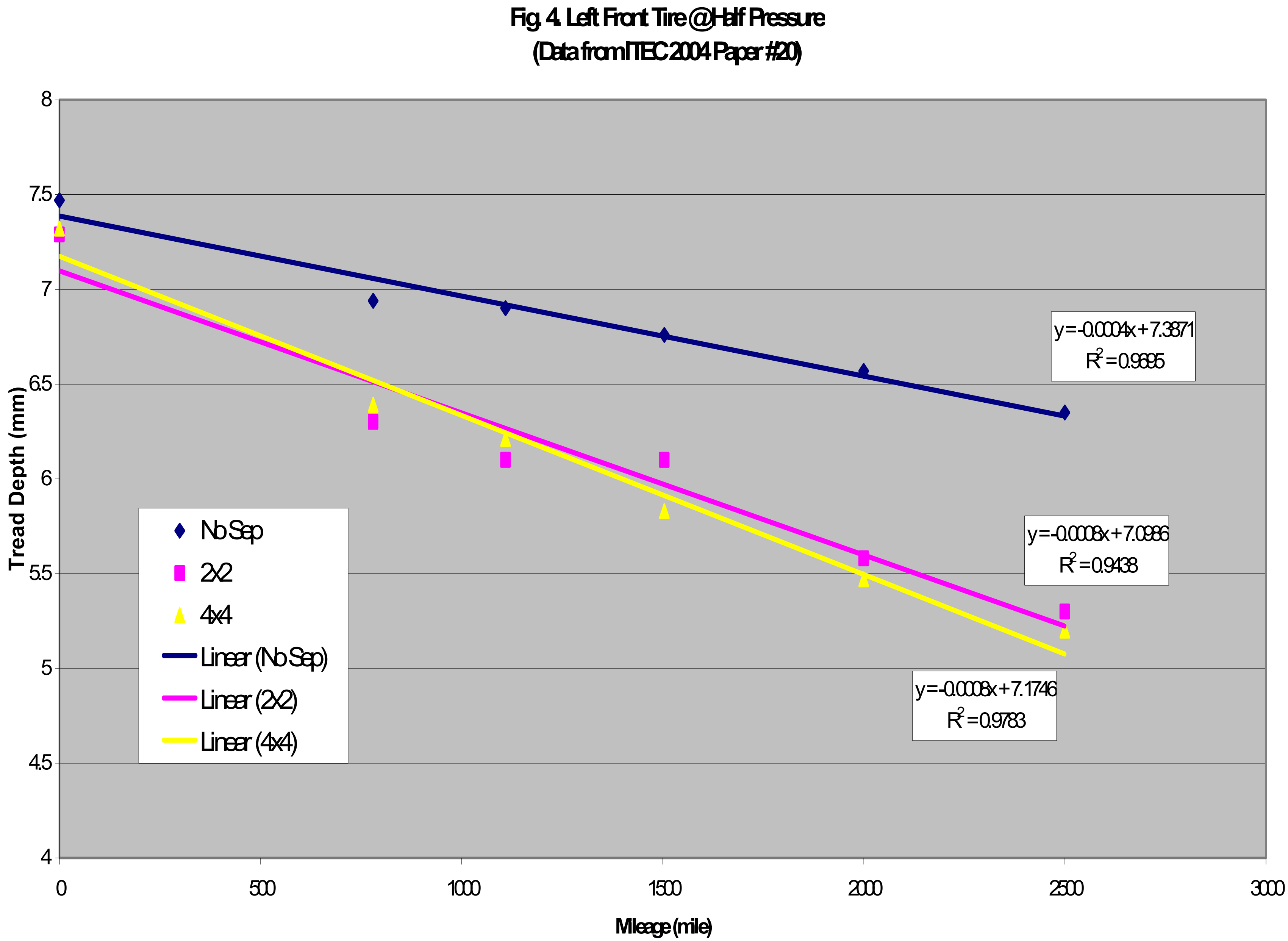

Fig. 4. Left Front Tire @ Half Pressure
(Data from ITEC 2004 Paper #20)
Tread Depth (mm)
Mileage (mile)
8
7.5
7
6.5
6
5.5
5
4.5
4
0
500
1000
1500
2000
2500
3000
No Sep
2x2
4x4
Linear (No Sep)
Linear (2x2)
Linear (4x4)
y = -0.0004x + 7.3871
R2 = 0.9695
y = -0.0008x + 7.0986
R2 = 0.9438
y = -0.0008x + 7.1746
R2 = 0.9783

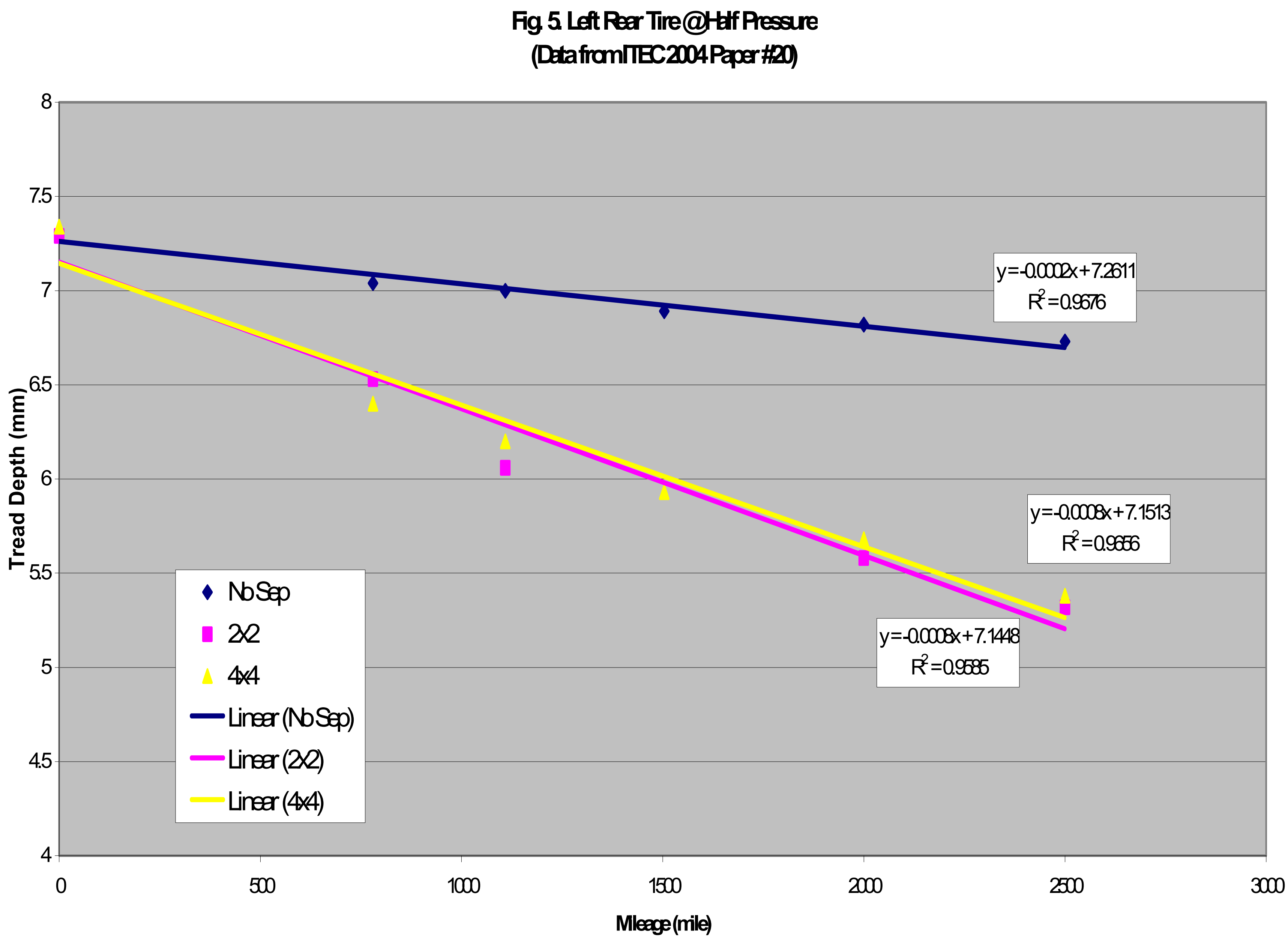
Fig. 5. Left Rear Tire @Half Pressure
(Data from ITEC 2004 Paper #20)
Tread Depth (mm)
Mileage (mile)
8
7.5
7
6.5
6
5.5
5
4.5
4
0
500
1000
1500
2000
2500
3000
y = -0.0002x + 7.2611
R2 = 0.9676
y = -0.0008x + 7.1513
R2 = 0.9656
y = -0.0008x + 7.1448
R2 = 0.9585
No Sep
2x2
4x4
Linear (No Sep)
Linear (2x2)
Linear (4x4)

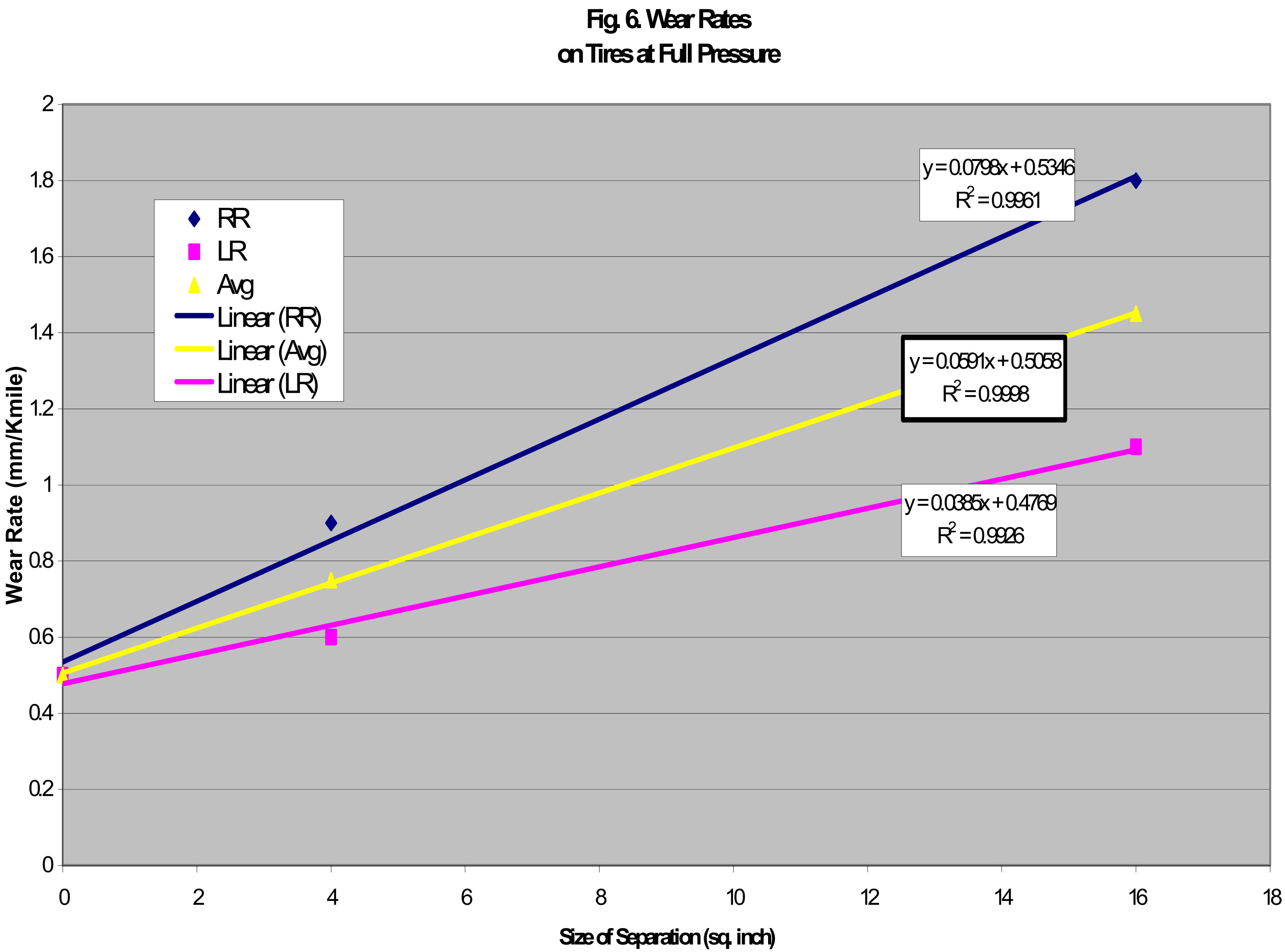
Fig. 6. Wear Rates
on Tires at Full Pressure
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Wear Rate (mm/Kmile)
RR
LR
Avg
Linear (RR)
Linear (Avg)
Linear (LR)
y = 0.0798x + 0.5346
R2 = 0.9961
y = 0.0591x + 0.5058
R2 = 0.9998
y = 0.0385x + 0.4769
R2 = 0.9926
0
2
4
6
8
10
12
14
16
18
Size of Separation (sq. inch)

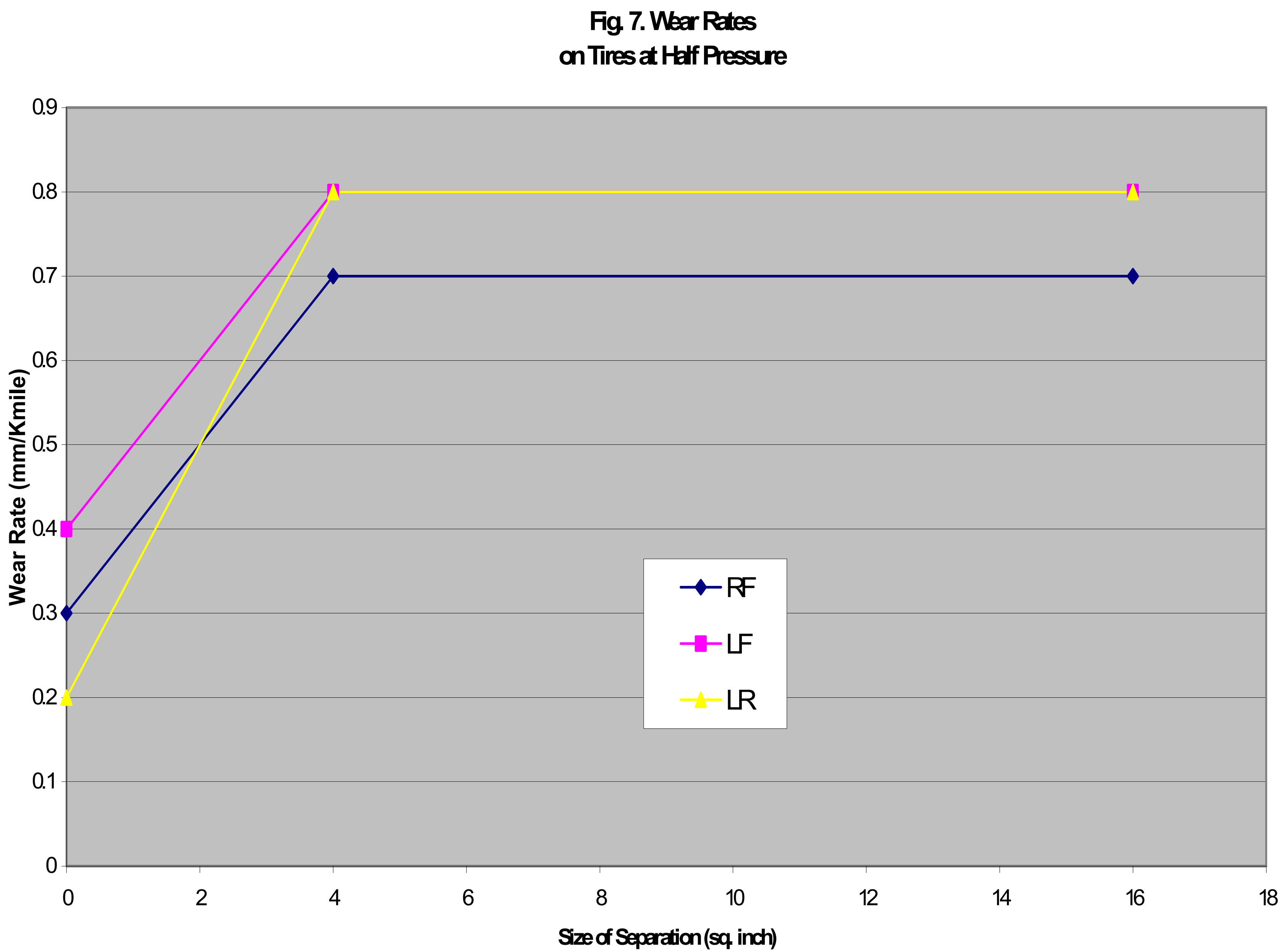
Fig. 7. Wear Rates
on Tires at Half Pressure
Wear Rate (mm/Kmile)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
2
4
6
8
10
12
14
16
18
Size of Separation (sq. inch)
RF
LF
LR

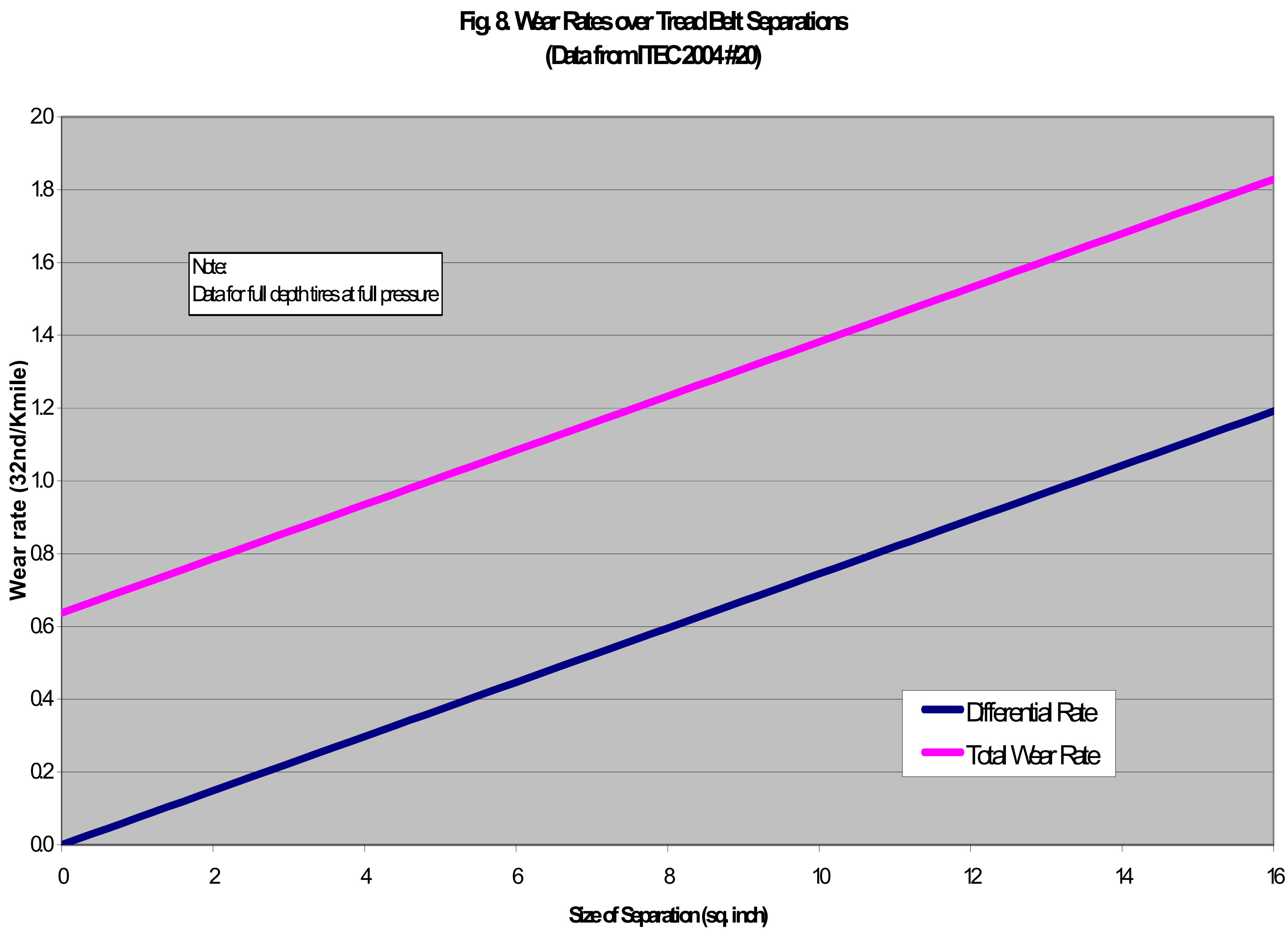
Fig. 8. Wear Rates over Tread Belt Separations
(Data from ITEC 2004 #20)
Wear rate (32nd/Kmile)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
12
14
16
Size of Separation (sq. inch)
Note:
Data for full depth tires at full pressure
Differential Rate
Total Wear Rate

Fig. 9. Differential Wear Ratio over Tread Belt Separations
(Data from ITEC 2004 #20)