Avrupa Bilim ve Teknoloji Dergisi
Özel Sayı, S. 16-21, Ocak 2018

Konferans Bildirisi

www.ejosat.com ISSN:2148-2683

European Journal of Science and Technology
Special Issue, pp. 16-21, January 2018

Conference Paper

Experimental Investigation on Fatigue Life of Cord-Rubber Composites

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Abstract

Air springs are used in automobile suspensions and perform under highly dynamic loading conditions. An essential component of an air spring mechanism is the rubber tube. The rubber tube produced from layered cord rubber composites. It is constructed as two-layer cord fabric reinforced rubber composites. The matrix crack, debonding and failure of the cord are the most observed damage modes of cord-rubber composites. The presented study investigated fatigue life behavior and damage mechanisms of the PA 6.6 Cord fabric/Natural rubber composites. Curing conditions of rubber such as pressure (7.5,12.5, 15 MPa), temperature (140,160 and 180 °C) and time (5,8 and 10 min) were taken as research parameters. Moreover, two type of PA 6.6 cord fiber and three different fiber orientation angle (40,42 and 45°) were studied as material parameters. All experiments performed by using De-Mattia cyclic fatigue test equipment under 5 Hz frequency. The experimental study designed by Taguchi method using L18 orthogonal series. The results show that 12.5 to 15 MPa curing pressure, 8-10 min curing time and 160 °C are optimum values for cord rubber layered composites to obtain high fatigue life. The fiber type of the cord fabric and fiber orientation angle between 40 to 45° does not affect the fatigue life of the cord-rubber composites. The post-mortem analysis performed to clarify damage mechanisms.

Keywords: Cord rubber composites, fatigue, natural rubber, damage.

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1. Introduction

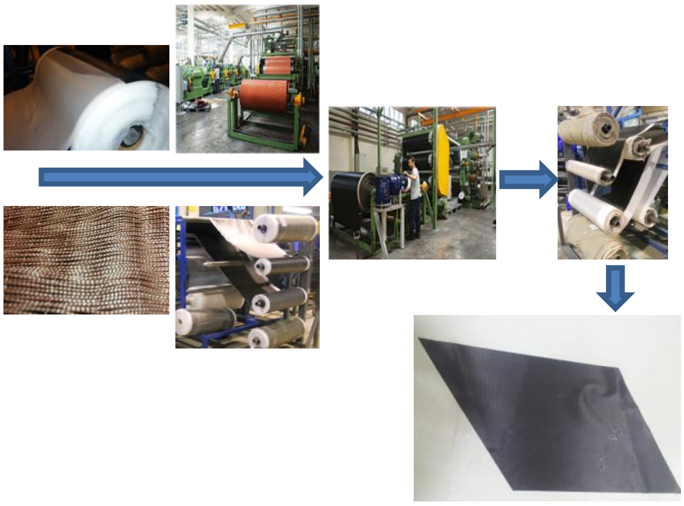
Rubber is a kind of valuable polymer material, which has the unique properties of other materials. Rubber material can withstand enormous strain but does not produce permanent deformation or damage and has the advantage that conventional engineering materials cannot match, which makes it has excellent application in many occasions (Zhang and Zhao 2015). Although these impressive properties of the rubber, their strength does not enough to self-use in many possible areas such as air springs, tires, and belts. To improve the strength properties of the rubber, different type of cord fiber reinforcements have been used, and cord/rubber composites developed. Several types of the cords have been used in tires as reinforcement, such as rayon, nylon 6 and 66, and polyester (Jamshidi et al. 2006). Fatigue life of the composite initially based on elastomeric matrix material and rubber/cord fiber interface. Both properties depend on vulcanization pressure, temperature, time process parameters and cord fiber twisting type and cord fiber surface preparations (Li et al. 2017). Although, cord fabrics improving the strength of rubber, the fatigue life of the rubber can be decreased by initiation of the cracks in the cord fiber/rubber interface and fiber end-tips (Valantin et al. 2015) In case of many parameters effects of the composite material's strength and fatigue life (Ozsoy et al 2016, Eksi and Genel 2017). Taguchi experimental design method is widely used to save experimental time and analyze effects of each parameter (Ozsoy et al. 2017).

In this study, fatigue life of the cord/rubber composites were studied under different process parameters. The research parameters of the cord/rubber composites were specified within the air-spring production parameters which all in the accepted tolerances by the air spring manufacturers. These were vulcanization time, vulcanization pressure and temperature, fabric orientation angle and cord fiber twist type. Taguchi experimental design was used to describe the experimental program.

2. Materials and Method

2.1 Materials

Natural rubber based composite matrix and cord fiber-based fabric were used in the manufacturing of rubber/cord composite specimens. Natural rubber based compound calendered as lining material. PEGA automotive Company supplies all the materials used in the experiments. Rubber coated cord fabric and lining rubber were used to form the reinforcing structure. The rubber coated cord consists of special rubber mixture and cord fabric. Lining rubber is prepared by calendering according to air spring standards. The thickness is 1.4 mm ± 0.05 and elongation at break % 450, and the strength is 21 MPA. The production line can be seen in Figure 1.



Exp No:	Cord Fabric Type	Fiber Orien. Angle (°)	Vulc. Time (min.)	Vulc. Temperature ºC)	Vulc. Pressure (Bar)
1	1	40	5	140	125
2	1	40	8	160	150
3	1	40	10	180	75
4	1	42	5	140	150
5	1	42	8	160	75
6	1	42	10	180	125
7	1	45	5	160	125
8	1	45	8	180	150
9	1	45	10	140	75
10	2	40	5	180	75
11	2	40	8	140	125
12	2	40	10	160	150
13	2	42	5	160	75
14	2	42	8	180	125
15	2	42	10	140	150
16	2	45	5	180	150
17	2	45	8	140	75
17	2	45	10	160	125

Figure 1. Rubber/Cord fabric composite materials production line.

Two types cord fabrics were used based on Nylon 6.6. The fabrics were produced by Kordsa Co./Turkey. The fabrics were used in the production of the Air springs as reinforcement materials. They have the superior tensile strength and offering for weight reduction, longer life, easy processability, improved safety and higher load capacity. They called in this paper as Type1 (1400x2-120 Number of total fiber 1740) and type2 (940x2-150 dtex, Number of total fiber 2030). The mechanical and physical properties of these fabrics were presented in Table 1

2.2 Design of Experiments

To achieve the fatigue determination of the natural rubber/cord fabric composite structure, the most effective parameters were selected. Because of long experimental time need for fatigue experiments, decided to use Taguchi DOE technique. Temperature, Vulcanization Time, Cord Fabric Type, Cord Reinforcing Angle and Vulcanization Pressure were selected as significant parameters to understand the effect of air-spring manufacturing tolerances. The parameters and their levels were given in Table 2. Using Taguchi Design of Experiment technique, L18 orthogonal series were applied. The Minitab ® software was used to a selection of efficient experiments. In Table 3, Taguchi DOE calculation results for the experimental program.

Table 1. Mechanical and physical properties of the cord fabrics.

Cord Yarn Properties	Type 1	Type 2
Yarn Count (dtex)	1400	940
Breaking Strength (Kg)	13.46	8.82
Tenacity (cN/tex)	93.3	91.7
Elongation (at 4.5 kg) %	8.1	9.2
Elongation at break (%)	18.2	17.5
Shrinkage (at 177ºC, 2 min.) (%)	6.6	7.4
Cord Fabric Properties		
Construction	1400x1x2	940x1x2
Breaking Strength Average (Kgf)	22.5	14.5
M adhesion (kg/10 mm)	15	10
Cord Thickness (mm)	0.65±0.05	0.54±0.04
Ply Twist, Z (tpm)	390±15	470±15
Cable Twist, S (tpm)	390±15	470±15

Table 2. Decided parameters and levels in the study

Parameters	Levels
Vulcanization Temperature (ºC)	140, 160 and 180
Vulcanization Time (min.)	5,8 and 10
Cord Fabric Type	Type1 and Type 2
Cord Fabric Orientation Angle (°)	40, 42 and 45
Pressure (Bar)	75, 125 and 150

Table 3. Taguchi experimental design.

2.3 Material Production and Specimen Preparation

Specimens were prepared according to the calculated experimental program. The rubbers were prepared by cutting to the desired size. Cord fabrics were cut at different angles determined by their type. After the material preparation processes, all production activities were performed in the laboratory environment. In Figure 2 cutting rubber coated cord fabrics respecting orientation angle of composite specimens were presented.

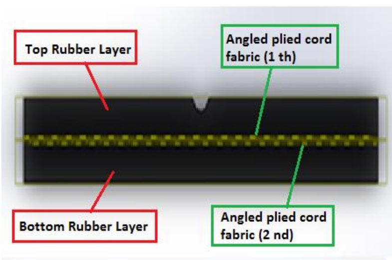


Figure 2. Cutting rubber coated cord fabrics according to orientation angle and placement of cord fabric between lining rubber material in the fatigue specimen.

Rubber coated fabrics were cut respecting described reinforcing orientation angles (40◦, 42◦ and 45◦) and standard Specimen size (25x 150 mm), lining rubber also cut specimen size and they set in the compression mold as decided layer configurations. Layer configurations and production flow were represented in Figure 3. Layered sheets were compressed and vulcanized under described process parameters such as pressure, time and temperatures.

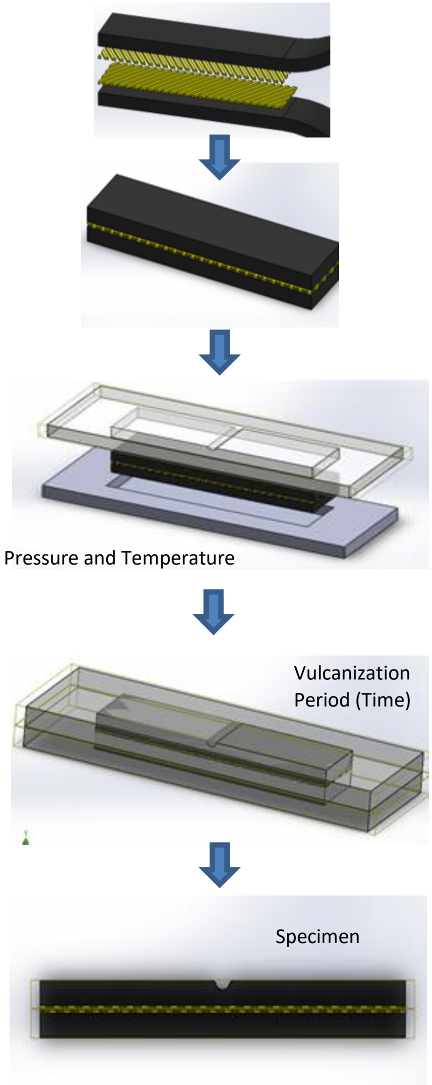


Figure 3. Specimen preparation flow schema.

The test specimens was obtained by vulcanizing prepared layered cord/rubber composites using a hot press at different temperatures, minutes and pressures. After the vulcanization process, rubber parts were taken out from the mold and rested for 16 hours at room temperature. Samples prepared according to De Mattia test device and ASTM D430-06 standard. Specimen dimensions and production mold and press were presented in Figure 4.

Figure 4. a) De-Mattia Specimen dimensions (ASTM D430-06) b) Mold c) Hot Press

2.4 Experimental Setup

The De Mattia fatigue test device is used at 5 Hz to initiate the formation of cracks by repeated flexing of cord/rubber composite specimens, prepared according to standards. The cord/rubber composite samples are clamped in the jaws of the De Mattia fatigue device as shown in Figure 5. The upper and lower jaws are fixed, and the middle part is movable. The middle part moves up and down to detect the crack initiation in the rubber. At the same time, 22 specimens can be loaded in the fatigue device. Each specimen was labeled from 1 to 18 and fatigue device was stopped each 50 000 cycle and specimens condition and crack initiation were observed and recorded.

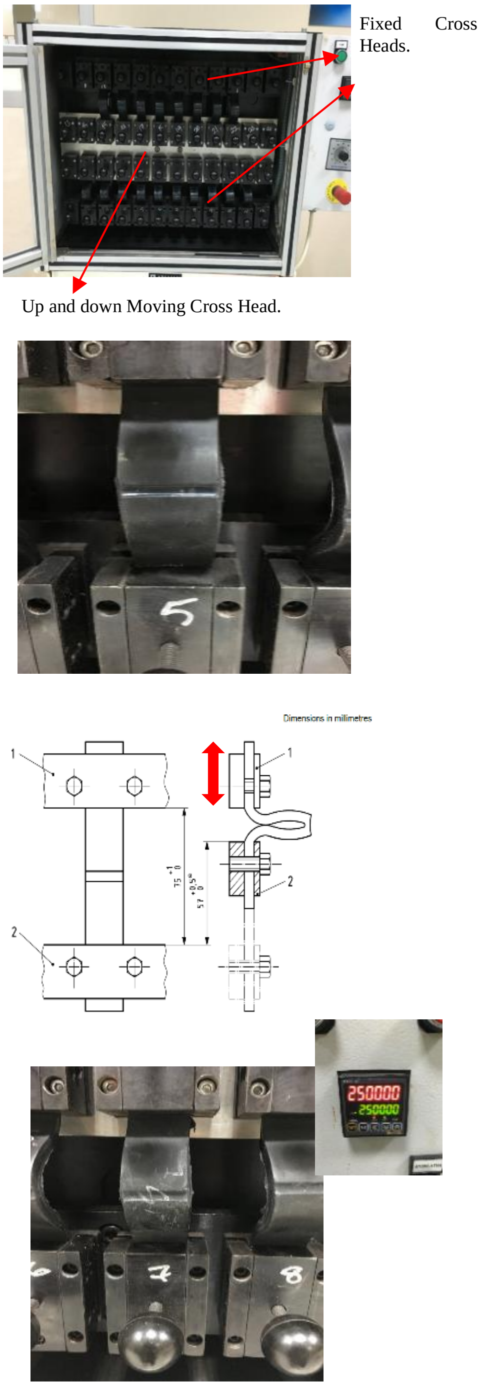


Figure 5. De Mattia fatigue test device and placement of specimens.

3. Results and Discussion

The fatigue life table of our samples results was obtained as given in Table 4. According to Taguchi analysis (Figure 7), Cord fabric type (Number 2) is more efficient than other parameters. It was observed that the temperature would be insufficient less than 160 ºC. Curing time as 8 min. is effective value for the fatigue life. Cord fiber orientation angles did not affect directly for selected orientation angles.

Table 4. Fatigue life results

Specimen Number	Cord Fiber Type	Fiber Orientation Angle (°)	Vulc. Time (min.)	Vulc. Temperature (ºC)	Vulc. Press. (Bar)	Fatigue Life Cycle
1	1	40	5	140	125	250000
4	1	42	5	140	150	260000
9	1	45	10	140	75	262250

The other 15 specimens were not shown any damage, fail or crack initiation up to infinite life (1x107). An example of the damaged specimen surfaces was given in Figure 6.

Figure 6. Damaged surfaces and crack initiation and propagation in a failed sample.

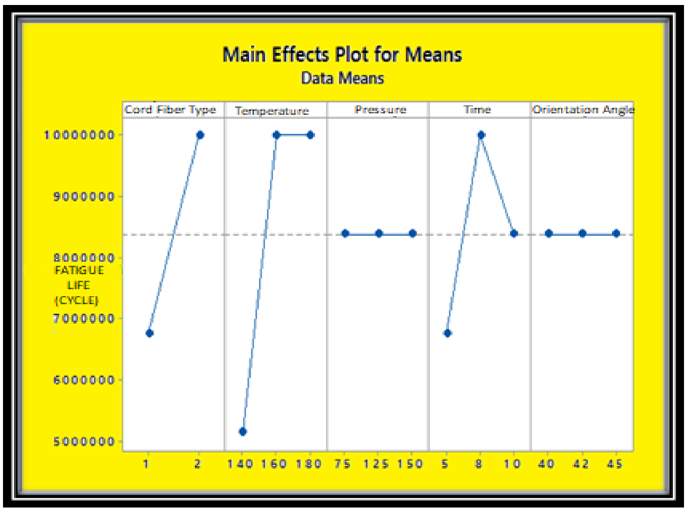


Figure 7. Taguchi analysis of parameters effect on fatigue life.

According to Taguchi analysis (Figure 7), Cord fabric type (Number 2) is more efficient than other parameters. It was observed that the temperature would be insufficient less than 160 ºC. Curing time as 8 min. is effective value for the fatigue life.

Cord fiber orientation angles did not affect directly for selected orientation angles.

4. Conclusions

In the presented study, fatigue life of the cord/rubber layered composites were investigated according to selected design and process parameters by experimentally, and the results can be concluded as given below:

- Cord fabric type is more efficient than other parameters.
- Under 140 °C temperature usage is not suitable for vulcanization.
- Vulcanization time as 8 min. is an optimum value for the fatigue life.
- Cord fiber orientation angles do not effect if they are around 45°.
- The cracks initiated in part, towards the inner edges due to bending because the surface of the material is not a flat surface relative to the outer surface.
- Inner side friction and contact between the two surface of is increased the surface temperature and increased the stress accumulation against to the notch tip.

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