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ESTIMATING FATIGUE OF NR45 NATURAL RUBBER USED IN CRANK PULLEY

KRANK KASNAKLARINDA KULLANILAN NR45 DOĞAL KAUÇUĞUN YORULMA TAHMİNİN YAPILMASI

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ÖZET

Kauçuk, otomotiv endüstrisinin başta olmak üzere birçok mühendislik uygulamasında titreşim sönümleyicisi olarak kullanılmaktadır. İçten yanmalı motorlarda burulma titreşimini sönümlemek için kauçuk kullanılmaktadır. Bu nedenle krank kasnakları belirli frekans aralığında krank milini sönümlemek için kullanılır. Krank kasnağının görevini uzun ömürlü bir şekilde gerçekleştirmesi için kauçuk dayanım ömrü oldukça önemlidir. Bu çalışmada krank kasnaklarında kullanılan iki farklı karışıma sahip NR45 doğal kauçuğun dinamik dayanım ömrü hazırlanan test yaklaşımıyla belirlenmiştir. Kayma deney numunelerde kullanılan metal-kauçuk bileşenli bir yapı oluşturulup üretimi gerçekleştirilmiştir. Metal-kauçuk bileşenin, krank kasnaklarında burulma titreşimini simüle edebilmek için kendi doğal frekansıyla ve belirlenen genlikte dikey yönde kauçuğa zorlamaya bırakılmıştır. Metal-kauçuk bileşeni belirlenen frekansta zorlamak için bir test düzeneği tasarımı gerçekleştirilmiştir. Çalışmada, genlik ve frekansa bağlı olarak ömür tahminleri deneysel veriler üzerinden oluşturulmuştur.

Anahtar Kelimeler: NR45 Doğal Kauçuk, Kauçuk Test, Yorulma Tahmini, Krank Kasnağı

ABSTRACT

Rubber is used as a vibration damper in many engineering applications, especially in the automotive industry. Rubber is used to dampen torsional vibration in internal combustion engines. Therefore, crank pulleys are used to dampen the crankshaft in a certain frequency range. Rubber durability is very important for the crank pulley to perform its duty for a long time. In this study, the dynamic life of NR45 natural rubber with two different mixtures used in crank pulleys was determined by the prepared test approach. A metal-rubber component structure used in the slip test samples was formed and produced. The metal-rubber component is left to force the rubber in the vertical direction with its natural frequency and specified amplitude to simulate torsional vibration in crank pulleys. A test setup design was carried out to force the metal-rubber component at the determined frequency. In the study, life expectancy estimates based on amplitude and frequency were created on experimental data.

Keywords: NR45 Natural Rubber, Rubber Test, Estimated Fatigue, Torsional Vibration Damper

INTRODUCTION

Crank pulleys are an engine part that absorbs the torsional vibrations that occur in irregular piston explosions in the crankshafts and also acts as a drivetrain (Grzędzielai, 2008; Homik, 2012). Torsional vibration is the most critical vibration in the crankshaft in internal combustion engines. Crank pulley is used to prevent problems that may occur as a result of torsional vibrations. With the changing technology, the damping capabilities of harmonic balancers have increased and different types of crank pulleys have emerged (Homik, 2011). Despite these different types, the main purpose of the crank pulley is to reduce the torsional vibration amplitude to acceptable levels. Torsional vibration damper is transferred to the pulleys on engine front assemblies such as air conditioner, compressor, water pump and alternator with poly-V belt (Silva et al., 2019). It is shown in Figure 1.

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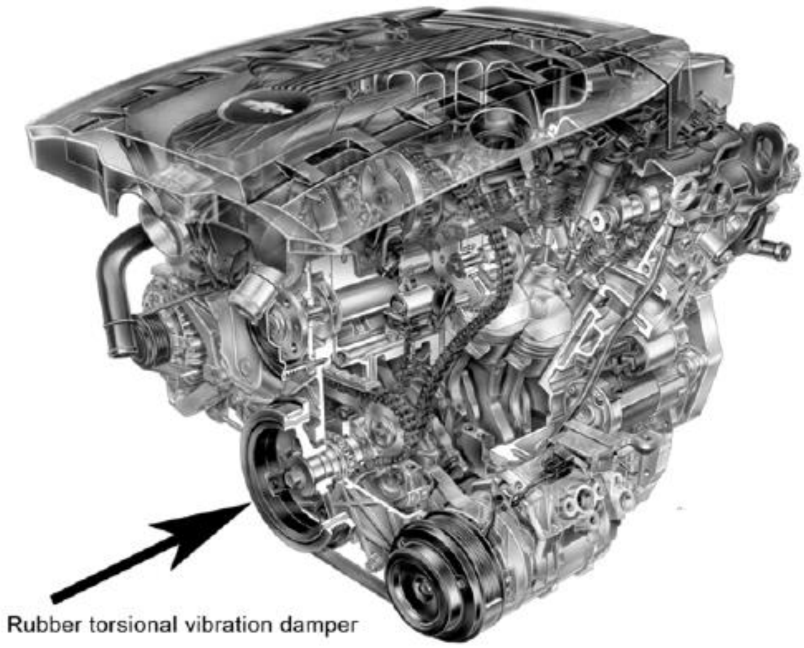

Figure 1. Crank pulley view on engine assembly (Deuszkiewicz and Pankiewicz, 2015)

The lifetime strength of crank pulleys is also the lifetime strength of the rubber element. Rubber is widely used in many sectors, especially the automotive sector, due to its vibration damping feature. Many experimental models have been proposed to predict fatigue in rubbers (Zhang et al., 2018). Natural frequency is one of the most important parameters in the life expectancy of rubber and other materials used in crank pulleys. The natural frequency changes after the rubber are fatigued in certain cycles. Therefore, changing the rubber natural frequency also changes the crank pulleys.

In this study, an experimental method based on natural frequency was used to determine the life expectancy of natural NR45 natural rubber component with two different mixtures. By taking the rubber form suitable for the slip sample as a reference, rubber-metal component samples were produced. These rubber-metal samples were subjected to stress at their natural frequency and determined amplitudes to model the torsional vibration generated in the crank pulley. In order to achieve this forcing, a test system was designed with the help of an electrodynamic force generator and the tests were carried out in this system. Fatigue estimations based on amplitude and frequency were created by using the determined experimental data. The operating performance of the fatigue prediction model is discussed.

TORSIONAL VIBRATION DAMPER

The most effective way to reduce torsional vibration on the crankshaft is to use a crank pulley. The method to be used to select the crank pulley parameters is developed based on the method to be used for designing a dynamic damper. Generally, elastomer material is used as dynamic element in crank pulleys used in internal combustion engines. Crank pulleys with elastomer material can be designed to target one or more frequencies in a compact structure, and they are named as single-mode, bi-mode, multi-mode according to this design. While there is only one inertia mass connected to the elastomer in the single mode crank pulley, there are two separate inertia masses connected parallel to the hub with elastomers as seen in Figure 2 in the originally designed dual mode crank pulley.

Rubber is used as the elastomer material in the crank pulley. The single-mode crank pulley consists of a hub, a rubber ring and an inertia ring. The multi-mode crank pulley consists of an assembly of two parts. The first part consists of the first inertia ring, the hub and the rubber between these two parts. With the rubber vulcanization process, it is injected between the inertia ring and the core in the specified form. The second part consists of an inertia ring, the hub and the rubber between these two parts. Crank pulleys are shown in Figure 2.

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Figure 2. Single and multimode of torsional vibration damper

RUBBER

In single and multimode crank pulleys, the dynamic characteristic must be determined in order to adjust it according to the torsional resonance frequency of the crankshaft. The most important component that determines the dynamic characteristic is rubber. More than one type of rubber is used in crank pulleys. Rubber types such as natural rubber (Nr), ethylene propylene diene rubber (EPDM), nitrile rubber (NBR) and styrene biutadiene rubber (SBR) vary according to their location. Rubber used in frequency damping of crank pulleys should have properties such as continuous operating temperature, low performance, durability to oil and mechanical (tensile strength, friction durability, etc.) (Nagar et al., 2013).

Since the rubber element is the main factor in determining the dynamic characteristic of crank pulleys, it is directly decisive in determining the dynamic properties of the curing characteristic. In rubber materials, curing is the desired elastic properties of rubber by undergoing a chemical structure change (cross-linking reaction) at optimum times and temperatures. It uses the curing curve to determine the rubber curing characteristic. Figure 3 shows a typical curing curve on a rubber sample. It is very important to determine the curing time in the final product, especially in products where the dynamic characteristic such as crank pulley is affected by the molding time. This study was carried out by keeping these issues in the foreground.

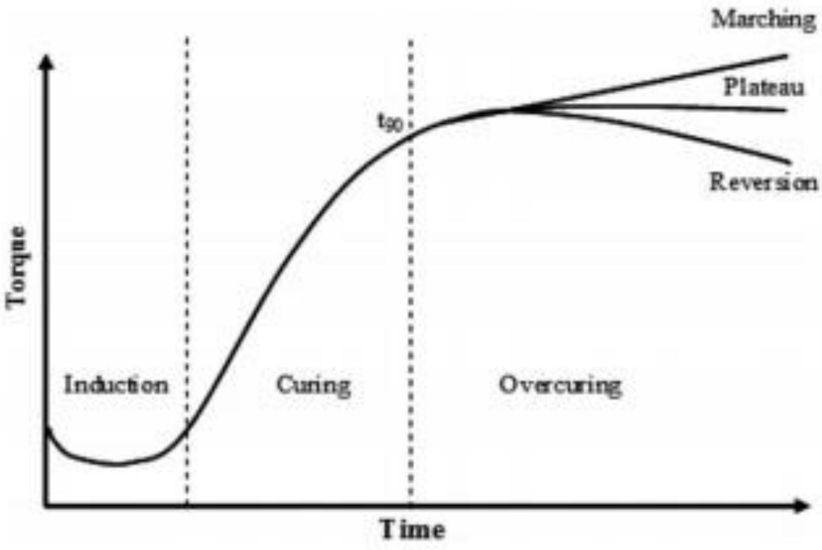

Figure 3. Rubber curing curve (Khimi and Pickering, 2014)

RUBBER SAMPLE PROPERATION

As a result of literature studies, there are multiple methods for rubber fatigue estimation. Parametric models are used to make fatigue predictions based on these methods. Based on these studies, the number of cycles is associated with the change of parameters such as amplitude and frequency. In the models established with parametric approaches, the rubber life estimation is determined according to the determined parameter with the coefficients obtained according to the test results.

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The design of the metal-rubber samples was designed according to the determined rubber type and the rubber samples belonging to the ASTM D945-92 standard used in the slip tests in its most basic form. The rubber form and dimensions of the rubber-metal component samples are shown in Figure 4, and the design of the rubber-metal component test samples are shown in Figure 5.

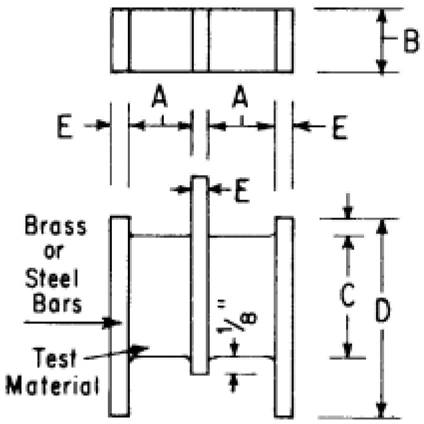

Figure 4. Slip test sample

Figure 5. Rubber-metal component test design view

Rubber-metal component test specimens were selected with NR 45 Shore A rubber material used in crank pulleys. Rheometer tests were carried out to obtain the above-mentioned curing graph for rubber. According to the test results, it is aimed to complete the curing. Thus, the increase or decrease in mechanical properties as a result of excessive curing is prevented and the rubber reaches the expected dynamic properties. The parameters obtained from the curing curve are of decisive importance for rubber molding and rubber dynamic properties. Considering these parameters, rubber-metal samples were produced with compression molding. It is shown in Figures 6 and 7.

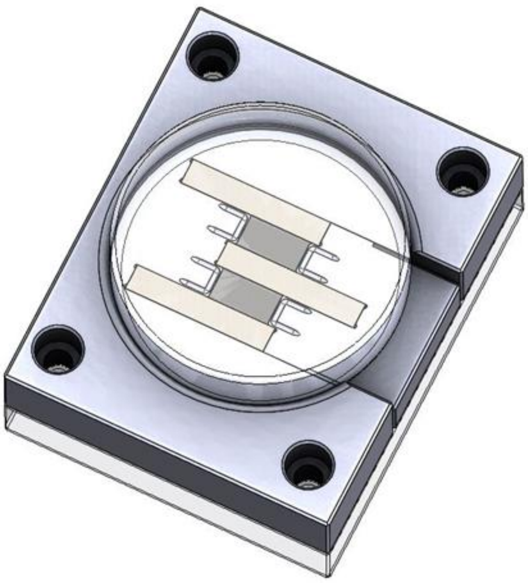

Figure 6. Sample compression mold design

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Figure 7. The sample produced

PROPERATION OF THE TEST BENCH

The test setup prepared for rubber-metal component samples is shown in figure 8. This test bench can be driven up to 1000 Hz. This drive is realized by an electrodynamic force generator. A structure is designed to test samples on top of the force generator. Samples are mounted on the electrodynamic force generator and fixed. Thanks to this force generator, the rubber is subjected to fatigue by forcing the sample in the vertical direction. The measurement of natural frequencies of rubber-metal component samples was measured using uniaxial acceleration (model) and modal hammer (model). The weight of the uniaxial accelerometer is negligible. In addition, shear stress was performed at displacements of 1, 2 and 3 mm to examine the effect of amplitude.

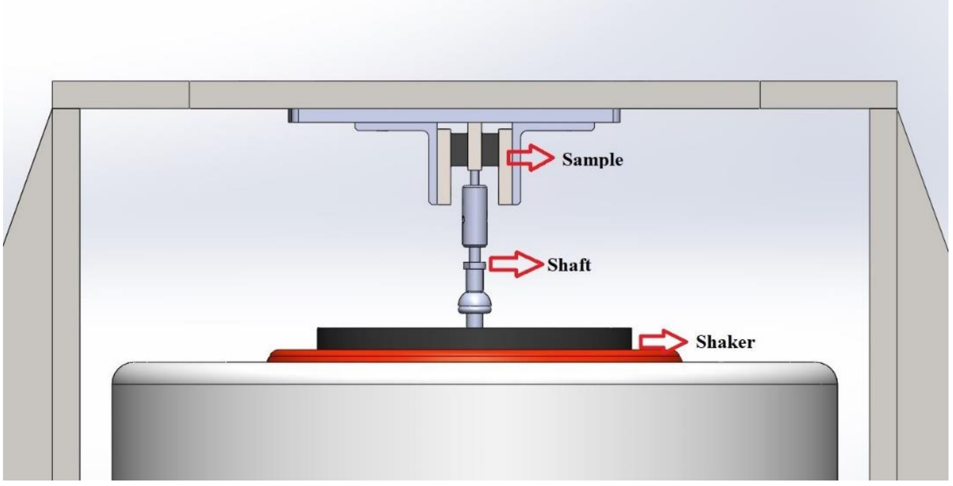

Figure 8. Sample testing setup

The fatigue test procedure was determined for the samples. First, the sample natural frequencies are measured. The natural frequency of the sample is adjusted by the electrodynamic force generator. The natural frequency of the samples was measured every 1 million cycles. Sample tests were completed in 5 million cycles. The tests were applied again at the determined amplitudes.

In the natural frequency measurements, the rate of change of the frequency was examined depending on the displacement and the cycle.

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ESTIMATION OF RUBBER FATIGUE BY TEST PROCEDURE

A parametric fatigue function and fatigue estimation test procedure were established by making a systematic study with the experimental setup and prepared samples for rubber fatigue prediction.

The first natural frequencies of the samples produced with two different mixtures and the natural frequencies in each 1 million according to the amplitude are given in Tables 1 and 2.

Table 1. Frequency-conversion relationship of samples produced with A mixture

Data	1 mm (Hz)	2 mm (Hz)	3 mm (Hz)
First Frequency	44,98	44,80	44,92
1 Million	44,72	44,68	44,55
2 Million	44,36	44,12	44,23
3 Million	44,10	43,96	44,48
4 Million	43,87	43,61	43,10
5 Million	43,71	43,34	42,96

Table 2. Frequency-conversion relationship of samples produced with B mixture

Veriler	1 mm (Hz)	2 mm (Hz)	3 mm (Hz)
First Frequency	44,62	44,59	44,77
1 Million	44,32	44,38	44,48
2 Million	43,88	43,99	44,06
3 Million	43,76	43,81	43,72
4 Million	43,51	43,42	43,36
5 Million	43,29	43,01	42,69

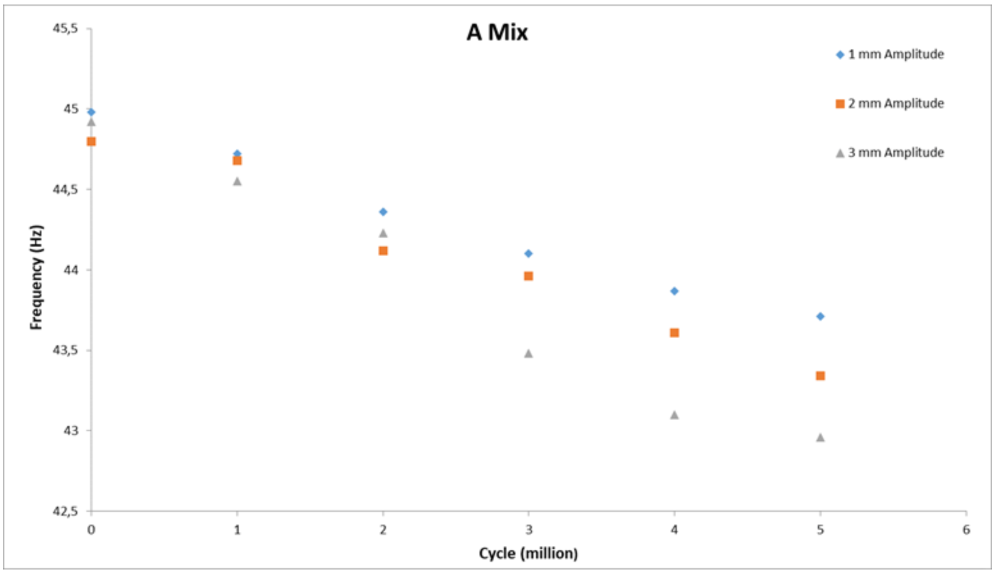

Figure 9. Frequency-cycle graph of A mixed rubber

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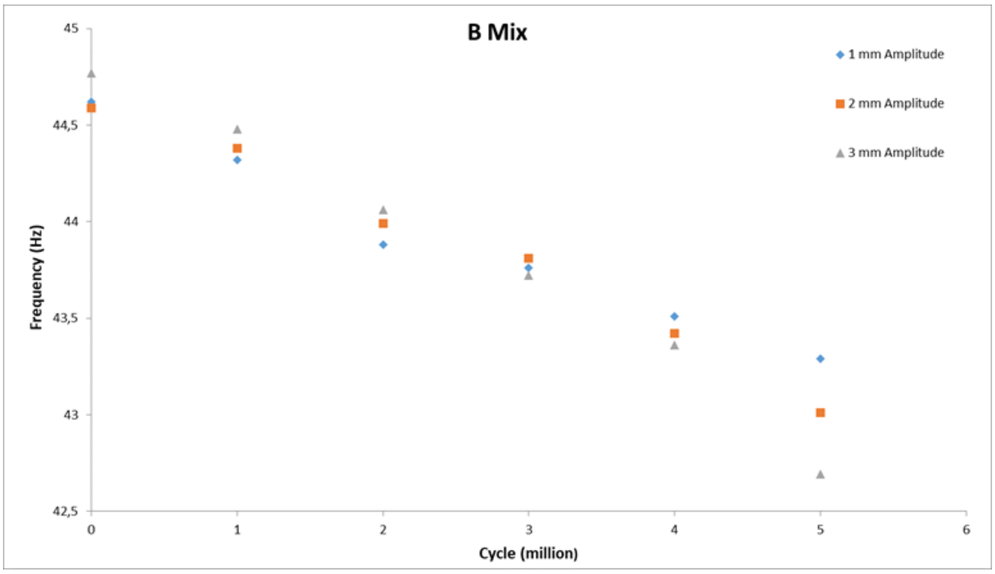

Figure 10. Frequency-cycle graph of B mixed rubber

In crank pulleys, the strength is expressed by the change of the natural frequency depending on the change in the characteristic of the rubber material. For this reason, in this study, the variation of the frequency with the number of cycles was examined. The variation of the frequency with the number of cycles as a result of the tests performed on the samples is shown in figures 11, 12 and tables 3, 4 below. As can be seen from the graph, it can be clearly seen that the natural frequency tends to decrease with the number of cycles, and the tendency to decrease is more with the increase of the forcing amplitude.

Table 3. Frequency ratio-cycle relationship of samples produced with A mix

Data	1 mm	2 mm	3 mm
First Frequency	1	1	1
1 Million	0,9942	0,9973	0,9918
2 Million	0,9862	0,9848	0,9846
3 Million	0,9804	0,9813	0,9679
4 Million	0,9753	0,9734	0,9595
5 Million	0,9718	0,9674	0,9564

Table 4. Frequency ratio-cycle relationship of samples produced with B mix

Data	1 mm	2 mm	3 mm
First Frequency	1	1	1
1 Million	0,9933	0,9953	0,9874
2 Million	0,9834	0,9865	0,9748
3 Million	0,9807	0,9825	0,9674
4 Million	0,9751	0,9738	0,9499
5 Million	0,9702	0,9646	0,9278

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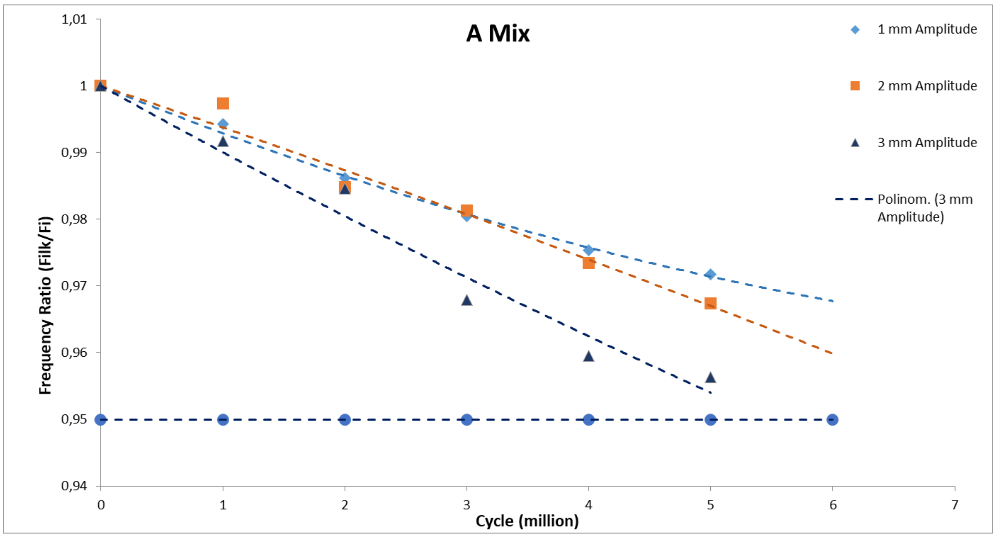

Figure 11. Frequency ratio-cycle graph of A mixed rubber

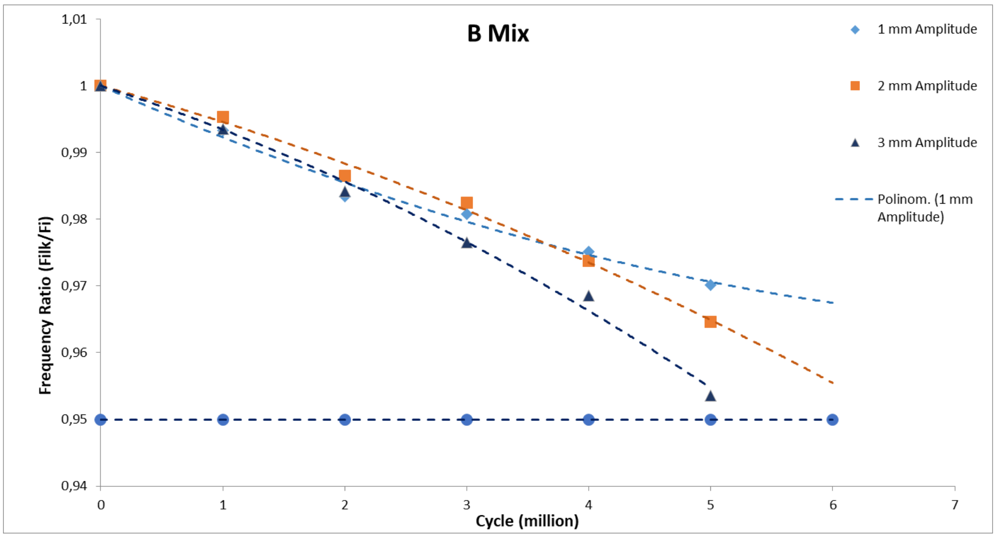

Figure 12. Frequency ratio-cycle graph of B mixed rubber

In order to obtain the fatigue strength characteristic of the rubber material, a parametric function was obtained by using the above graphics. Since the frequency value (drop in frequency) is given as a measure of strength, the horizontally drawn curve in this graph represents the equivalent fatigue strength. As can be seen, this horizontal curve cuts the tests performed at different amplitudes at different points, in other words, at different cycle numbers. By taking the numerical values at these intersection points, the graphs showing the relationship between the forcing amplitude and the equivalent forcing cycle number are drawn as seen in the figures below.

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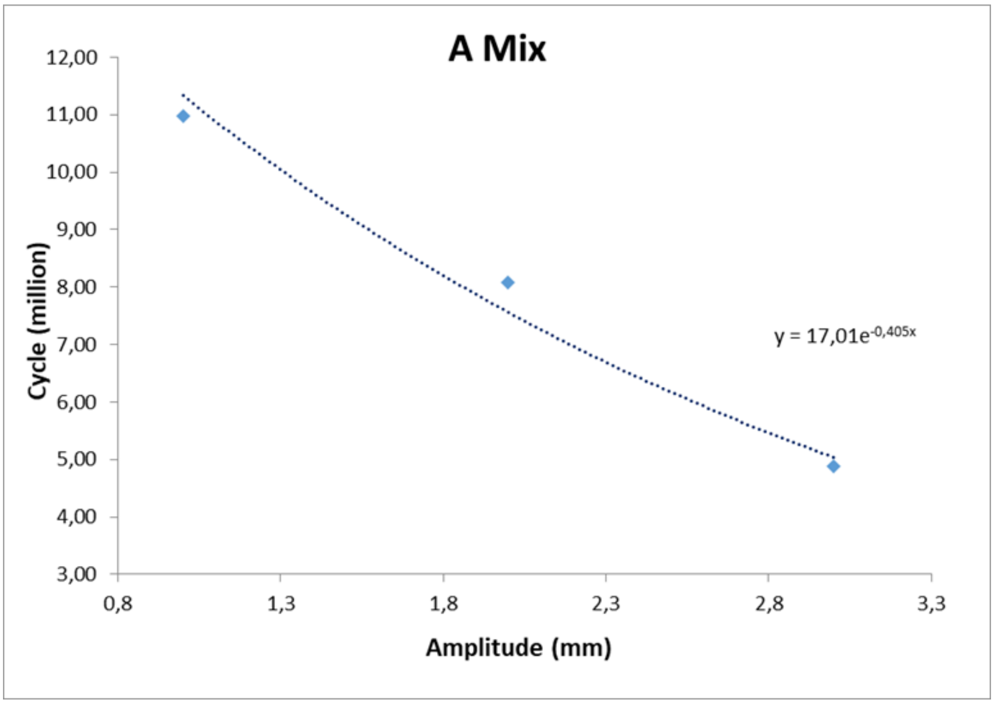

Figure 13. Cycle-amplitude graph of A mixed rubber

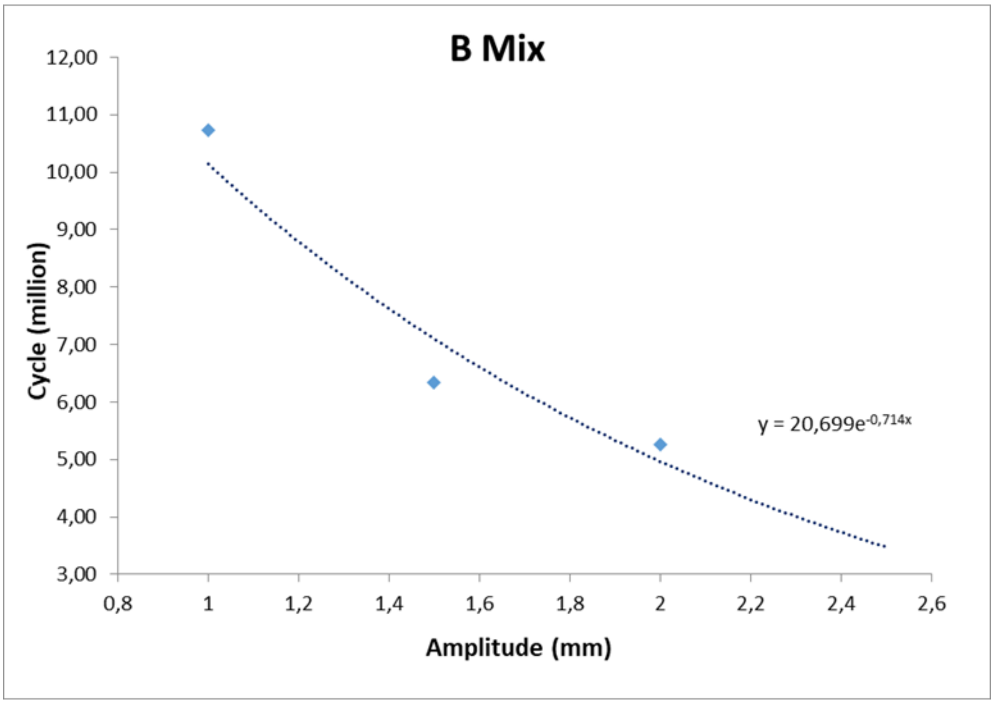

Figure 14. Cycle-amplitude graph of B mixed rubber

As can be seen from the graph, a nonlinear relationship is observed between the increase in amplitude and the fatigue strength. Considering the studies in the literature, a logarithmic/exponential curve was fitted to express the number of cycles as a function of the amplitude over the data obtained, and the functions of these curves are given below.

The formula for A mixture is:

$$N = f(A) = 17{,}01e^{(-0{,}405x)}$$

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The formula for B mixture is:

$$N = f(\mathrm{B}) = 20{,}699e^{(-0{,}714x)}$$

CONCLUSION

In this study, both test system and parametric model were created for NR45 rubber used in crank pulley. While establishing the test system and procedure, rubber-metal component samples were produced in accordance with ASTM D945-92 standard. The produced samples were left to force with the design made on the electrodynamic force generator. This forcing is performed by the natural frequency of the sample. According to the test procedure, samples were tested at amplitudes of 1, 2, 3 mm. For the results obtained, firstly, the frequency ratio-cycle relationship was established for different amplitudes depending on the loop. A curve of ±5% was drawn to the acceptable frequency ratio of the generated curves. The number of cycles was determined at the intersection points with the drawn boundary line. According to the determined cycle numbers, the fatigue cycle number relationship depending on the amplitude was established and an exponential function of the fitted curve was expressed. When the graphs of A and B mixed rubbers are examined, it is concluded that the strength of A mixed rubber is higher. If the number of cycles does not exceed the strength limit (±5%) specified in the regulation, it can be said that the fatigue strength criteria are met.

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