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The Tensile and Fatigue Properties of Vulcanized Natural Rubber Under Ambiant Temperatures

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ABSTRACT - A design of rubber components against fatigue failure is one of the critical issues to prevent the failures during the operation. Therefore; fatigue life prediction was the key technologies to assure the safety reliability of mechanical rubber. In present study, mechanical properties of natural rubber and fatigue life (constant amplitude stresses) were carried out experimentally at room temperature and 40 ^{o}C. The mechanical properties and constant fatigue life were compared with previous study. Tensile and Fatigue life tests were performed using Dumb-bell specimens. The experimental mechanical properties and fatigue life of natural rubber component agreed fairly with the published data of previous study above. While the mechanical properties and fatigue lives at 40 ^{o}C were decreased with about 33% of tensile properties at 0.2 strain and about 99% fatigue properties at $5x10^{6}$ cycles compared with room temperature.
***Keywords:* -** Rubber component, Fatigue life prediction, Fatigue test, Different temperatures.

1. INTRODUCTION

Rubber is a material used in automotive systems to cushion the static loads transmitted from the vehicle body structure. Since rubber elements have the unique properties of high elongation, reversibility incompressibility, and damping.

In general, rubber material shows a large deformation and the relation between load and deformation is nonlinear. However, very few studies have been found for the comparison between the analysis and experimental results, especially for static and dynamic characteristics.

The static tests are compared with Mooney-Rivlin results under different temperature conditions[3,4,5].

A model for mechanical properties of rubber was proposed by Bohumil and Libor [6]to offer a very good description of stress strain dependences in different deformation modes of virgin and strain-softened networks of natural rubber and SBR(Styrene-Butadiene Rubber). Up to high strains. From the knowledge of the first-extension behavior, the Mullins-type strain-softening is predicted and shown to be composed of two contributions:

The strain-induced filler-cluster breakdown and the strain-induced increase in the network mesh size, which is consistent with the mechanism of entanglements removal at the matrix filler interface recently proposed and discussed by Hanson et al [7].

Fatigue lifetime prediction methodology of the rubber component was proposed by incorporating the finite element analysis and fatigue damage parameter from fatigue test. Finite element analysis of rubber component was performed based on hyper-elastic material model determined from material test. Fatigue life of rubber component was predicted by using the fatigue damage parameter at the critical location. Predicted fatigue life of the rubber components agreed fairly well with the experimental fatigue lives [8].

Experimental and numerical studies have been performed for the solid rubber.

Styrene-butadiene rubber (SBR) packed in a cylindrical mold of inner diameter 74.6 mm, was heated by one-dimensional, transient heat conduction from the mold. Radial temperature profile and also radial distribution of the degree of cure were measured after the prescribed heating time was reached. Two methods for the mold temperature control were adopted. One is that the heating is continued at a constant temperature until the uniform temperature profile across the rubber was observed. The other is that the heating was cut off before the uniform profile was formed in order to study the effect of residual heat on the cure process. Numerical prediction was performed for the distributions of the temperature and the degree of the cure. Heat conduction equation for one-dimensional, transient heat transfer is coupled to the cure kinetics of the SBR, Heat generation term, expressed as a function of cure rate and the total heat generation due to cure reaction, is introduced to account for the effect of heat librated during the process. Results of the prediction showed a good agreement of the measured profiles of the temperature and the degree of cure [9].

The heat-aging effects on the material properties and fatigue life prediction on natural rubber were experimentally investigated. The rubber specimens were heat-aged in an oven at the temperature ranging from 50 ºC to 100 ºC for a period ranging from 1 day to 90 days. Fatigue life prediction methodology of vulcanized natural rubber was proposed by incorporating the finite element analysis and fatigue parameter determined from fatigue test (10).

Natural rubber components filled with N330, N650 or N990 were experimentally investigated in order to examine the effects of carbon black on the fatigue life. It was found that the logarithmic value of the fatigue life was linearly proportional to the square root of the product of the critical J-value and the hysteresis (11).

2.EXPERIMENTAL WORK

The material of rubber components was vulcanized natural rubber, which had the hardness of the International Rubber Hardness Degree 35(NR 35). Mechanical test was loaded by testing machine (Tensilmeter) at a speed of 100 mm/min.

The test machine is shown in figure (1-a).While the tensile test specimen is illustrated in figure (1-b). While the tensile and fatigue specimens are of type (Dumb-bell) according to (ASTM-412) as shown in figure (2-a-b). The maximum stress levels were 0.34 MPa for simple tension and maximum strain 0.55. The stress-strain relationship of the rubber changed drastically during the first several cycles , and stabilized after 5-6 cycles , which is known as Mullin’s effect(6).

In order to evaluate a fatigue life of the rubber material, fatigue tests were carried out using a specimen type according to (ASTM-4484). Fatigue tests were conducted in an ambient temperatures and 40 ºC with a sine waveform of 5Hz and the maximum displacement is 0-50mm. The fatigue failure was defined as a number of cycles at which the maximum load dropped to zero. With increasing cycles in the initial phase, the maximum load decreased little by little till failure.

Table (1): The chemical composition of the vulcanized natural rubber used in this work.

Silica Z1165	Carbon black	CSDPF CRX4210	Aromatic Processing Oil	Zinc Oxide	Stearic Acid	Antioxidant (Santoflex 13)	Wax (Sunproof Imp)	Sulfur

80	72	72	1.8	3.0	2.0	1.0	3.5	1.4

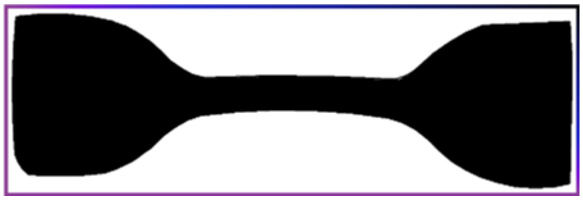

Fig. (2-a): Fatigue specimen before failure (ASTM 4484) .

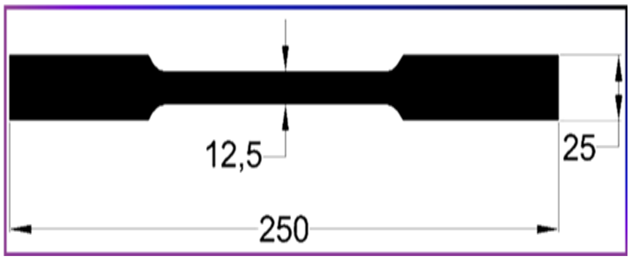

Fig. (1-b): tensile specimen geometry (ASTM -412).

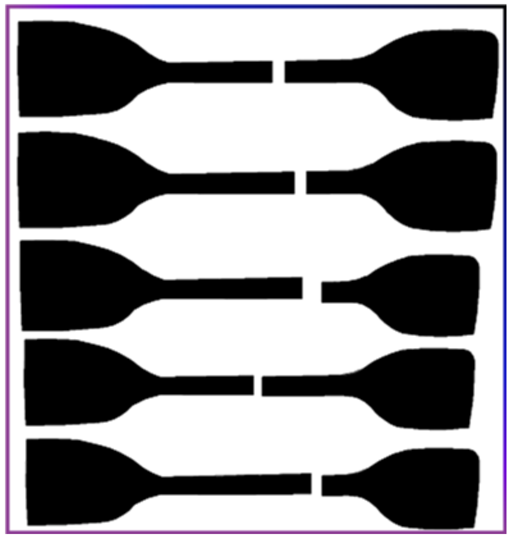

Fig.(2-b): Fatigue specimen after failure.

3. RESULTS AND DISCUSSION

Fig.(3) shows the relationship between the stress and strain for three cases a natural rubber at room temperature , 40 ºC , and results of Ref.(8). It is clear that the tensile properties of Ref.[8] are better than the result of the present work. This is due to the amount carbon black which is greater than the amount in the present study by 5% [10]. 33% reductions in the tensile properties due to raising the temperature to 40^{o}C and this conclusion agreed well with Ref.(5).The stress - strain relationship may expressed in the following equations:

A) At room temperature (25^{o}C) :

$$\sigma = 0.7042\varepsilon^{0.389} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

B) At 40 ºC:

$\sigma = 0.56\ \varepsilon^{0.95}$ …………………….. (2)

Where:

σ :Tensile stress (MPa)

ε :Strain

Fig. (4) shows the relation of stress with fatigue life .It was observed that the stress was a good parameter in describing the fatigue lives of the dumb-bell specimen. The life equation may be written as in the following form:

A) At room temperature:

$\sigma = 1.13 * 10^6\ N_f^{-0.872}$ ………………. (3)

B) At 40 ºC:

$\sigma = 14.74 * 10^6 N_f^{-1.338}$ ……………. (4)

Where:

N_f: Number of cycle to failure.

Fatigue life time

The predicted life of dumb-bell specimen was calculated using the experimental equation of fatigue life for natural rubber from Eq.(1)and (2). Correlation between the experimental fatigue life and predicted fatigue life of Ref.(8) is shown in Figure (4). The predicted lives are reasonable compared with the experimental lives.

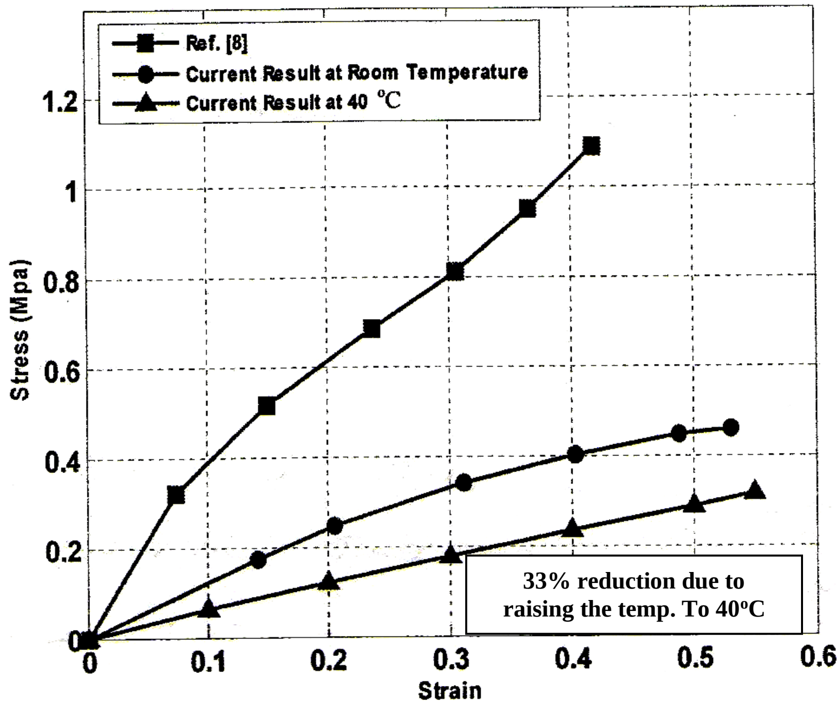

Fig.(3): Comparison between the tensile properties at different conditions.

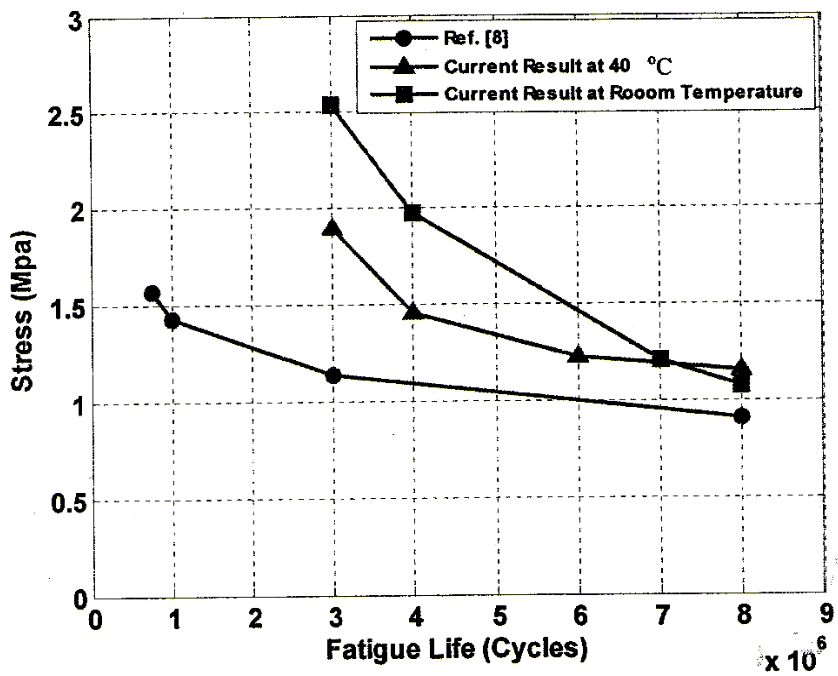

Fig.(4): Comparison between the fatigue life under different conditions.

4. CONCLUSIONS

1. The effect of increasing the temperatures will decrease the tensile properties and fatigue characteristics. The tensile properties decreased by a 33% due to raising the temperature to 40^{o}C at 0.2 strain while the fatigue properties decreased by 99% at the life 5x10^{6} cycles.
2. Fatigue lives of the rubber component were in fairly good agreements with the result of Ref.[8]within factors of two-three.
3. The increasing of the amount carbon back is improved the tensile and fatigue properties compared with Ref.(8).

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خصائص الشد والكلال للمطاط الطبيعي تحت درجات حرارة المحيط

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رعد حميد ماجد — **مدرس مساعد**

قسم الهندسة الكهروميكانيكية– الجامعة التكنولوجية

الخلاصة

أن تصميم أجزاء من المطاط ضد الفشل الكلالي هو احد المتطلبات الحرجة لحمايته من الفشل أثناء عملية أستخدامه , فلذلك يعتبر تخمين عمر الكلال هو المفتاح التقني لضمان السلامة و الأمان و الديمومة للمطاط المستخدم في الأجزاء الميكانيكية, تم في هذه الدراسة إيجاد الخصائص الميكانيكية للمطاط الطبيعي وعمره الكلالي (تحت اجهادات ذات سعة ثابتة) عمليا عند درجة حرارة الغرفة و ٤٠ درجة مئوية و تم مقارنة الخواص الميكانيكية والعمر الكلالي ثابت السعة مع الدراسة السابقة أعلاه ,اختبارات الشد ومدة الكلال تم انجازها باستخدام عينات(Dumb-bell) الخصائص الميكانيكية العملية و العمر الكلالي للمطاط الطبيعي توافقت مع دراسة سابقة بينما تناقصت هذه الخصائص والعمر الكلالي عند درجة حرارة (٤٠ درجة مئوية).بينما تناقصت خصائص الشد بنسبة حوالي ٣٣٪ عند انفعال ٠.٢ و حوالي ٩٩٪ من خصائص الكلال عند عمر ٥x١٠٦ دورة مقارنة مع درجة حرارة الغرفة.