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AL-MUTHANNA JOURNAL FOR ENGINEERING SCIENCES

مجلة المثنى للعلوم الهندسية

Diaphragm Actuator Design with New Rubber Compounds

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ARTICLE INFO

Received: 27/January/2016

Accepted: 05/June/2016

Keywords

Rubber, Diaphragm, Brake Chamber, Stress Analysis, Mooney-Rivlin.

ABSTRACT

The current work deals with the design of new rubber compounds as a viable alternative for commercial compounds used in diaphragm actuator of brake systems in most commercial vehicles like trucks, tractor-trailers and buses. Two new recipes were proposed to work instead of commercial recipe with experimental and analytical study to prove the high performance properties and workability. The finite element method by ANSYS 13 software was used to study the behavior of these compounds with Mooney-Rivlin 2-parameters during the work pressure range. Most of the results are acceptable competitive.

تصميم دايفرام صمام أنظمة التوقف مع مركبات مطاطية جديدة

الخلاصة

يتناول العمل الحالية تصميم مركبات مطاط جديدة كبديل عملي للمركبات التجارية المستخدمة في دايفرام صمام أنظمة التوقف (**diaphragm actuator of brake systems**) في معظم المركبات التجارية مثل الشاحنات ومقطورة جرار والحافلات. اقترحت الدراسة الحالية وصفات جديدة للعمل بدلا من الوصفة المستخدمة في المنتجات التجارية مع دراسة تجريبية وتحليلية لإثبات خصائص الأداء العالية والقابلية للتشغيل. تم استخدام طريقة العناصر المحددة وبرنامج **(ANSYS V.13)** لدراسة سلوك هذه المركبات مع موني-ريفلين ذو المعاملين(2) خلال مديات ضغط العمل. وكانت معظم النتائج مقبولة وذات قدرة تنافسية.

الكلمات المفتاحية

المطاط، دايفرام، صمام منظومة التوقف، تحليل اجهادات، موني رفلن.

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Introduction

The principles of stopping the vehicle influenced with the relationship between parts and work stresses still [1]. The safety of vehicles on the roads sensitive directly by the brake system. The fulfillment of brake systems that used in heavy duty vehicles such as trucks, buses are very affected by many factors such as adjustment of push rod stroke, brake lining replacement [2]. Another factor has the same effect on the performance of brake system such as material selection of actuator diaphragm and shape design.

In the two previous decades, many researches and studies focused on safety of trucks and passenger cars due to the importance of these with human life in addition to economical losses [3]. Brake system is an energy conversation system, where the momentum or kinetic energy was converted to heat or thermal energy. The stopping forces produced by these systems as a result of step on the brakes are larger than the influential forces needed to motion the car. The air brake system is made up of two subsystems, pneumatic and mechanical. The first one includes the compressor, storage reservoirs, treadle valve (the brake application valve), brake chambers, etc. while the second includes push rods, slack adjusters, S-cams, brake pads and brake drums as shown in fig.1. The application of the treadle valve regulates the air supply from a supply reservoir to the brake chamber and little sensory feedback is available to the driver [4-6].

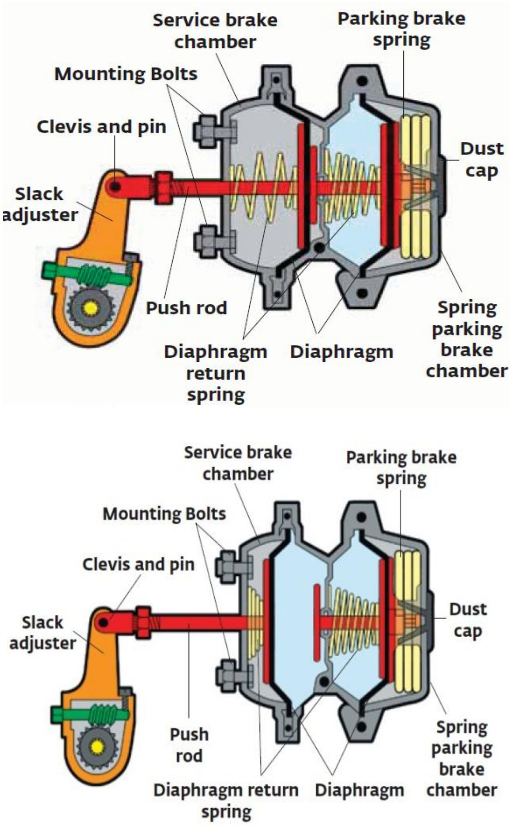

Figure 1. Brake Chamber (off/on) [5].

The present work was focused on a new design of recipes rubber compounds for actuator diaphragm locally manufactured by the process of material selection in order to get distinct performance characteristic equivalent to the standard designs for products of global companies.

Air Brake Chamber

Air brake chamber is a circular container divided into two parts by flexible diagram. The diaphragm is one of the brake chamber components that are similar to tire sidewall, clamped between two steel housing and having uniform area and work as a piston as shown in figure (2). The diaphragm transfers the forces that applied from the air pressure to move the slack adjuster (lever) to apply the brakes. The push rod forces are affected by air pressure and diaphragm effective surface area. The diaphragm size is an effective factor on the forces exerted in brake chamber. The quality and performance properties of diaphragm is very important factor in brake chamber effectiveness, the occurrence of any leak in diaphragm effectively on the brake system performance, either diaphragm torn leads to completely failure of this system, which results in significant losses [6,7].

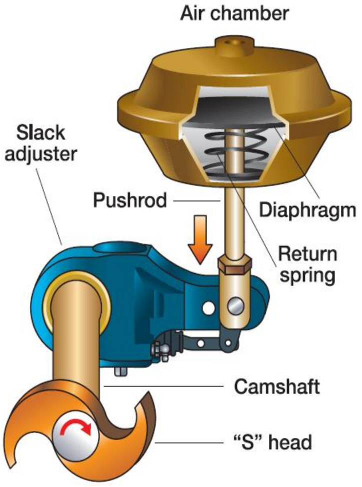

Figure (2): Mechanical Subsystem of a S-cam Air Brake System [7].

Pressure Governing Equations

In exhaust phase, air is exhausted from the brake chamber to the atmosphere as a result to release the brake pedal and opening exhaust port by primary piston. The primary piston motion can be described by the equation represent application process during applies and hold phases [4]:

$$\begin{aligned} \boldsymbol{k_2 x_{pp}} &= \boldsymbol{k_{ss}x_p + F_{gs} + F_1 - P_{pd}(A_{pp} - A_{pv})} \\ &\quad \boldsymbol{- P_{ps}A_{pv1}} \\ &\quad \boldsymbol{+ P_{atm}A_{pp}} \quad \dots\dots\dots(\mathbf{1}) \end{aligned}$$

The push rod stroke (x_p) can be calculated from:

$$\boldsymbol{x_p} = \frac{\boldsymbol{(P_b - P_{atm})A_b - F_{kbi}}}{\boldsymbol{K_b}} \quad \dots\dots\dots(\mathbf{2})$$

Mooney-Revilin (2-Parameters)

The 2-parameter Mooney-Rivlin option has an applicable strain of about 100% in tension. Compared to the other options, higher orders of the Mooney-Rivlin option may provide better approximation to a solution at higher strain.
The form of the strain energy potential is:

$$w = C_{10}\,(I_1 - 3) + C_{01}\,(I_2 - 3) + \frac{1}{d}(J - 1)^2 \quad \dots\dots\dots (3)$$

Where:

I_1:$\lambda_1{}^2 + \lambda_2{}^2 + \lambda_3{}^2$

I_2:$\lambda_1{}^2\lambda_2{}^2 + \lambda_2{}^2\lambda_3{}^2 + \lambda_3{}^2\lambda_1{}^2$

where:

$\lambda i = 1 + \varepsilon i$ principal stretch ratio in the ith direction

Finite Element Method:

SOLID45 is used for the 3-D modeling of solid structures. The element is defined by eight nodes as shown in fig.3. The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities. A reduced integration option with hourglass control is available. After built the solid model, established element attributes, and set meshing controls, the model ready to generate the finite element mesh. First, however, it is usually good practice to save the model before initiate mesh generation, in current study a free meshing was used as shown in fig.4.

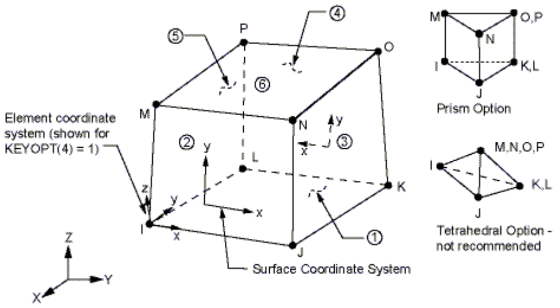

Figure 3. Solid45 Geometry.

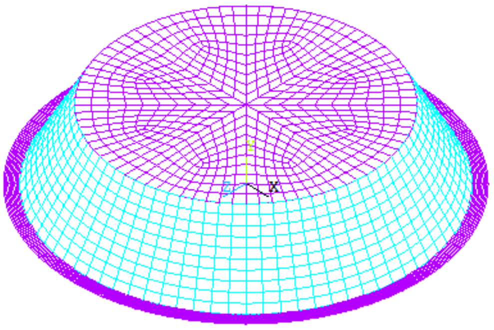

Figure 4. Free Diaphragm Mesh.

Experimental Work

Material and Apparatus

Tables (1) ,(2) and (3), show standard diaphragm recipe and new design for diaphragm recipe I and II.

Table (1): Standard Diaphragm Recipe.

Material	Phr
EPDM rubber	100.000
Carbon Black (CB) 326	80.000
Sulphur	1.500
Zinc Oxide (Zno)	5.000
Stearic acid	1.000
Petroluim Oil	50.000
Mercabto Benzo Thiozole (MBT)	0.500
Tetramethylthiuram disulfide (TMTD)	1.000

Table (2): New Diaphragm Recipe I.

Material	Phr
Butyl rubber	100.000
Zinc Oxide (Zno)	4.000
Carbon Black (CB) 326	50.000
Paraffin Oil	7.500
Neoprene rubber	5.000
Vulcaresin (PA105)	7.800

Table (3): New Diaphragm Recipe II.

Material	Phr
Natural rubber (SMR20)	60.000
Synthetic rubber (SBR1502)	40.000
Zinc Oxide (Zno)	8.000
Stearic acid	1.400
Carbon Black (CB) 326	64.000
Renicit	0.100
Sulphur	3.000
Accelerator, DCBS	0.500
Anti-Scorch Retarder (PVI)	0.150

In the present work, some of laboratory tests will be performed, two types of stocks standard sock recipe according to commercial company and new designed stock will be tested to understand the behavior of diaphragm under verity values of pressure for rubber-cord reinforcement by Nylon 6/6 (polyamide) cross (bias) ply reinforcement to limit deformation and give equilibrium response with controlled region in all directions. Figure (5) shows nylon fabric cross (bias) ply orientation.

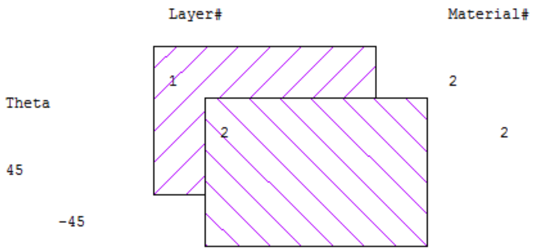

Figure 5. Cross (bias) ply.

Tensometer (Monsanto) machine was used to perform the tensile test according to ASTM D412. Finally, Wallace De Mattia flexing machine according to ASTM D430 and ASTM D813 was used to understand the mechanical behavior of diaphragm in case of present defects.

In the finite element analysis, two types of diaphragm material where examed under pressure range between (0.1- 0.7) MPa or (14.5-101.6) Psi and all these results were compared with the experimental results to know the validity of the new design recipe to work as a part of air brake system.

Results and Discussions

Figures (6) and (7) show the experimental and theoretical deflection and stress result of standard diaphragm recipe, new diaphragm recipe I and II respectively.

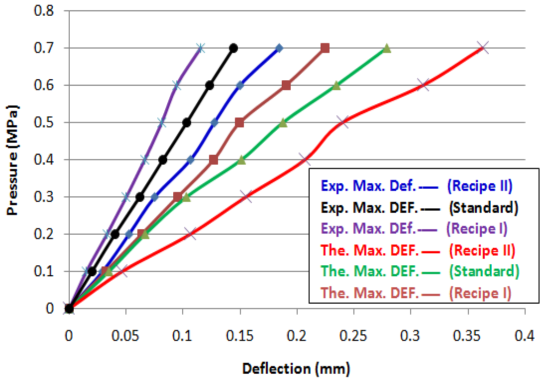

Figure (6): Maximum Deflection.

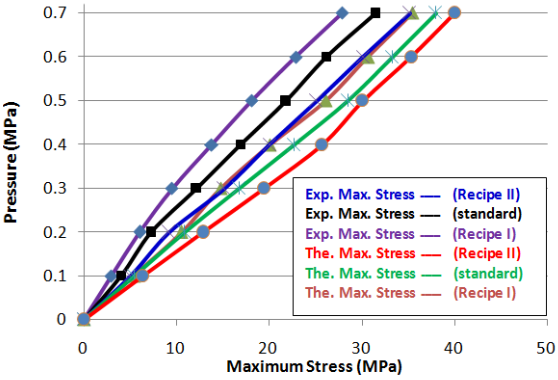

Figure (7): Maximum Stress.

Figures (6) and (7) illustrate clearly the good response for the two suggested recipes compared with the standard recipe. The experimental deflection and stress results were less than theoretical results generally. The experimental results (deflection and stresses) of recipe I was less than experimental (deflection and stresses) of standard recipe and recipe II, while standard recipe was the best compared with recipe II. The theoretical results did not give different indication. Table (4) shows these results and the discrepancy between them.

Table (4): Discrepancy Between Experimental and Theoretical Results.

Recipe No.		Sta.	I	Disc (%)	II	Disc (%)
Experimental	Maxi. Defl (mm)	0.14	0.11	21	0.17	-21
	Max. Str (MPa)	30	28	6.67	33	-10
Theoretical	Maxi. Defl (mm)	0.27	0.23	14.8	0.35	-29
	Max. Str (MPa)	37	34	8.1	38	-2.7

The behavior of these recipes may be related to the mechanical and physical properties of the material. In EPDM, the elongation range is (100%-700%) with good tensile, resilience and vibration damping property [8-11]. Also, Butyl rubber (IIR) in recipe I, is a synthetic rubber, a copolymer of isobutylene with isoprene. It has excellent impermeability, and the long polyisobutylene segments of its polymer chains give it good flex properties [12,13]. Neoprene or polychloroprene in recipe I use to activate the recipe and maintains flexibility over a wide temperature range, in addition to resists degradation more than natural or synthetic rubber. It has balanced properties such as good mechanical strength, high ozone resistance, good aging resistance and adhesion to many substrates [14,15].

Natural rubber (SMR20) and synthetic rubber (SBR1502) in recipe II have good physical and mechanical properties that made this recipe is an appropriate choice, and from these properties, good abrasion resistance, good aging stability, processability, low cut growth rate, low hysteresis and low cost. The right price and wide range of this recipe in addition to good operational life make it acceptable choice to work in new design for diaphragm actuator [16-18].

The finite element results illustrated the responses against applied stresses at numerous pressure values (0.1- 0.7) MPa. Figures (8-13) present the contour deflection for standard (Standard Recipe), new diaphragm I (Recipe I) and II (Recipe II) recipes respectively.

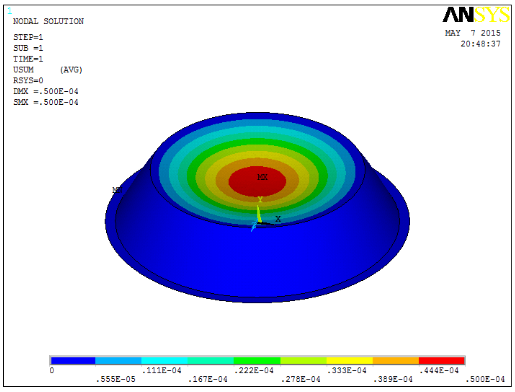

Fig.(8):At Pressure 0.1 MPa (Standard Recipe)

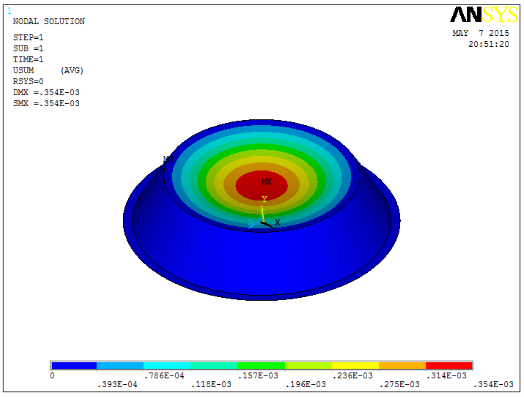

Fig.(9):At Pressure 0.7 MPa (Standard Recipe)

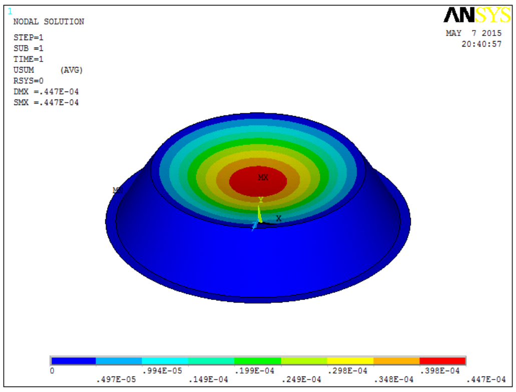

Fig.(10):At Pressure 0.1 MPa (Recipe I)

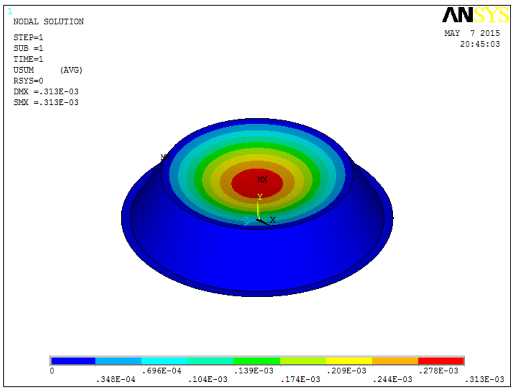

Fig.(11):At Pressure 0.7 MPa (Recipe I)

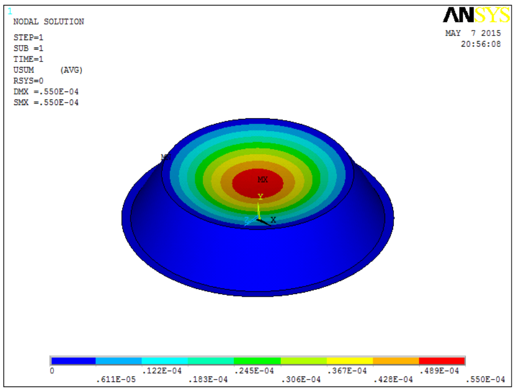

Fig.(12):At Pressure 0.1 MPa (Recipe II)

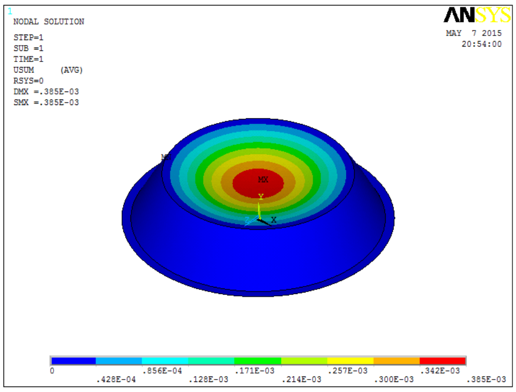

Fig.(13):At Pressure 0.7 MPa (Recipe II)

Also, figures (14 - 19), show the contour of the stress distribution of standard (St. Rec.),new diaphragm I (Rec. I) and II (Rec. II) recipes under same pressure range.

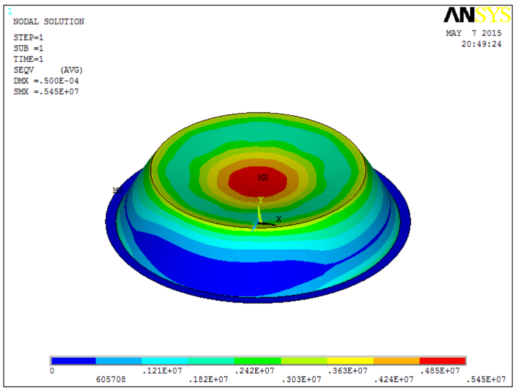

Fig.(14):At Pressure 0.1 MPa (Standard Recipe).

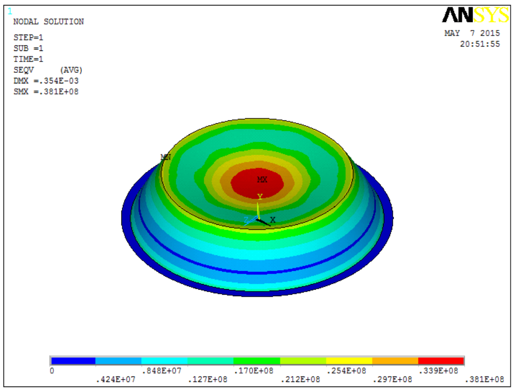

Fig.(15):At Pressure 0.7 MPa (Standard Recipe).

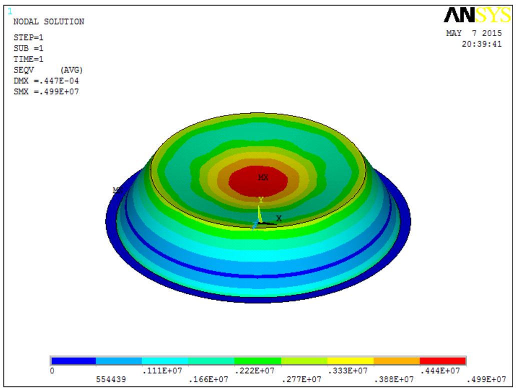

Fig.(16):At Pressure 0.1 MPa (Recipe I).

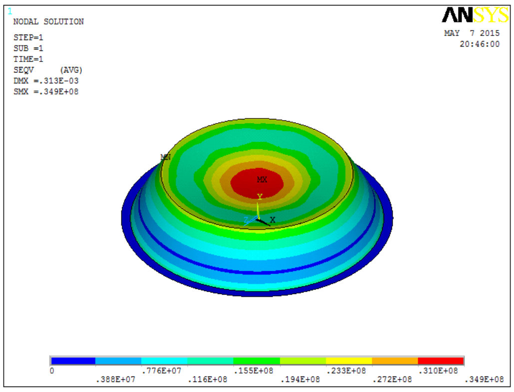

Fig.(17):At Pressure 0.7 MPa (Recipe I).

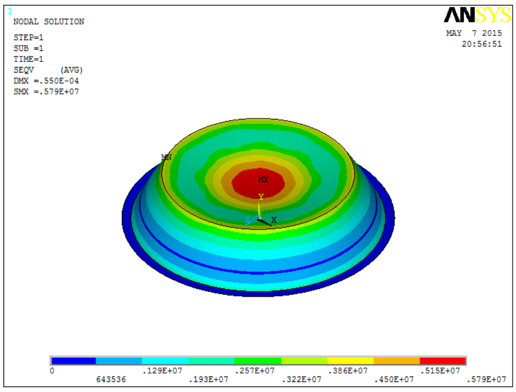

Fig.(18):At Pressure 0.1 MPa (Recipe II).

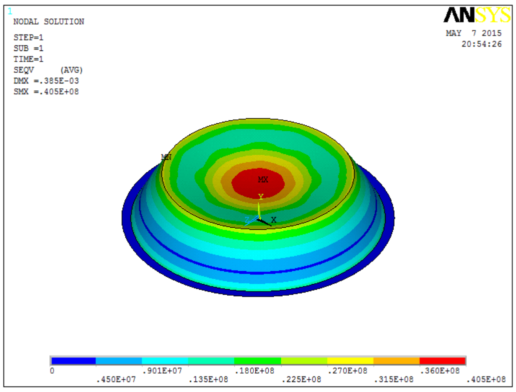

Fig.(19):At Pressure 0.7 MPa (Recipe II).

Table (5) shows comparison between maximum deflection results at max. and min value of pressure, also for maximum stress for all recipes.

Table (5): Max. Deflection and Max. Stress.

Recipe No.		**0.1**	**0.7**	**Recipe No.**		**0.1**	**0.7**
Max. Defl. (mm)	St.	0.05	0.354	**Max. Str. (MPa)**	St.	5.45	38.1
	I	0.045	0.313		I	4.99	34.9
	II	0.055	0.385		II	5.79	40.5

Table (6), represents the flexing results by De Mattia flexing machine tester that was used to test rubber specimens for resistance to cracking produced either by extension or bending and according to ASTM D 813 for all recipes, where recipe II gives best results comparing with recipe I and standard recipe and these result may be related to the properties of NR and SBR. The flexing increase as a consequence of stereoregularity of NR which makes it sensitive to crystallization against straining. The crystalline domain of NR limits the free ends of flexible segment in rubber chains and gives high cut growth resistance.

Table (6): Flexing Life Results.

Recipe	**Life (cycle)**
Standard	11500
I	13000
II	16000

Conclusion

The originality of the present work represented by study an active subject where the lack of resources and references that deals with specific product to find viable alternatives with analytical study to determine the response of these alternatives under working conditions. The two new recipes (I and II) considered acceptable in performance properties compared with standard, but the economic comparison between these two recipes (I and II) make the advantage for the second (recipe II) because of economic benefits.

Acknowledgment

The author would like to thank Rubbery Industrial Company/ Al-Dewanyha and Babylon Tire Factory. Also, to thank Al-Qadissiyha University, College of Engineering.

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