Prediction of fatigue crack growth in retreaded truck tire- rubber.

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Abstract

Tire retreading is of huge size business so from safety point of view quality standards should be of great importance. Tire failures during running condition is a serious point to be studied. One of the reasons of failures is growth of flaws in tire rubber. In this paper we have studied the growth of crack due to tearing energy. A sample 15.0cm*2.5cm*0.3cm,of rubber is taken between sidewall and belt edge of retreaded tire. 2 mm crack at center of edge is cut by sharp razor along 15.0cm. Testing is done on universal testing machine at strain of 10%. A graph is plotted between stress v/s strain for different crack lengths for R =0 at uniaxial loading cycles with frequency 5 Hz. Strain energy density is calculated from the area under the curve. .Mathematical model is developed for crack growth and tearing energy.

.***Keywords*** *; De-Mattia flexing machine; crack growth; retreaded truck tire; strain energy density; mathematical model.*

1. Introduction

In India tire industry is fast growing. Nowadays due to competitive market tire retreading Industry is also of huge size. No transporter can afford to run transport business without going for rereading. Since truck tire is contributing major part of total business we focused more on truck tire problems compared to others like passenger, light commercial vehicle tires.

Tire blast due to generation of air /flaws in rubber layers of tire during running of truck is a serious problem to life of driver and safety of material. The uncertainty and severity hidden into that made it necessary to study the problem. Catastrophic result in crack propagation in rubber resulting in exploded tyre.

Majority of research literature is related to new tires. Now the retreading technology is well developed and it is of huge size. It is found, more research work is required to be done on crack nucleation growth of this crack initials to critical size and propagation in retreaded truck tires. Tire (casing) selection plays key role in retreading process. Present methods of checking, are of visual or of resonance test. Very few industries can afford to go for shearography testing which can detect air bubble / flaws in tire casing before process. Actually tire rubber contains different fillers, curatives, additives .It also contains micro voids which becomes center for crack initiation during fatigue. (1) Now leads to catastrophic failure. After thorough checking during and after the (pre-cured) retreading, flaws in tire may grow to critical size during running after certain period of time. Our whole effort is to predict the rate of growth of flaw /crack in this paper. The analytical simulation is validated with experimental results. Rubber-Fracture mechanics: During cyclic loading, rate of crack propagation depends upon strain (stress) release rate and material properties. When we plot graph between rate of crack propagation (dc/dn) and strain energy density (tearing energy). Crack propagates through four regions. Initial region is constant crack growth. second is transition region where there is sharp increase in crack growth rate

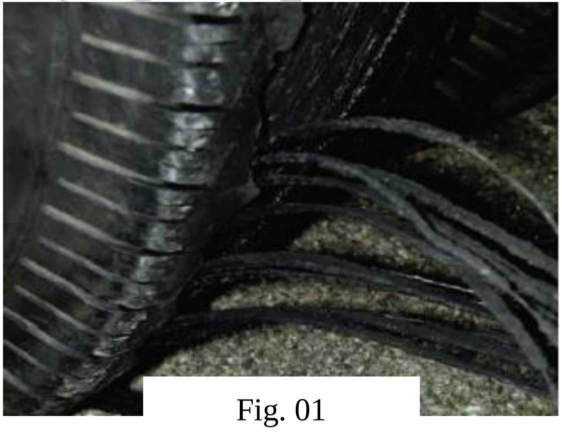

Fig. 01

following crack growth threshold. In third region power law relation is followed. In final region unstable crack growth which leads to catastrophic failure.

Strain energy release rate is also termed as tearing energy and is defined as

$T= -\delta U/\delta A$

U= Total elastic strain energy stored in sample

A=Area of on fracture surface of crack (unstrained condition)

And partial derivative indicates that the sample is considered at fixed deformation so the external forces do not work (strain controlled rather than force controlled deformation).(2) Other than tearing energy, fatigue crack growth rate is affected by rubber compound, environmental factors including oxidative effect ,environmental cracking ,cutting ,abrasion etc.

2. Experimentation:

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2.1 Test specimen

Fig. 02

Table 01				
Make	Size	Rating	Orientation	Remark
MRF	10.00*20	16	Bias	1stRetread

Table 02		
S N	Dimension	Unit cm
1	width-b	2.5
1	length-l	15.0
1	thickness-t	0.3

2.2 Set –up

Computerized universal testing machine

Fig. 03

Table 03			
Stress at 10% strain kgf/cm^2	Crack Length cm	Load kgf	Extension cm
4.75	0.2	3.32	1.075

4.09	0.4	2.92	1.025
4	0.6	2.85	1.008
3.85	0.8	2.74	1.024
3.72	1.0	2.65	1.025

2.3 Method

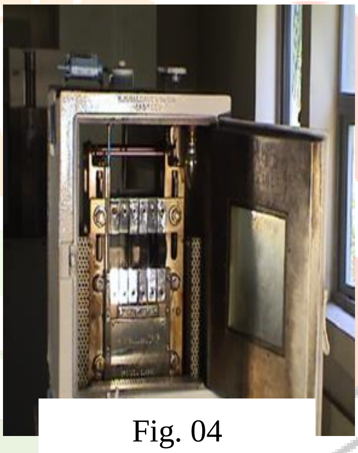

Fig. 04

De Mattia Flexing Machine:-

The De-Mattia flexing machine test method is used to test rubber specimen for resistance to cracking produced either by extension or bending, depending on the relative adjustment of the stationary and movable grips, and the distance of travel of the latter. The Tests for dynamic fatigue are designed to stimulate the continually repeated distortions received in service by many rubber articles, such as tire These distortions may be produced by extension, compressive and bending forces or combinations of them. The effect of the distortions is to weaken the rubber until surface cracking or actual rupture occurs. In the case of combinations of rubber with other flexible material such as fabric, the effect may be evidenced by separation at the interface between the materials, caused either by breaking of the rubber or failure of the adhesion or both. The choice of type of strain is optional but notations shall be made of the type actually used, giving full details of the relative position of the grip and of the travel.

PROCEDURE

For cut growth

1. The test sample is punched with the help or punching machine to introduce the 2 mm crack at the center of its edge of the sample.
2. Test specimen is clamped in the De-Mattia machine.
3. Set the temperature of the machine if required.

4. Start the machine and note the no. of cycles when crack growth reaches up to specified length/ percentage growth.

The part of tire which undergoes continuous flexing during its life cycle is the sidewall. Hence we concentrated on the flexing resistance studies of the sidewall near belt edge.

Testing of sample

Sample – Pre-cured (cold tire retread) Truck tire rubber sample is selected for fatigue crack propagation

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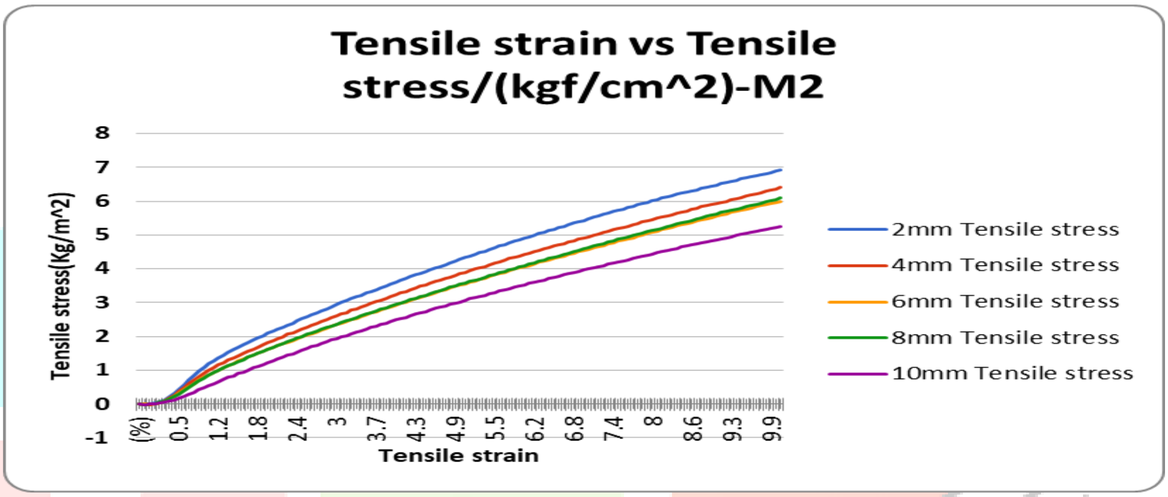
3. Results/discussion

3.1 Strain -Stress Curve

Initially we have selected to test the sample for 0% to 10% strain ,corresponding curve for stress strain for different crack length is plotted. see table no. 10

Graph 01



Strain energy density is calculated for each cut growth at 2mm,4mm,6mm,8mm & 10mm and then it is differentiated wrt crack length and multiplied by specimen dimensions to get tearing energy.

Table 04

SED For 2 mm
1.19= a .01^2+0.01b+c (0.01, 1.19)
3.66= 0.04^2 a+0.04b+c (0.04, 3.66)
6.01= 0.08^2a+0.08b+c (0.08, 6.01)
A= -336.9 , b= 99.17, c= 0.2319 checked
Y = - 336.9 X^2 + 99.17 X +0.2319
integrating from 0 to 0.1 strain
= 336.9 (0.1^3)/3 +99.17 (0.1^2)/2+0.2319
SED For 2mm = 0.6154

Table 05

SED at 4 mm
1.0= 0.01^2 a+0.01b +c (0.01, 1.0)
3.13= 0.04^2a+0.04b+c (0.04, 3.13)
5.26=0.08^2a+0.08b+c (0.08, 5.26)
Solving a= -253.57 ,b= 83.67, c= 0.1887
Y= -253.57 x^2+83.67x+0.1887
Integrating wrt x for 0 to 0.1 strain we get
Y= -253.57 (0.1^3)/3 +83.67 (0.1^2)/2+0.1887
for 4mm = 0.523

Table 06

SED for 6mm cut
0.79 =0.01^2 a+0.01b+c (0.01,0.79)
2.83= 0.04^2a+ 0.04b+c (0.04,2.83)
4.85=0.08^2a+0.08b+c (0.08,4.85)
Solving a=-250, b=80.5, c=0.01
Y= -250x^2+80.5x+0.01 Integrating w r t x for 0 to 0.1 we get
Y= -250* 0.1^3/3+80.5*0.1^2/2 +0.01 **SED at 6mm = 0.327**

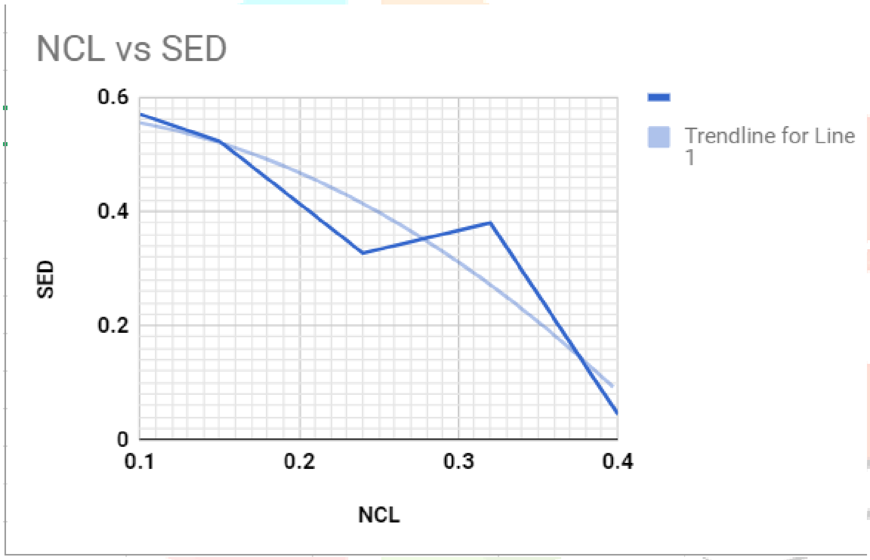
Table 07

SED at 8mm cut
0.77= a 0.01^2+b0.01+c (0.01,0.77)
2.85= a 0.04^2+b 0.04+c (0.04,2.85)
4.94= a 0.08^2+b0.08+c (0.08,4.94)
Solving a= -244.04, b=81.95, c = -0.025
Y= -244x^2+81.95x – 0.025 integrate wrt x for 0 to 0.1 strain
= -244(.1^3)/3 +81.95 (0.1^2)/2-0.025 for 0 to 0.1
0.3855 SED for 8mm = 0.3855

Table 08

SED at 10 mm crack length from 0 to 10% strain M2 sample
It is a quadratic equation y = ax^2+bx+c , 10% max strain ie 0-01
0.48=a(0.01)^2+b(0,01)+c (0.01, 0.48) (Strain, Stress)
2.4 =a(0.04)^2+b(0.04)+c (0.04, 2.4)
4.27=a(0.08)^2+b(0.08)+c (0.08, 4.27)
Calculating equations a= -260, b=76.32, c= -0.257
Y= -260 x^2+ 76.32x- 0.257, integrating this eqn with respect to strain. we get
Y= -260x^3/3+76.32x^2/2-0.257 from 0 to 0.1 we get
SED at 10mm cut = 0.0446

Table 09		
Crack length mm	SED Kgf/cm^2 per unit volume	Fatigue cycles—M2 sample
2-Ncl- 0.08	0.6154	0
4-- 0.16	0.523	11
6-- 0.24	0.327	21
8--- 0.32	0.3855	28
10-- 0.40	0.0446	37



A graph is plotted between strain energy density and normalized crack length. As crack length increases, strain energy density (SENER) goes on reducing.

After curve fitting

Graph 2

Table 11	
NCL	SED
0.1	0.55
0.15	0.52
0.24	0.42
0.32	0.27
0.40	0.09

Table 10

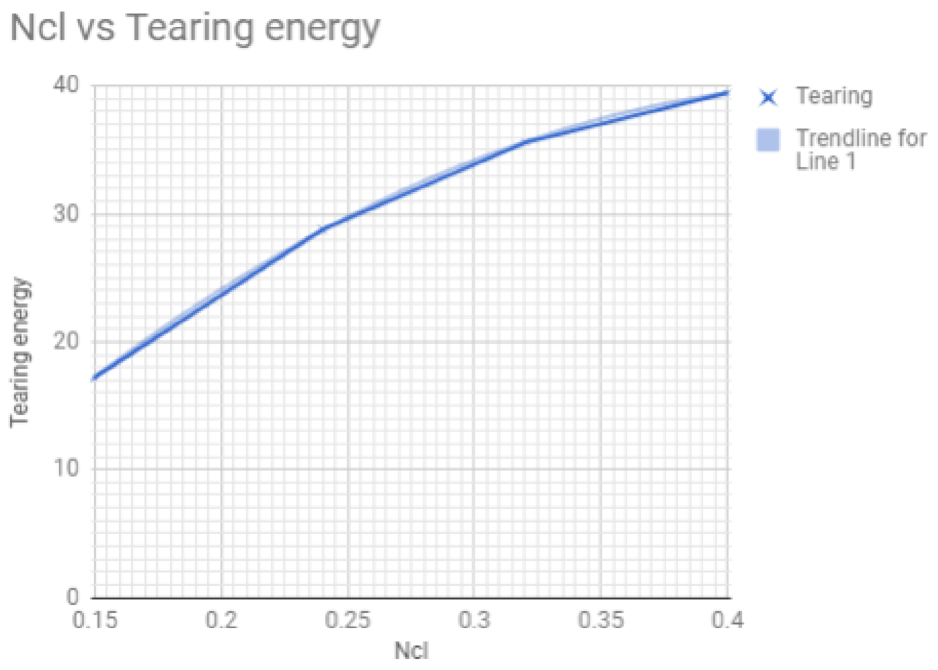
Tearing energy :

0.09 = (0.4)^2 a + 0.4 b +c--------------1
0.27 = (0.32)^2 a +0.32 b + c-----------2
0.42 = (0.24)^2 a+ 0.24 b + c-----------3
A a= -3, b= -0.375, c=0.72
Expression for above curve is
Y = -3x^2 - 0.375x + 0.72
By differentiating SED vs NCL curve expression get tearing energy by multiplying it with specimen dimension.

Tearing energy = - du/da

Table 12

Expression value	value	(2.5-c) L(15) Cm^2		Tearing energy
-(-6(0.1)-0.375) =	0.637	34.5	21.97	-
-(-6(0.15)-0.375) =	1.275	31.5	39.18	17.21
-(-6(0.24)-0.375) =	1.815	28.5	50.74	28.77
-(-6(0.32)-0.375) =	2.295	25.5	57.54	35.57
-(-6(0.4)-0.375) =	2.775	22.5	61.45	39.48



Graph 03

c- crack length in cm

Table 13	
NCL	Tearing
0.15	17.21
0.24	28.77
0.32	35.57
0.4	39.48

Y = - 246 x^2 +224.69 x -10.95

17.21 = a (0.15)^2+b(0.15)+c -------1
28.77 = a (0.24)^2 +b(0.24)+ c ---------2
39,48 = a(0.4)^2 + b(0.4) + c ---------3
Solving a= -246 , b= 224.69 , c= -10.95
Y = - 246 x^2 +224.69 x -10.95 x = c/2.5 = NCL , c- crack length in cm
-with this expression we can find crack length for any tearing energy

Conclusions

When we get the relation between tearing energy and normalized crack length ,we can easily predict the crack length for expected tearing energy. We know the tearing energy is strain energy density loss per unit volume. We have calculated strain energy density from stress-strain curve and plotted with readings taken during experiment on universal testing machine.

Scope for further research

Fatigue life of tire rubber can be calculated by various value of R and amplitude .
Simulation of fatigue crack of tire rubber at actual condition of tire can be done to predict more realistic crack growth.

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Table 14

Tensile strain	2mm Tensile stress	4mm Tensile stress	6mm Tensile stress	8mm Tensile stress	10mm Tensile stress

(%)	(kgf/cm^2)	(kgf/cm^2)	(kgf/cm^2)	(kgf/cm^2)	(kgf/cm^2)
0	0	-0.01	0	-0.01	-0.01
0	0	-0.01	0	0	0
0	0.02	0.01	0.01	0.01	0.01
0.1	0.05	0.04	0.04	0.05	0.04
0.2	0.11	0.1	0.09	0.09	0.07
0.3	0.2	0.17	0.16	0.15	0.1
0.4	0.31	0.26	0.24	0.22	0.13
0.5	0.44	0.37	0.33	0.3	0.17
0.6	0.57	0.48	0.42	0.4	0.22
0.7	0.72	0.59	0.52	0.5	0.28
0.7	0.85	0.71	0.61	0.59	0.35
0.8	0.98	0.81	0.7	0.69	0.42
0.9	1.09	0.91	0.79	0.77	0.48
1	1.19	1	0.86	0.85	0.55
2	2.15	1.87	1.67	1.67	1.28
3	2.94	2.61	2.35	2.36	1.94
4	3.66	3.29	2.97	2.99	2.53
5	4.28	3.85	3.52	3.54	3.02
6	4.9	4.42	4.07	4.09	3.53
8	6.01	5.45	5.07	5.13	4.44
9	6.48	5.93	5.55	5.62	4.86
10	6.91	6.4	6	6.09	5.26