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Research Article

EXPERIMENTAL INVESTIGATION OF THE EFFECT OF RANDOM DISTRIBUTED REINFORCEMENTS ON MECHANICAL BEHAVIOUR OF REINFORCED RUBBERS

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ABSTRACT

In this study, the mechanical behaviors of rubbers reinforced with continuous fibers piled in various forms are experimentally investigated under tensile load. In the study, unreinforced and reinforced rubber specimens are used in tensile tests. Polyester with various thicknesses and Nylon 6.6 are used as the reinforcement material. Also, tensile tests are carried out with Polyester and Nylon 6.6 cord. All reinforced specimens subjected to the test are prepared in two layers. A rubber layer is placed between the layers to prevent the fibers from contacting each other. The specimens are prepared as standard tensile test specimens. All tests are performed at a speed of 0.5 mm/s. The distribution difference of the reinforcement material (fibers piled at the center, fibers piled around the edges and fibers distributed uniformly) are investigated when the tensile forces applied to the specimens. Their effects on amount of deformation is also investigated. During testing, slippage of fibers with respect to the rubber matrix are also discussed.
Keywords: Reinforced rubber, continuous fiber, nylon 6.6, polyester, tensile test.

1. INTRODUCTION

Natural rubber is a commercial material that accounts for %70 of the total use of rubber and used as the raw material for many products in the industry [1]. The purpose of using natural rubber-based materials is because of their better mechanical properties than others. Natural rubber is known as a hard elastomer that can handle large deformations [2]. Besides, commercial usage field of natural rubber is greatly improved because it is a recyclable material. However, in many products in order to improve the mechanical properties, natural rubber is used in the way that it is reinforced by using continuous fibers. Numerous products such as vibration isolation, belts, gaskets, tires, pressure hose, and airbags are widely used in many fields, especially in the automotive industry [3-4]. In Figure 1, various examples of fiber-reinforced rubbers commonly used in the automotive industry are shown.

Silicon rubber is used in many applications such as automotive industry, electronics, shoes, robotic grippers, hand rehabilitation, artificial muscle, medical devices, aviation, toy etc. [5-8]. In

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this study, silic one rubber is reinforced with various strengthening materials to investigate the mechanical properties of the reinforcements in different distribution states.

Figure 1. Examples of various fiber-reinforced rubbers [9-10]

In the literature, Rey and et al. conducted the effect of temperature on the mechanical properties of two silicon rubbers [5]. Li and et al., in order to adhere reinforcement materials to a natural/styrene butadiene rubber and develop mechanical properties, continuous basalt fibers were immersed in RFL (resorcinol-formaldehyde-latex) system by the action of a connecting silane agent and without silane [11]. Herrera-Franco et al. investigated HDPE (high-density polyethylene) reinforced with continuous natural fibers. To enhance the fiber-matrix interaction; researchers increased the contact area, revealed cellulose microfibrils and improved fiber wettability and absorption by intervening fiber exterior properties [12]. Tsai and et al. studied the effect of changing the Polyester rubber-fiber layers and their orientations on the mechanical properties of chloroprene rubber composites [13]. Zhang and et al., developed a different method to create random fiber distribution with high fiber density, in the cross-sectional area of the fiber-reinforced composites [14]. The damage mechanisms in unilateral fiber-reinforced plastics are investigated by Parambil et al. For this purpose, on the micro-scale, the improvement of 3-D repeating unit cells with randomly piled fibers are studied [15]. Unfilled silicone rubber is tested to determine its mechanical properties by Meunier et al. Finite element simulations of experiments are done by the hyperelastic models. Later, researchers compared the experimental and numerical results [16]. The mechanical properties of various artificial muscle and modeling are investigated and a finite element analysis is carried out by researchers [17-21]. Gong and et al. developed a flexible pneumatic artificial muscle (FPAM) using silicone rubber as matrix and Kevlar fibers as reinforced materials. They compared their muscle with McKibben artificial muscles [22]. Adachi and et al. studied the drop weight test and the results of the theoretical analysis of thin-walled cylinder [23]. He and et al. examined the mechanical properties of silicone rubber reinforced with various white carbon black [24]. Durante and et al. performed a numerical model and experimental validation of a PMA (pneumatic muscle actuator). They numerically created and modeled the actuator. The producing model was experimentally verified using a prototype [25]. Zhu and et al. investigated a numerical study of random fibers distributions and its influence on the mechanical properties of thread in-plane woven carbon fiber-reinforced composites. Random distribution of fibers almost has no effect on the axial tensile strength [26].

The tensile test results of the reinforced natural rubber composite are shown in Figure 2. Figure 3 shows that fibers are aligned along tensile direction. In this case, uniform distances between fibers are changed as a result of applied pressure.

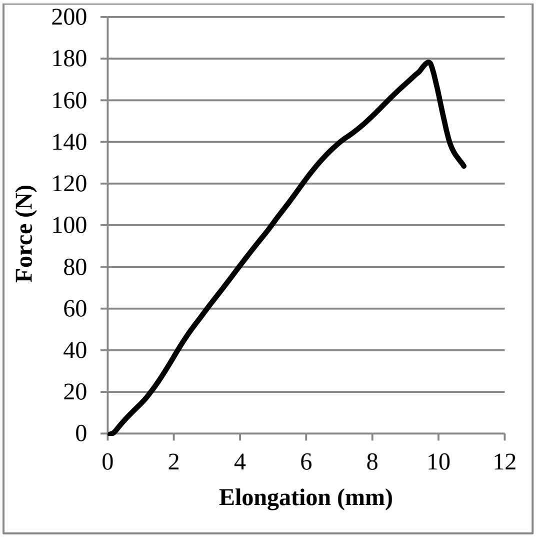
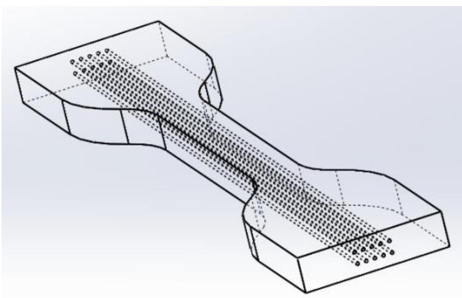
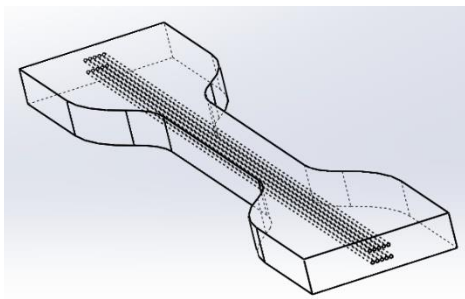


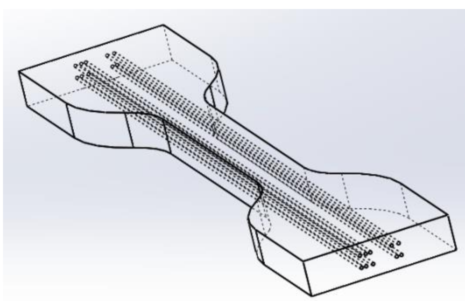
Figure 2. Tensile test results whe re the fibers are two-layered and uniformly distributed (angle is 0° between fibers)



a) Uniformly



b) At the center



c) Around the edge

Figure 3. a) Uniformly, **b)** at the center and **c)** around the edge distributed fiber-reinforced rubber specimen model (angle is 0° between fibers)

Figure 4 shows the technical drawing of the die which is used in the study.

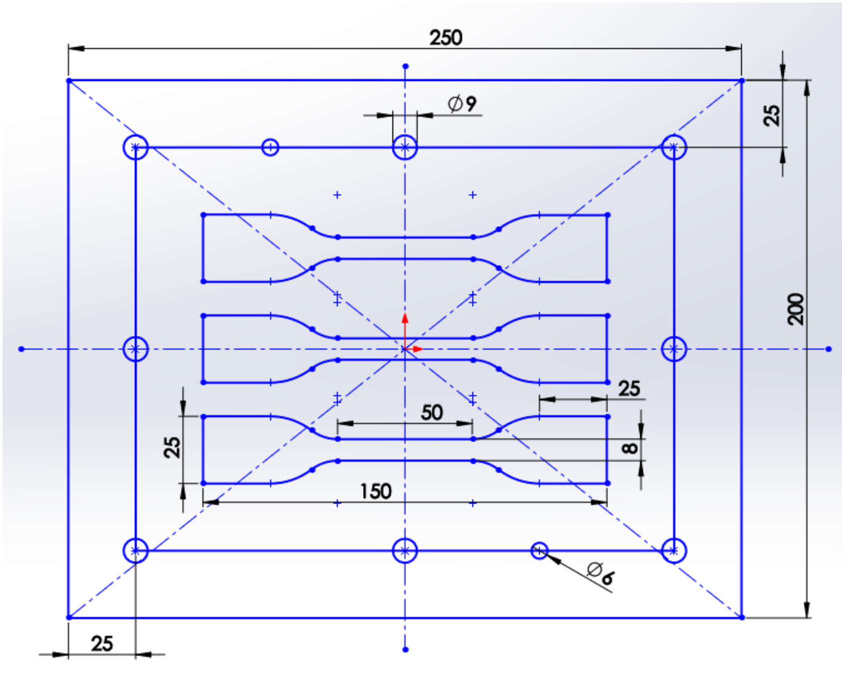


Figure 4. The technical drawing of the die

2. MATERIAL AND METHOD

2.1. Preparation of Die and Specimens

Tensile testing of fiber-reinforced rubbers is important because it explains the mechanical properties of these materials. Therefore, in this work, the die of composite materials to be used is prepared by cutting in the wire erosion machine. In order to obtain die for tensile specimens, four different sheets are cut in the wire erosion machine with dimensions of 200x250 mm and 1.1 mm in thickness. In addition, 4 mm thickness of two sheets is used as the top and bottom plates of the die. Figure 5 shows the die that is used in the study. In this study, all specimens are prepared according to DIN53504 S-2 standard.

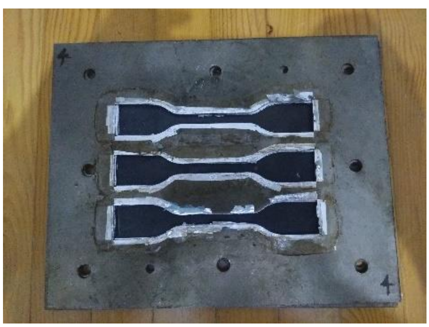


Figure 5. Specimen preparation die

Figure 6 shows the silicone rubber and fibers. As matrix material, silicone rubber is used and as reinforcements, no:20, no:50 Polyester cords and Nylon 6.6 cords are used. No:20 cords are generally called as towel threads and no:50 cords are called lace threads. Nylon 6.6 cords are usually called as polyamide. The fiber diameters of no:20, no:50 Polyester and Nylon 6.6 are 0.9 mm, 0.6 mm and 0.7 mm respectively.

Figure 6. Silicone rubber paste and reinforcing fibers

The fibers are arranged in two layers and five fibers are used in each layer. After the die is prepared, fibers are placed on rubber layer in the die and one more rubber layer is covered on top. After the rubber layer is fully inserted, the base of the second layer is already finished. In similar to the first layer, fibers are placed on the obtained layer. Then, it is compressed by covering one more rubber layer on the fibers. Finally, the composite rubber specimen is vulcanized at 150°C for 1 hour under pressure and the specimen production process is completed. Figure 7 displays the preparation of the specimens and the removal of specimens exposed to vulcanization process from the die.

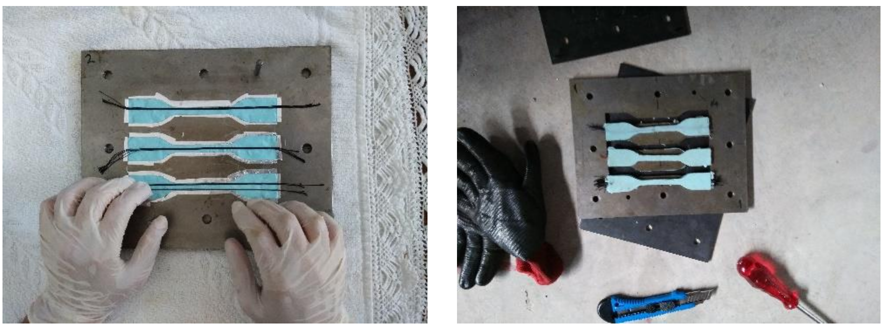


Figure 7. Preparation of specimen, die and specimens

2.2. Conducted Tests

Before testing the randomly dispersed reinforced rubbers, tensile tests of the reinforcements are carried out and then the rubber specimen without reinforcement are subjected to the tensile test. In order to test the mechanical properties of the rubbers reinforced with continuous fibers, tensile tests are performed on specimens. Unless the fibers in the rubber composite specimens are fixed to each other by connecting, it is observed that the fibers are stripped from the specimens. All tensile tests are carried out at a speed of 0.5 mm/s and the tested specimens are examined in two parts: the fibers are stripped (stripped from the rubber) and the fibers are non-stripped.

The test of composite specimens conducted by Shimadzu AG-X Plus (250 kN) and the test of unreinforced rubbers and cords carried out by Shimadzu AGS-X (1 kN) are indicated in Figure 8.

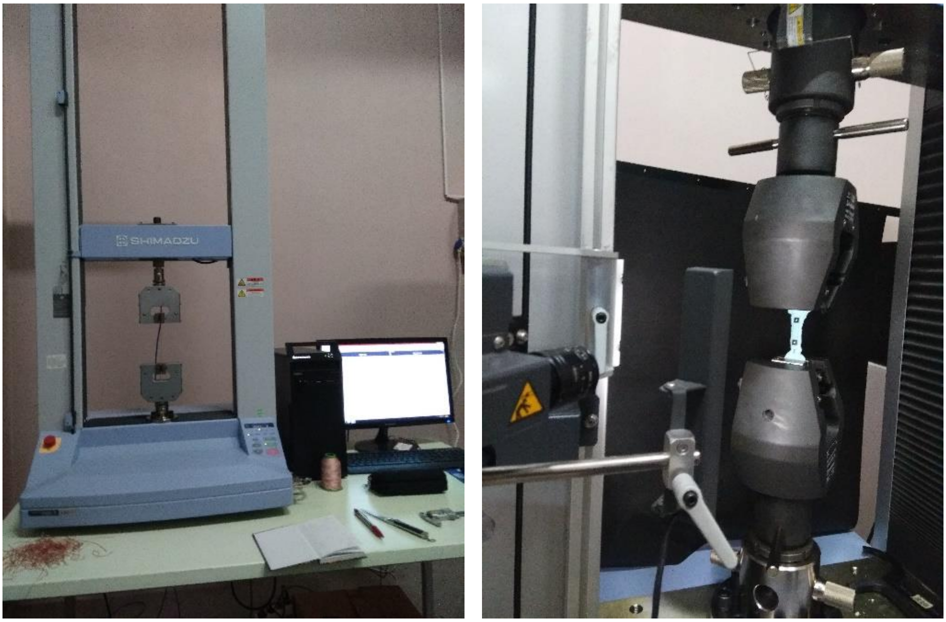


Figure 8. Tensile testing machines where tensile tests are carried out

3. RESULTS AND DISCUSSION

As a result of the tests conducted, the following force-elongation graphs are obtained. Nylon 6.6 cords by itself carry around 170 N (Figure 11). Normally, ten fibers are used in each specimen. So, totally 1700 N force can be carried by a specimen. However, test results show that a specimen can only carry 500 N force approximately. Thus, the strength of Nylon 6.6 is significantly decreased during the vulcanization process. Compared to Nylon 6.6, the strength of Polyester cords is not reduced that much.

In this study, randomly distributed fibers (piled at the center and piled around the edges) carry less load than uniformly distributed fibers, although in the work of Zhu and et al. [26], random distributing of fibers has almost no effect on the axial tensile. In tensile tests, fibers broke one by one in specimens and this is validated by the work of Zhu et al [26].

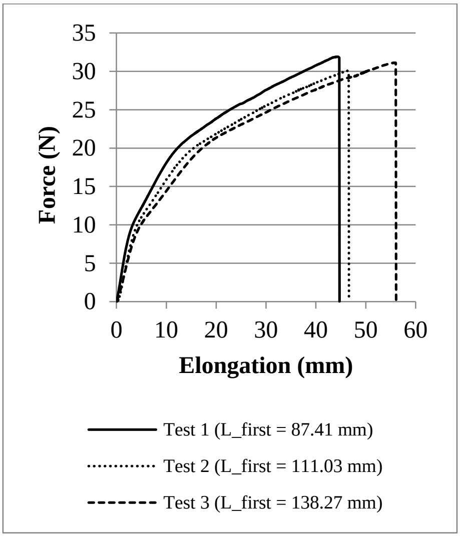


Figure 9. Polyester no:50 cord tensile tests, force-elongation diagram

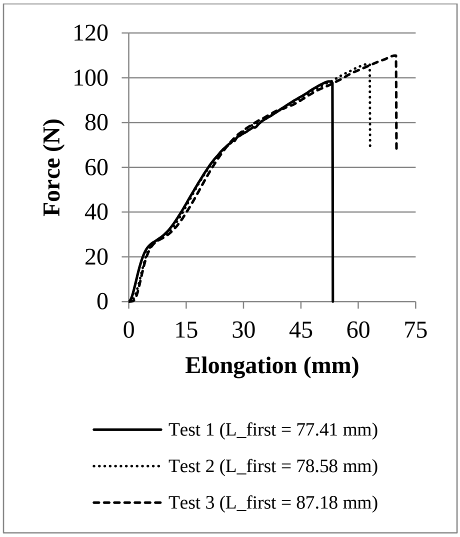


Figure 10. Polyester no:20 cord tensile tests, force-elongation diagram

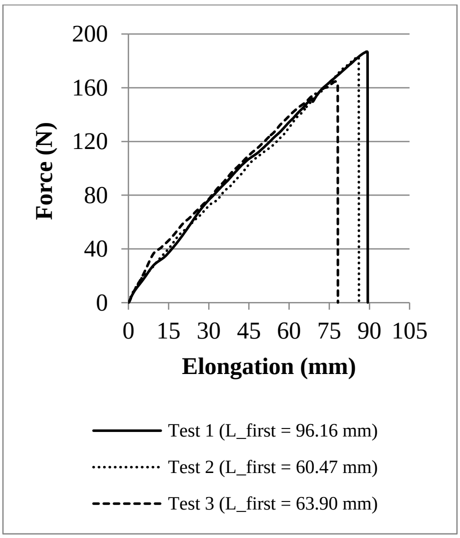


Figure 11. Nylon 6.6 cord tensile tests, force-elongation diagram

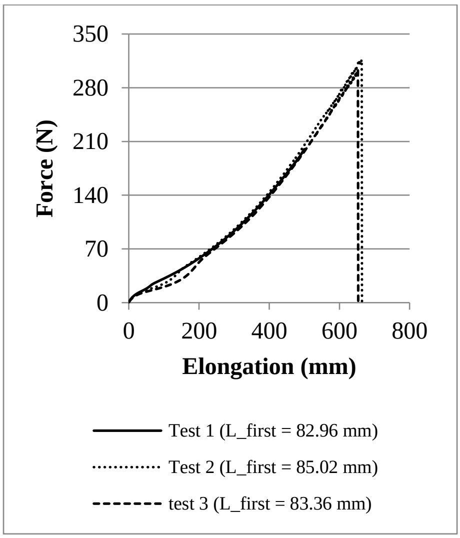


Figure 12. Unreinforced rubber tensile tests, force-elongation diagram

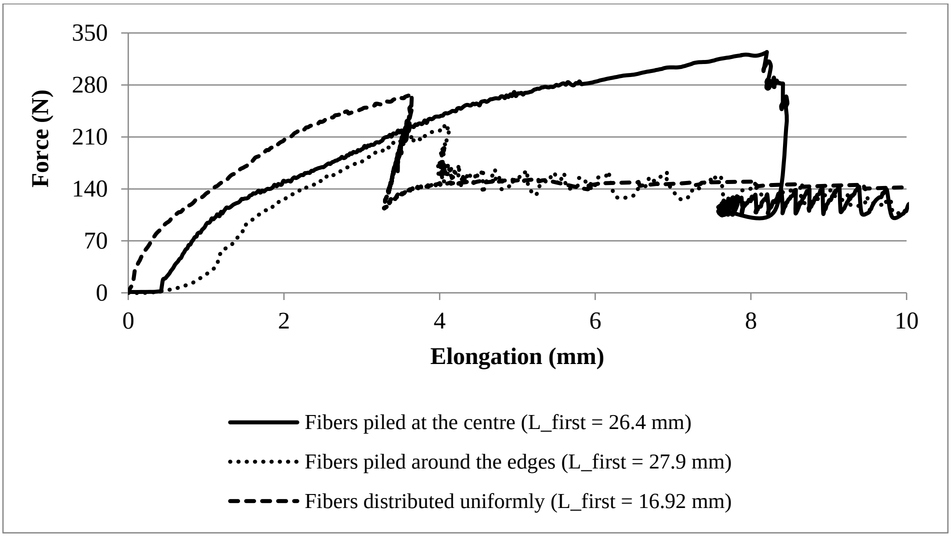


Figure 13. The force-elongation diagram of the rubber composite with slippage fibers as Polyester no:50 in various conditions

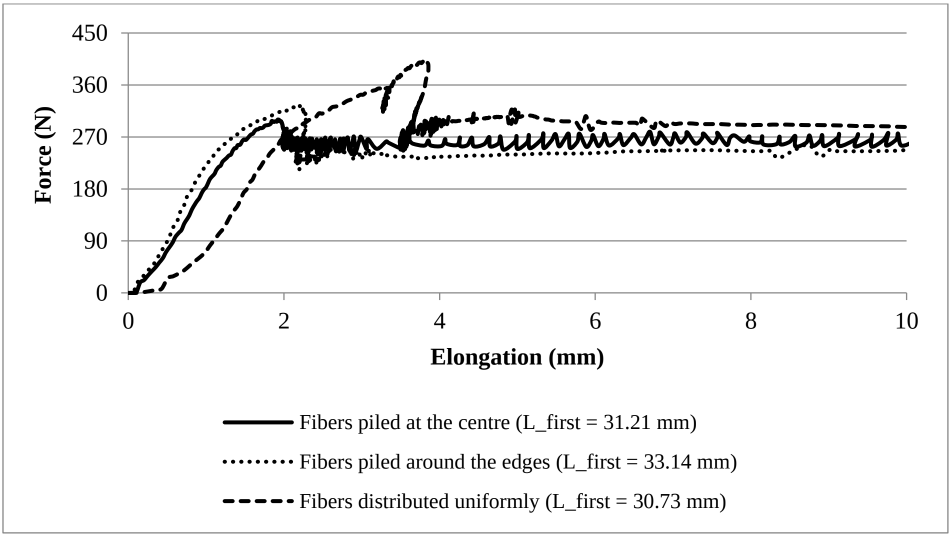


Figure 14. The force-elongation diagram of the rubber composite with slippage fibers as Polyester no:20 in various conditions

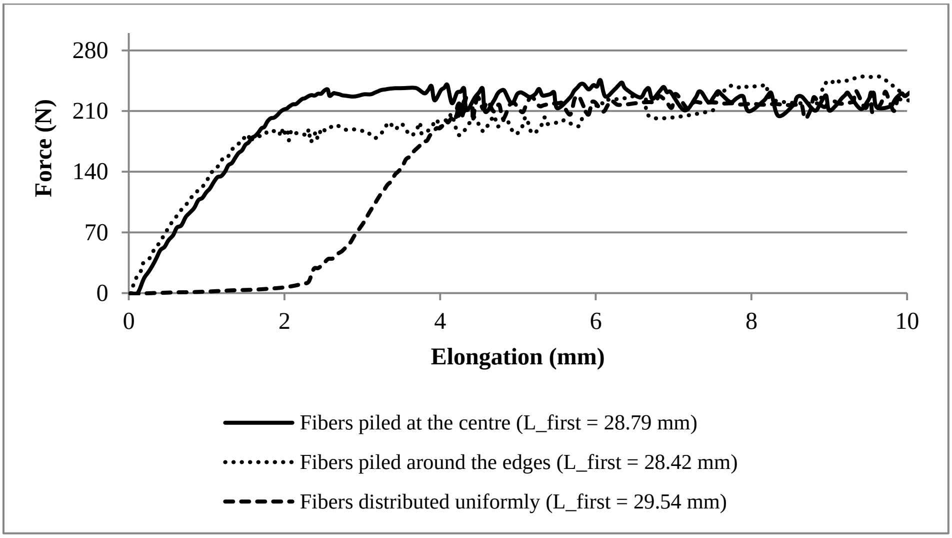


Figure 15. The force-elongation diagram of the rubber composite with slippage fibers as Nylon 6.6 in various conditions

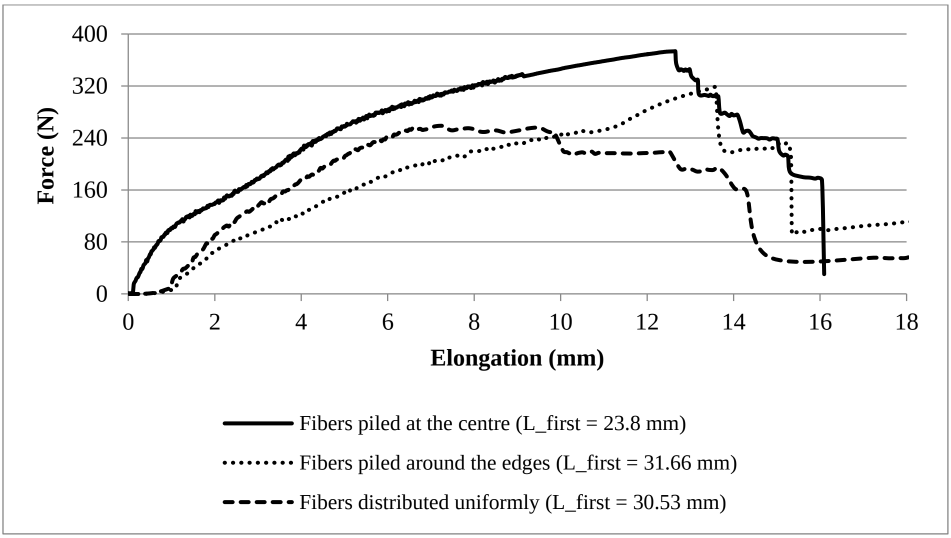


Figure 16. The force-elongation diagram of the rubber composite with no-slippage fibers as Polyester no:50 in various conditions

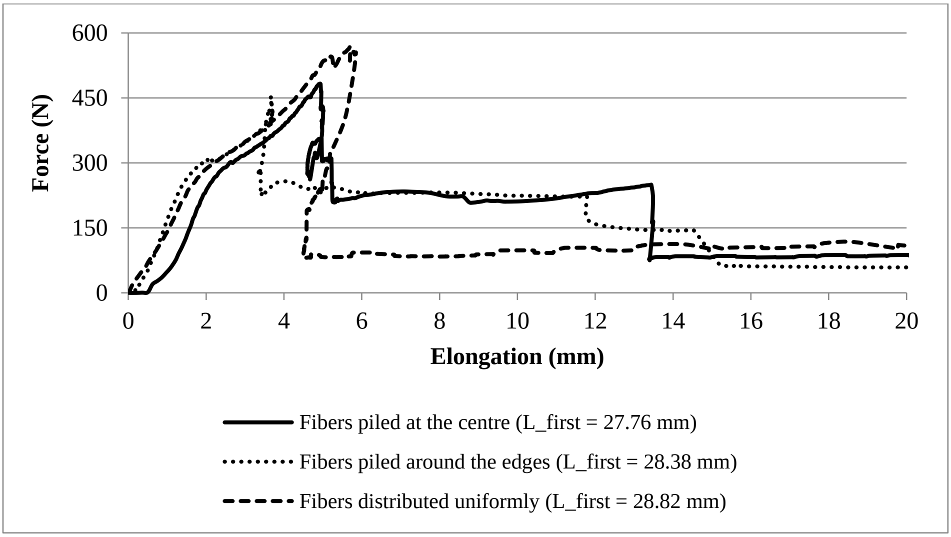


Figure 17. The force-elongation diagram of the rubber composite with no-slippage fibers as Polyester no:20 in various conditions

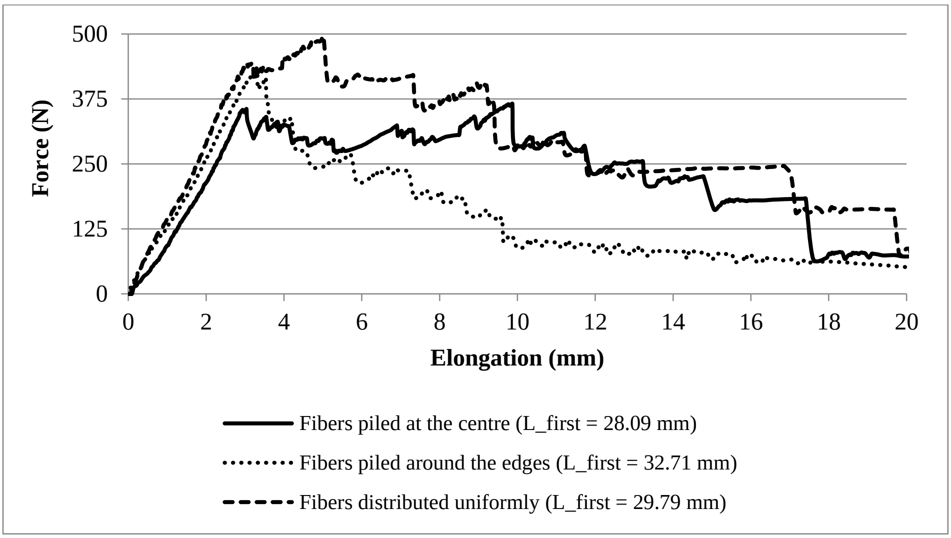


Figure 18. The force-elongation diagram of the rubber composite with no-slippage fibers as Nylon 6.6 in various conditions

4. CONCLUSION

As a result of the experiments (tensile tests of a single cord, unreinforced rubber specimen, and rubbers reinforced with continuous fibers piled in various forms), force-elongation graphs are obtained. When the cord tensile tests of Polyester no:50 are examined, a single cord can carry about 30 N loads and it is observed that the length of cord increases from %40 to %50. In the cord tensile test of Polyester no:20, the cords can carry 100-110 N and the length of the cord increases from %70 to %80. In the same test of Nylon 6.6, the cords can carry 160-180 N whereas the length extends from %90 and %140 of its original length. Test results show that strength of Nylon 6.6 in specimens is significantly decreased during the vulcanization process, and when compared to Nylon 6.6, strength of Polyester cords is not reduced significantly. When the tensile tests of an unreinforced specimen are examined, rubber can change its shape elastically until 300 N force then it breaks. The length of the unreinforced rubber increases 7-8 times of its original length. In reinforced rubbers, fibers are arranged in two layers and five fibers are used in each layer. When the reinforced rubbers by cotton cords are examined, during the vulcanization process, cotton cords cannot resist the high temperature and pressure so that they are partially melted or broken. The slippage of fibers of rubber composites is also investigated. Both displacement and force are much bigger in specimens that fibers are piled at the center than piled around edges and uniformly distributed. No-slippage condition of fibers of rubber composites are examined as well. Both displacement and force are much bigger in specimens that fibers are distributed uniformly than piled at the center and piled around the edges. If uniaxial load is important in the applications, uniformly piled fibers and the usage of center piled can be advantageous. Also, as the distance between fibers increases, each fiber is separately broken due to the material differences between the fibers. So, load carrying capacity reduces.

REFERENCES

[1] Bahruddin, A. Ahmad, A. Prayitno, R. Satoto, Morphology and Mechanical Properties of Palm Based Fly Ash Reinforced Dynamically Vulcanized Natural Rubber/Polypropylene Blends, *Procedia Chemistry*, 4 (2012) 146-153.

[2] M. Zaghdoudi, Z. Tourki & P.-A. Albouy, Characterisation of Vulcanised Natural Rubber Behaviour by Monotonic and in Situ Cyclic X-ray Scattering Tests, *Plastics, Rubber and Composites*, 44(6) (2015) 211-217.

[3] Morton, M., Rubber Technology, Van Nostrand Reinhold, New York, 1987.

[4] O. Qing, S. Yin, The Non-linear Mechanical Properties of an Airspring, *Mechanical Systems and Signal Processing*, 17(3) (2003) 705-711.

[5] T. Rey, G. Chagnon, J.-B. Le Cam, D. Favier, Influence of the Temperature on the Mechanical Behaviour of Filled and Unfilled Silicone Rubbers, *Polymer Testing*, 32(3) (2013) 492-501.

[6] S.C. Shit, P. Shah, A Review on Silicone Rubber, *The National Academy of Sciences*, 36(4) (2003) 355-365.

[7] G. Bao, K. Li, S. Xu, P. Huang, L. Wu, Q. Yang, Motion Identification Based on SEMG for Flexible Pneumatic Hand Rehabilitator, *Industrial Robot: An International Journal*, 42(1) (2015) 25-35.

[8] Y. Li, Y. Chen, Y. Yang, Y. Wei, Passive Particle Jamming and Its Stiffening of Soft Robotic Grippers, *Ieee Transactions on Robotics*, 33(2) (2017) 446-455.

[9] https://www.alibaba.com/product-detail/High-quality-1-inch-dieselfuel_60360678419.html (access on June 12, 2017).

[10] https://www.northamericanmotoring.com/forums/tires-wheels-and-brakes/114093-how-do-you-know-when-your-tires-are-worn-out.html (access on June 12, 2017).

[11] Li Z., Xiao T., Zhao S., Effects of Surface Treatments on Mechanical Properties of Continuous Basalt Fibre Cords and Their Adhesion with Rubber Matrix, *Fibers and Polymers*, 17(6) (2016) 910-916.

[12] Herrera-Franco P.J., Valadez-Gonzalez A., Mechanical Properties of Continuous Natural Fibre-reinforced Polymer Composites, *Composites Part A: Applied Science and Manufacturing*, 35(3) (2004) 339-345.

[13] Tsai P.A., Wu J.H., Influence of Tire-cord Layers and Arrangement Direction on the Physical Properties of Polyester Tire Cord Reinforced with Chloroprene Rubber Composite Materials, *Science and Engineering of Composite Materials*, 22(4) (2014) 405-410.

[14] Zhang T., Yan Y., A Comparison Between Random Model and Periodic Model for Fiber-reinforced Composites Based on a New Method for Generating Fiber Distributions, *Polymer Composites*, 38(1) (2017) 75-86.

[15] Parambil N.K., Gururaja S., Micromechanical Damage Analysis in Laminated Composites with Randomly Distributed Fibers, *Journals of Composite Materials*, 50(21) (2016) 2911-2924.

[16] Meunier L., Chagnon G., D. Favier, L. Orgéas, P. Vacher, Mechanical Experimental Characterisation and Numerical Modelling of an Unfilled Silicone Rubber, *Polymer Testing*, 27(6) (2008) 765-777.

[17] G.K. Klute, B. Hannaford, Fatigue Characteristics of McKibben Artificial Muscle Actuators, *Proceedings of the 1998 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 1-3 (1998) 1776-1781.

[18] K.C. Wickramatunge, T. Leephakpreeda, Study on Mechanical Behaviors of Pneumatic Artificial Muscle, *International Journal of Engineering Science*, 48(2) (2010) 188-198.

[19] H. Taniguchi, Flexible Artificial Muscle Actuator Using Coiled Shape Memory Alloy Wires, *APCBEE Procedia*, 7 (2013) 54-59.

[20] M.B. Jaber, M.A. Trojette, F. Najar, A Finite Element Analysis of a New Design of a Biomimetic Shape Memory Alloy Artificial Muscle, *Smart Structures and Systems*, 16(3) (2015) 479-496.

[21] C.-P. Chou, B. Hannaford, Measurement and Modeling of McKibben Pneumatic Artificial Muscles, *Ieee Transactions on Robotics and Automation*, 12(1) (1996) 90-102.

[22] Y. Gong, C. Ren, X. Wang, B. Zhang, Development and Performance Analysis of the Flexible Pneumatic Artificial Muscle, *23rd International Conference on Mechatronics and Machine Vision in Practice*, (2016), 110-115.

[23] T. Adachi, T. Ozawa, H. Witono, S. Onishi, Y. Ishii, Energy Absorption of Thin-walled Cylinders Filled with Silicone Rubber Subjected to Low-velocity Impact, *Mechanical Engineering Journal*, 4(5) (2017), 1-10.

[24] Q. He, A. Li, Y. Zhang, S. Liu, Y. Guo, L. Kong, A Study on Mechanical and Tribological Properties of Silicone Rubber Reinforced with White Carbon Black, *Tribology – Materials, Surfaces & Interfaces*, 12(1) (2018) 9-16.

[25] F. Durante, M.G. Antonelli, P.B. Zobel, T.Raparelli, Development of a Straight Fibers Pneumatic Muscle, *International Journal of Automation Technology*, 12(3) (2018) 413-423.

[26] C. Zhu, P. Zhu, Z. Liu, W. Tao, Numerical Investigation of Fiber Random Distribution on the Mechanical Properties of Yarn In-plain Woven Carbon Fiber-reinforced composite based on a New Perturbation Algorithm, *Journal of Composite Materials*, 52(6) (2018) 755-771.