wjert, 2022, Vol. 8, Issue 3, 62-74. *Original Article* **ISSN 2454-695X**

World Journal of Engineering Research and Technology
WJERT
www.wjert.org **SJIF Impact Factor: 5.924**

PREDICTING THE TIRE TREAD AGE (POTENTIAL MILEAGE) ADOPTED ON SPECIFIC MECHANICAL PROPERTIES IN THE LABORATORY

Mujid Hadi Al-Hatemmi*

Asst. Prof. Dr. At University of Kufa, Mechanical Dept., Engineering Faculty, Annajaf, Iraq.

Article Received on 10/01/2022 **Article Revised on 30/01/2022** **Article Accepted on 20/02/2022**

***Corresponding Author**
Mujid Hadi Al-Hatemmi
Asst. Prof. Dr. At
University of Kufa,
Mechanical Dept.,
Engineering Faculty,
Annajaf, Iraq.

ABSTRACT

As the mileage of tyre is still evaluated by road test though it is a very expensive and time-consuming process. It is required to investigate a new laboratory method for predicting tire age (potential milage) by using a parameter called Potential Mileage Index (PMI) of tire. The mechanical wear in a tire is dependent on *tire geometry* and *tread compound*. So, for predicting tire wear which is leading for estimating the tire age in the laboratory, therefore it is necessary studying some mechanical properties that have a strong tie with tread compound. In this paper it has been studied some mechanical properties of different *tread compounds* considering the tire geometry is constant. The mechanical properties are *modulus, heat built-up and relative abrasion (wear) loss* then, the tire mileage is calculated in both normal and aged conditions by using PMI which is computed from an empirical relation. As PMI can mainly give an indication for wear resistance which is the major measure of tire age (mileage) therefore, practically predicting the mileage of tire in the laboratory become possible. For checking whether laboratory results given actual prediction or not, it has also studied the actual mileage of bus tires at hot re-treading condition using the same compounds, where the comparison between them shows significant results. Six mixes are used for this purpose. Results have been promising, competitive and valid for evaluating the tire life especially when compared with actual values.

KEYWORDS: PMI; relative abrasion loss; heat build-up; modulus; hot re-treading.

1. INTRODUCTION

The wear behaviour of tire is an important phenomenon which depends on the compromise between friction and abrasive wear properties. Different laboratory tests on abrasion have been developed to correlate these properties with the wear behaviour of tires under service conditions. But these tests mainly deal with the mechanics of abrasion as stated by Satake *et.al.* (1970), Schallmach(1965), Halim(1990) and Marco(2004)[1-4] Actual correlation of laboratory test results with tyre wear is unlimited, but predicting at least the tire wear by using some specified mechanical properties that give an indication for the tire wear is possible as confirmed by Hall (2001) and Wolff (1993)[5,6] This paper has taken such aspects in consideration.

Earlier studies show that the abrasion of rubber compounds is dependent on several factors like heat built-up, fatigue properties, ageing of rubber compounds, etc. which had been conducted by Senapati (1986) and Manas (2001).[7,8]

Other than tread compound, factors such as driving habit, vehicle design, travelling conditions (i.e., Speed, load, slip angle etc.) and tire geometry all of these factors are considered to be constant as mentioned by Farhan (2014) and Rubber Compounding (2017)[9,10] excepting surrounding atmospheric conditions which have a fair effect on tyre wear. Basically, the wear in a tyre is dependent on two aspects tread compound and tyre geometry. Regarding tread compound, the laboratory tests has taken into account the prediction of the potential mileage of tires through calculating PMI depending on some specified mechanical properties such as *relative abrasion loss by volume* which is inversely proportional with *abrasion resistance* (mechanical wear), *heat build-up* represented by hysteresis and loads applied on the tires represented by *modulus*.

The geometry aspect of tire has different parameters which are related to the mould design and tyre construction, where they have been proposed constant. So, in the case of re-treading process, which means creating a new tread on the used tire or re-treaded the tire, the wear of the tire will mainly depend on the tread compound. One of the ways to improve the mileage of a re-treaded tyre is to improve the abrasion (wear) resistance of tread compound as the tyre geometry remains constant or neglected.

There are four broad categories of tyre tread wear depending on the different wear mechanisms which may coexist simultaneously. They are; 1- Abrasive wear, 2- Hysteresis wear, 3- Wear due to squirming motion, and 4- Tread reversion due to high ambient temperature.[7]

Depending upon above tread wear mechanisms three different mechanical properties are considered for studying re-treading compound so as to enhance abrasion resistance and thereby interpreting the tire mileage. Enhancement has carried out via proper formulation coming from experience and standards recipes, *the mechanical properties* are summarized as.[7,10]

1. ***Abrasion resistance*** measured by *(inverse relative volume loss)* due to wearing of tread compound which is related to tire traction and road severity.
2. ***Heat built-up*** which has accumulated due to resilience cycling of a tread compound through rolling the tire on road.
3. ***Modulus*** of a compound which is related to squirming motion or shifting between the tire tread elements and road surface.

The normal and aged values of these above mechanical properties help to be correlated with the abrasion resistance behaviour of the rubber which is an important parameter for tire tread mileage. Also, its average of normal and aged values taken in laboratory will simulate the results taken from road tests which concern truck tire test for several kilometres on road.

2. MATERIALS AND METHODS

Six different mixes were considered (Table 1) which proposed by the current study. Mixing of compound was carried out on an open roll mill (150mm ø x300mm stroke), moulding and laboratory testing were done as per ASTMs & DINs (Standards) methods. Basically, all these mixes (recipes) are fit to be base compound for making tire tread of trucks so as to be tested in laboratory and on road. Tests of *300%Modulus*, *Tensile Strength* (T.S) and *Elongation% at break* (Elong.) are done by means of Tenso-meter (Monsanto T10), in accordance with ASTM-412-16. *Hardness* was conducted according to ASTM-D-2240-15 ORD-531-15. *Abrasion loss* has been calculated with accordance of ASTM D1630, also Designation 1630 describes the apparatus and procedure for using the National Bureau Standards Abrader in USA. The *Heat Build-up* test was carried out by using Goodrich Flexo-Meter as described in ASTM-D623-14(2014), all mentioned standards are used from reference of Annual Book of ASTM Standards (2017) **[11]**. The test results were tabulated in (Table 2). The major mechanical properties which study has based on are *300%Modulus, Abrasion loss and Heat Build-up*, the others like Tensile Strength (T.S), Elongation% at break (Elong.) and hardness are taken Only for observation and inspection which are giving an indication for the mentioned mechanical properties.

2.1 Hypotheses

The relative PMI which is the major guide parameter for illustrating tire mileage are calculated as per the following details:

According to the evidence taken from history of road tests. It is proposed that the Potential mileage index or tire wear Index ***PMI*** is ***directly*** related to *relative abrasion loss* ***RAL*** *(by volume loss)* and *heat build-up (due to resilience)* of tread compound considering the *modulus* is constant. Similarly, the tyre wear Index ***PMI*** is ***inversely*** related to *modulus* considering *relative abrasion loss* and *heat built-up* are constant where clarified by Mutar (2013).[12] Relating to hypotheses mentioned above where PMI is directly proportional with Relative Abrasion Loss and Heat Built-Up and inversely proportional with Modulus. So, it could be considered an empirical relation containing a constant to have the following equation (1):

$$PMI = C \bullet \frac{\text{Relative Abrasion Loss RAL (by volum loss)} \times \text{Heat Built-Up}}{\text{Modulus}} \quad \text{-------------} \ (1)$$

Where **C** is constant, and that constant is considered *ONE* for calculation purposes.

It can be also assumed that ***PMI*** *is inversely a measure of abrasion resistance* or tire wear resistance when, ***PMI*** *increases means abrasion resistance decreases and vice versa*. This relation could be mentioned as $PMI \ \alpha \ \frac{1}{\text{Abrasion Resistance}}$ -------- (2)

In other words when abrasion resistance is going to be high, PMI will be low and relative potential mileage (tire life) is consequently high.

For verification that the results computed using equation (1)" is really predicting the tire wear. It is required to make a comparison with actual measurements for tire wear (road tests). As the six mixes sets mentioned in table-1 are used for laboratory test, it would be recommended to use the same six mixes sets as a bus tire tread which have been re-treaded for road test. Considering the same working conditions of re-treaded bus tire tread, compounds will be prepared in laboratory should be aged as the same of bus tread compound. The mileage of tire was estimated via comparing the laboratory tests by means of equation 1, and road tests calculated by equation 3. Road test is the actual test taken in consideration the

mechanical wear which means relative abrasion loss (RAL) by using the following equation.[10]

$$\textit{Mechanical Wear (RAL)} = \frac{Tread\ volume\ before\ wear - Tread\ volum\ after\ wear}{Total\ Tread\ volume\ before\ wear} \quad \text{--- (3)}$$

2.2 Design of the mixes

All the following six mixes appearing in table 1" are designed by the researcher of this paper depending upon rubber technology literatures and tire technology explained by Vanderbilt Hand Book (1999) and Al-Jebory, *et.al*. (2021)[13,14] besides experience of researcher during conducting a lot of experimental rubber mixes in State Company for Tire Industries in Annajaf. All mixes are designed with different levels of each rubber compound in tri-blend of Natural rubber (NR) type ISNR-20 as base rubber, styrene butadiene rubber (SBR) type SYNAPRENE-0212 and polybutadiene rubber (PBR) type 1220 resulting in different mechanical properties.

In the 1st set of mixes (mixes1, 2 & 3), is designed to have lower loading of carbon black reinforcement 40 part per hundred rubber (pphr) and higher loading of oil (14 pphr), and (25pphr) of SBR to achieve *medium modulus*, except for mix 3, SBR is of (20pphr) to have comparative mechanical properties to mixes 1 and 2.

Mixes of the 2nd set (mixes4,5 &6), are designed to have higher quantity (50-60 pphr) of Styrene-Butadiene Rubber (SBR) SYNAPRENE-0212 but with higher level (18pphr) of process oil in low natural rubber (30-40pphr) blend compared to the 1st mix set. This formulation permits to have *high average of modulus* and tensile strength (T.S). High levels of carbon blacks (50-60pphr) are designed to have further improved abrasion resistance in one side but, in other side there will be having high heat built-up. Addition of Stearic acid with higher dosage (6-7pphr) assist in getting tighter network, suppressing the heat built-up and enhancing better ageing resistance[13] Other ingredients are equally distributed for all tread recipes. Due to the fact that road test takes into account the excess heat as a result of friction with the street. The laboratory test takes in consideration that the recipes were aged by leaving them for three days in the oven at a temperature of 105 degrees Celsius.

Table 1: Formulations of Recipes.

INGREDIENTS (PPHR)	*Mix No.*					
	1st set (mixes 1,2 &3)			*2nd set (mixes4,5 &6)*		
	1	*2*	*3*	*4*	*5*	*6*
Natural Rubber (ISNR-20)	*70*	*70*	*70*	*40*	*35*	*30*
Styrene-Butadiene Rubber (SBR) SYNAPRENE-0212	*25*	*25*	*20*	*50*	*55*	*60*
Polybutadiene Rubber (PBR-1220)	*5*	*5*	*10*	*10*	*10*	*10*
Carbon Black (N-220)	*40*	*40*	*40*	*50*	*55*	*60*
Process Oil	*14*	*14*	*14*	*18*	*18*	*18*
Zinc Oxide	*5*	*5*	*5*	*5*	*5*	*5*
Stearic acid	*3*	*3*	*3*	*6*	*6*	*7*
Antioxidant	*2.5*	*1.5*	*2.5*	*2.5*	*2.5*	*2.5*
Antiozonant	*0.75*	*-*	*0.75*	*0.75*	*0.75*	*0.75*
CBS	*0.9*	*0.9*	*0.9*	*0.9*	*0.9*	*0.9*
Sulphur	*1.5*	*1.5*	*1.5*	*1.5*	*1.5*	*1.5*
Retarder CTP-100.	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*	*0.3*

3. RESULTS AND DISCUSSIONS

3.1 Mechanical Properties of the Mixes

Table-2, gives the mechanical properties of the all mixes. It is clear from the table that different mixes exhibit properties as per the design parameter of the mixes.

Fig. 1, shows Abrasion loss or mechanical wear loss represented by relative volume loss in cm^3 of all the six mixes. Mixes 1, 2 and 3 are nearly equivalent at both normal and aged conditions whereas mixes 4, 5 and 6 show lesser relative volume loss at normal condition especially for mix 6 meanwhile, volume loss at aged case keeps nearly constant for mixes 4 &5 but low value appeared for mix 6 which is competitive to normal. So, the mileage of tyre tread using mixes 4, 5 or 6 are high at final stage but this mileage advantage will be reduced under aged condition at the fourth and fifth mixes because of reversion or over-curing of the rubber mixes which agree with reference of Michael (2004).[15]

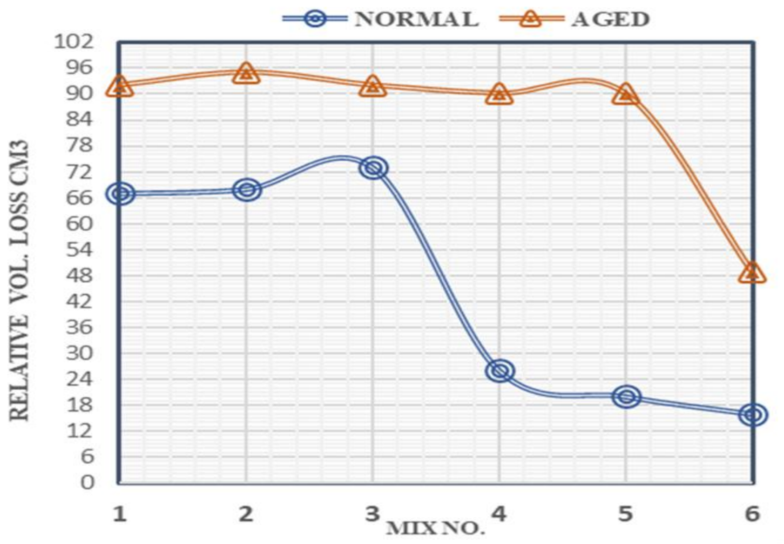

Figure 1: Relative abrasion loss (Volume loss by cm^3) before and after ageing.

Fig. 2, shows the heat build-up of all the mixes at normal and aged conditions. Mix 1 shows medium and identical heat built-up for normal and aged conditions and this is due to high oil and low carbon black loading. Heat built-up increased at normal and aged for mix 3 and decreased gradually for other mixes 4, 5 & 6, this result is compatible with reference of Rukkur (2010).[16] It is normally seen in rubber technology that higher doses of polybutadiene rubber and black filler increase heat built-up, but the *interesting observation* is that higher dosage of *stearic acid* reduces heat built-up to a great extent (mix 5&6). It is clear that rubber mixes have low heat build-up before and after aging, indicating their good resistance to mechanical wear especially for mixes 4, 5 and 6 as the same that indicated in reference by Rangsit (2012) and Wang, *et. al*. (2020)[17,18] These results give evidence that mixes 4,5 &6 are candidate for long mileage of tire tread.

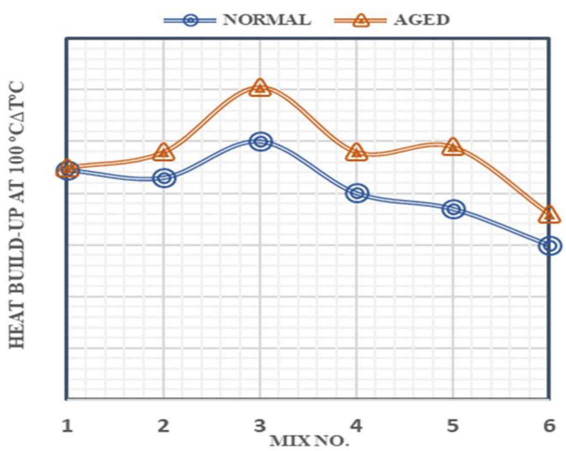

Figure 2: Heat build-up before and after ageing.

Fig. 3, shows 300 % Modulus of different mixes at normal and aged conditions where the study considered the average of modulus as a guide for evaluation. First mix shows medium modulus in normal and aged condition which are close together, meanwhile mix2 which shows normal and aged are spaced apart. Mix 3 shows lower level of modulus among all mixes which reflects poor wear resistance. Mixes 4, 5 and 6 shows a high value of modulus for normal and aged comparing with the 1st three mixes. High modulus primarily gives an indication for high abrasion resistance which lead for good mileage of tires as illustrated in reference Dunlop Co., (1998).[19]

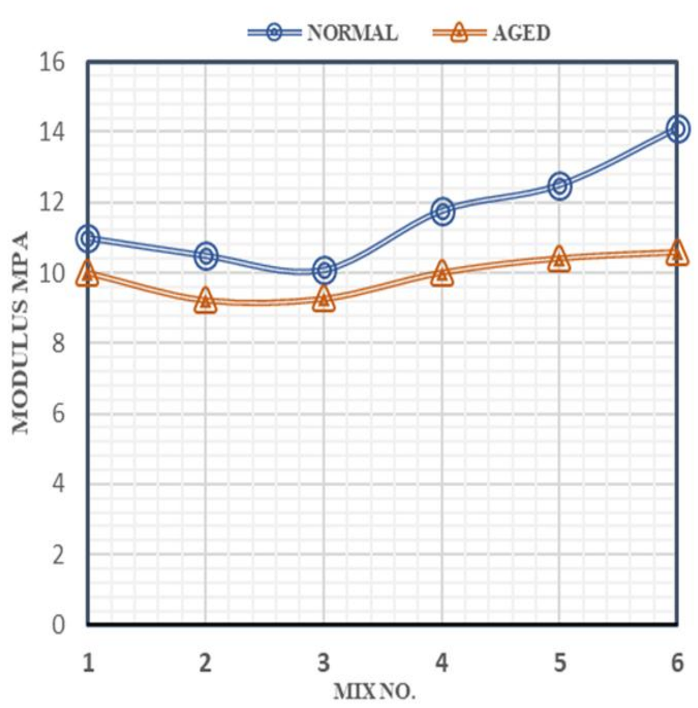

Figure 3: Modulus of mixes before and after ageing.

Figure .4, gives the right correlation between road tests and laboratory tests in such a way that the laboratory test represented by the selective mechanical properties represented by PMI parameter can simulate the results given by actual road test (mechanical wear or relative abrasion loss RAL), where predicting the tire wear is possible. The two test results (actual and lab.) are increasing and decreasing nearly in the same rhythm and working as hand by hand. This will give an encouraging and promising results which call us to adopt cheap laboratory test instead of expensive road test as in this study. Also, from fig.4, it can be seen that as the mechanical wear (by using road test) goes down to give an indication of increasing the milage of tire in one hand, PMI parameter also going down to indicate increasing of abrasion resistance which consequently indicates an increase in tire milage in the other hand.

The sixth mix gives the suitable recipe that can provide us with recommended mechanical properties that the mixing director is looking after. The fourth figure can definitely give a road map for estimation that PMI parameter and the milage of tire are twin and are correlated directly where enhancement and prediction of the tire life is within reach and this is the goal of the study.

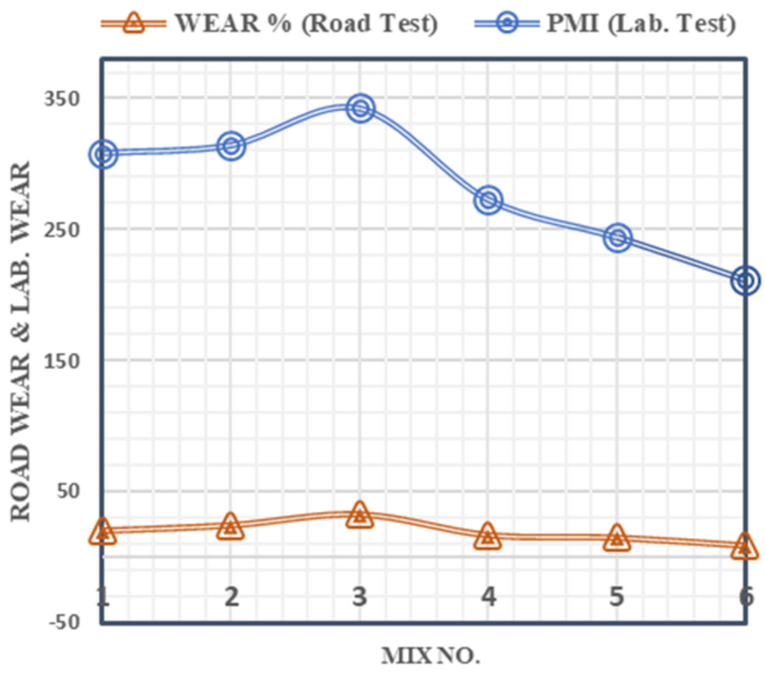

Figure 4: Comparison of wear between actual road test and laboratory test.

3.2- Potential Mileage Index (PMI)

The potential mileage index is calculated based on the empirical relation explained earlier and the values are given in Table 2. Although relative volume loss differs too much in case of 1st set to 2nd set of mixes the average potential mileage are comparable to a certain extent of all the set of mixes. By means of the relation 2 mentioned before, as the average of potential mileage index (PMI) is lower which means higher abrasion resistance, it will show higher mileage (long life) of tire tread. For the 1st set it can be seen that the average potential mileage index of mix 1 is lower than that of mix 2 and mix 2 is having lower average potential mileage index than mix 3.

So, it is expecting that tire tread made from mix 3 will show lower mileage (very bad wearing resistance) than that of mix 2 and mix 1 respectively. Average of potential mileage INDICES of mixes 1, 2 &3 are in order: Mix1 < Mix 2 < Mix 3.

Similarly, the average of potential mileage *INDICES* of the three other mixes (2nd set) are of the following order: Mix6 < Mix 5 < Mix 4. This shown that mix 6 has higher mileage (good abrasion resistance) than mix 5, and mix 4 respectively. If the two sets of mixes are considered with each other, the sequence of Potential Mileage Index will be as follow: 2nd set is lower than 1st set of mixes, lower index values will give an indication for long life of tire, in other words tire tread which will be made by recipes of 2nd set has higher mileage (long life for tire tread) than that of 1st set. Actually, Mix6 is the best one that suitable for long mileage of tire or good wear resistance than that made from mix 5 and so on. It can be said that Mix6 < Mix 5 < Mix 4< Mix1 < Mix 2 < Mix 3 in good wear resistance or abrasion resistance. If these results compared with the actual percentage of wear have been taken from the road test which is actual and relatively perfect as mentioned in table 3", the same sequence for the mixes could be appeared and the results are symmetrical. This strictly means that the mechanical properties tested for prediction the mileage of tire can compensate the road tests successfully and can predict the potential mileage of tire easily even though not exactly.

Table-2: Mechanical properties of the vulcanizate compounds.

Mix No.	*Cond-ition test*	*Relative Abrasion loss (by vol. loss cm^3)*	*Aver-age of Abrasion loss cm^3)*	*Heat build-up at 100 °C ΔT °C*	*Aver-age of Heat build-up*	*300% modulus Mpa*	*Aver-age of 300% modulus*	*Aver-age of PMI*	*T.S Mpa*	*Elong. % at break*	*Har-dness Shore A*
1	**normal**	**67**	**79.5**	**44.5**	**44.75**	**11.0**	**10. 5**	**308.6**	**20.04**	**550**	**57**
	aged@	**92**		**45**		**10.0**		**4th**	**9.42**	**310**	**64**
2	**normal**	**65**	**80**	**43**	**45.5**	**10.5**	**9.86**	**314.7**	**23.73**	**500**	**63**
	aged@	**95**		**48**		**9.23**		**5th**	**10.42**	**230**	**66**
3	**normal**	**73**	**80.5**	**50**	**55.25**	**10.09**	**9.68**	**342.8**	**22.47**	**510**	**65**
	aged@	**88**		**60.5**		**9.27**		**6th**	**16.08**	**350**	**70**
4	**normal**	**26**	**58**	**40**	**44**	**11.76**	**10.88**	**271**	**16.68**	**540**	**60**
	aged@	**90.1**		**48.1**		**10.0**		**3rd**	**7.25**	**141**	**66**
5	**normal**	**18**	**48**	**49**	**43**	**12.49**	**11.44**	**244**	**17.41**	**520**	**66**
	aged@	**78**		**37**		**10.4**		**2nd**	**8.61**	**350**	**70**
6	**normal**	**16**	**32.35**	**30**	**33**	**14.09**	**12.32**	**239.7**	**20.95**	**570**	**62**
	aged@	**48.7**		**36**		**10.57**		**1st**	**18.28**	**380**	**67**

@ Samples were aged at 105^{0}C, for 3 days.

3.3- The Actual Wear Percentage (road test)

Six bus tires were taken without tread then, they were hot retreaded by using the specified six mixes (compounds) mentioned in table 1. They were made to follow the similar conditions as that in the previous mixes. Those retreaded tires were studied for wear resistance in the actual service at constant speed, same tire geometry and road severity. Wear resistance was calculated by using equation No.3 after subjecting the retreaded tires to road test for different mileage calculated in kilometer.

Table-3 gives the average wear percentage using six experimental compounds. Tires with such compounds tested on the road through 40,000-150,000 kilometers for computing relative abrasion loss (RAL) as average. Its final results put in ORDERED form relative to its abrasion resistance magnitude. Comparing the laboratory tests depending on certain mechanical properties as shown in table 2, with actual road test shown in table 3 may give the right prediction. Table 3, shows that the same sequence of mixes is correlative and applicable in laboratory and through road test. Regarding this paper, it can be estimated that the actual wear loss can be easily predicted from the Laboratory properties without going for actual field trials which is very expensive and time-consuming process. It can be seen the order of six compounds of tire tread calculated on the base of the average of wear loss or RAL during 150,000 kilometers travel distance, that the sequence of mixes is in the order as in the same that determined during laboratory tests of PMI as in table 2, or it has the templet of this series; Mix3 > Mix 2 > Mix 1> Mix4 > Mix 5 > Mix 6. Where the two results are completely symmetrical.

Table-3: Mileage of Type Bus Tire (Road Test).

Mix No.	***1***	***2***	***3***	***4***	***5***	***6***
Kilometers Run RAL (by vol loss cm^3) for the six mixes per traveled distance						
40,000	**10.7**	**14.5**	**16**	**8.42**	**8.1**	**3.15**
50,000	**12.75**	**15.87**	**19.12**	**9.5**	**8.55**	**4.0**
75,000	**15.8**	**19.5**	**21.5**	**13.42**	**11.65**	**7.5**
100,000	**23.42**	**26.85**	**28.6**	**20.0**	**18.1**	**11.25**
125,000	**27.77**	**32.0**	**33.25**	**24.0**	**21.25**	**12.57**
150,000	***31.8***	***38.27***	***42.15***	***25.6***	***23.52***	***15.15***
***RAL Average* for each mix**	***20.37***	***24.49***	***32.77***	***16.99***	***14.98***	***8.94***
Abrasion Resistance ORDER	**4th**	**5th**	**6th**	**3rd**	**2nd**	**1st**

CONCLUSIONS

This paper concludes the followings findings where it comes from the comparison between potential mileage index *PMI* calculated from Eq.1, in laboratory test and mechanical wear (relative abrasion loss) calculated from Eq.3, in road test.

1. The potential mileage of a tire (tire life) is going to be higher and higher as the index is going to be lower and lower in both aged and normal conditions. This case could be confirmed by the results of actual relative abrasion loss *(RAL)* came from actual road test

through Eq.3, *where increasing of mechanical wear means lowering the abrasion resistance and the potential mileage of tire and vice versa.*

2. Recipe 6 is found to be the best one proper mix for tire tread manufacturing supported by results of laboratory and road test. It will have the higher potential mileage than other recipes because it has the maximum mechanical wear resistance or abrasion resistance. The recipes can be considered in the descending order **[6 ⟹ 5 ⟹ 4 ⟹ 1⟹ 2 ⟹ 3]** of higher potential mileage.
3. The potential mileage of a tire can be predicted from certain mechanical properties such as Relative abrasion loss, Heat built-up and Modulus at before and after ageing conditions instead of only wear loss that had been studied on retreaded bus tires which is a very expensive and time-consuming process.
4. Study shows a significant findings difference between aged and normal due to ageing, reversion and other conditions.
5. As recommendation this paper needs further studies to be established in prediction the mileage of tire taken in account the different size and pattern of tire treads.

ACKNOWLEDGEMENTS

I would like to express my great appreciation to the general state company for tires industry in Annajaf represented by their general manager and technical staff for their assistance especially the staff of laboratories department for facilitating the experimental work and the testing operations.

Conflicts of interest: there is no conflicts of interest.

REFERENCES

1. K. Satake, T. Hamada and K. Hayakawa "Abrasion Resistance of Tire Tread" Longman October, 1970; 217-250.
2. Schallamach "*Rubber Chem. And Technology*", 1965; 41: 209.
3. M.H. Halim, (Truck Tire & Abrasion Resistance Ph.D. Thesis) Loughborough University's Institutional Repository, London, 1990.
4. N. N. Marco, (to Pirelli Pnumatic S.P.A.) U.S. Patent, 2004.
5. Hall, D. E.; Moreland, J. C. "*Rubber Chem. Technol.*", 2001; 74(3): 525.
6. Wolff, S.; Gorl, U.; Wang, M. J.; Wolff, W., Carbon Black-based tread compounds, *"Background and Performance. Tire Tech."* '93, Basel, Switzerland, October, 1993.
7. K. Senapati and S. K. Chakraborty, "*Rubber Rep,* 1986; 53.

8. Manas, J. Hocan. "Wear of OFF – ROAD Tires Evaluation" *PMA & Rubber Con.*, 2011.
9. H.A. Farhan., J.C. Aaron, (to Goodyear Tire & Rubber Co.) U.S. Patent, 2014; 2.
10. Rubber Compounding, p.369; *Encyclopedia of Chem. Techn., Jhon Wiley & sons*.
11. Annual book of ASTM Standards, volume 09.01, IHS Markit July, 2017.
12. M.A. Mutar, Ebonite & hard resin rubber based on Natural synthetic rubber, Ph.D. Thesis, Babylon University, Babylon, 2013.
13. Scope of "formulation of Rubber Materials & Compounding Products", 546, *Vanderbilt hand book, Published by Van-Nostrand Reinhold Co*., 1999.
14. Al-Jebory, Saad A., and M.H. Al-Maamori. "The Effect of Adding Waste of Cement "Fly Ash" in some of the Mechanical Properties of NBR Composites", International Letters of Chemistry Physics and Astronomy, 2021.
15. Contributed by Michael Cremeens Fenner Dunlop A mericas Member, NIBA Member Services & Marketing Committee Beltline Reprint September, 2004.
16. Sanae Rukkur, "Effect of Filler on Heat Build-up of Rubber". The First TSME International Conference on Mechanical Engineering 20-22 October, Ubon Ratchathani, 2010.
17. Wanvimon Arayapranee Rangsit,*"Rubber Abrasion Resistance"* Abrasion Resistance of Materials, (Ed.) by Dr Marcin Adamiak, ISBN: 978-953-51-0300-4, published by InTech, University of Thailand, 2012.
18. Wang Qiang et. al., Discussion on Tire Retreading and Reuse Technology, IOP Conf. Series: Earth and Environmental Science 512 012146, 2020.
19. Dunlop Co., document No.4, tire specifications and instructions granted to the General Company for the Tire Industry in Annajaf-IRAQ, 1998.