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Pull-out analysis of laser modified polyamide tire cords through rubber matrix

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ABSTRACT

Today with regard to the increased tire failure accidents, strengthening the tire cord adhesion to rubber compounds to reduce the tire blow-out risks is being of great importance. The main aim of this research is strengthening the adhesion of tire cord to the plastic/rubber matrix by the use of laser treatment method to achieve a high performance material. In this study, the polyamide (known as nylon 66) tire cord was prepared and the surface treatment was performed by CO_2 laser, prior to Resorcinol formaldehyde latex (RFL) dipping.

To obtain the ideal irradiation condition, surface roughness was evaluated by image analysis using both Fractalyse2.4 and Mountainsmap7 Software. The cord parameters such as count, twist, strength and toughness and also H-Test, FTIR and XRD analysis were tested before and after laser treatment. The results showed that cord count, twist and strength did not have any significant changes. However, the other parameters such as cord elongation, shrinkage and toughness were changed so that enhanced adhesion properties. FTIR and XRD analysis revealed that the crystalline structure of irradiated cords has been decreased.

The results showed that laser treatment increases the interfacial shear strength of rubber/fiber without reducing strength of cords. Finally, a mechanical model of failure based on pull-out method was used to investigate the effect of laser treatment on the adhesion strength of cord/rubber. Thus, an index of laser intensity was introduced which would be capable of predicting the influence of any laser treatments on interfacial shear strength between cords and rubber.

1. Introduction

Polymer cords, being resistant to changing shape, play an important role in rubber reinforcement in a wide range of industries such as tires, hoses and belts. However, due to different specifications of the two substances, the adhesion between polymer cords and rubber has always been a matter of concern for the engineers [1]. Many recent studies have investigated the tire blow-out risks [2,3], reminding the importance of tire adhesion strength as an important factor more than ever before [4,5]. For instance, Yang et al. have shown that Both Von-Misses stress and shear stress increase significantly at the interface between the cords and the rubber [6].

In most tire cord applications, the polymer cord is heavily soaked in adhesive compounds, such as Resorcinol formaldehyde latex (RFL), before it is attached to the rubber [7]. Nylon 66 is one of the polymer cords, which has various applications due to its specific properties. Today, through performing surface treatments on nylon 66 and improving its compatibility, it has received more applications [8,9]. However, unlike PET [10,11] and other polymer cords, Rayon and Nylon have not made developments in the area of

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improving adhesion between rubber and cord [7].

The adhesion strength of cord/rubber is generally assessed in static (H-Test method) and dynamic (investigating the fatigue) methods. Jamshidi et al. provided an equation for estimating dynamic adhesion through investigation of results obtained from H-Test and introduced a linear relation between H-Test adhesion and fatigue. As the H-Test adhesion testing method is simpler than fatigue tests, the rate of fatigues could be directly calculated through the proposed equation [12].

One of the methods to improve static adhesion of cord/rubber is performing treatments on the surface of materials, which are commonly divided in to four categories of mechanical, chemical, combustion and plasma based techniques. Recently, UV laser radiation and radioactive laser treatments on the surface of polymer cords such as aramids [7] have been carried out. Some researchers have shown that by irradiating laser on polyester cord, the performance and comfort [13] and on PET cord, the other features such as optical properties [14] could be modified considerably.

The CO_2 laser irradiation is another method that due to its high adoptability and compatibility and high strength, has been used for many years in material processing fields [15]. Among all the existing lasers in commercial scale, the CO_2 laser produces the most cost effective and quality radiation. Clean processing, high accuracy and no need in contact with the substance are among the general advantages of utilizing this laser [16].

Although previous researchers reported heating problems during polymer processing by lasers, there were some other researches showing that these problems depends on the type of the substance [17]. Reports of patterning on the surface of nylon 66 reveal that the surface energy and the polar component will decrease and the surface roughness will increase significantly. The total surface energy and the polar component [18] and the amount of Oxygen increase of the surface are the factors involved in reducing the contact angle [9]. On the other hand, according to the research performed by Jahangiri et al. (2016) laser would cause further melting of polyamides in some surface areas, by which the substance surface would become smoother and the roughness would decrease [16]. However, the results of the research by Waugh and Lawrence indicate that the laser treatment of surfaces create more roughness [19]. Bahtiyari showed that the crystalline structures of polyamide fabrics have changed during laser treatments [20]. Therefore, in the case of tire cords, further investigations are sensed to be essential to lead us to a conclusion about the effects of laser irradiation on polyamide cords.

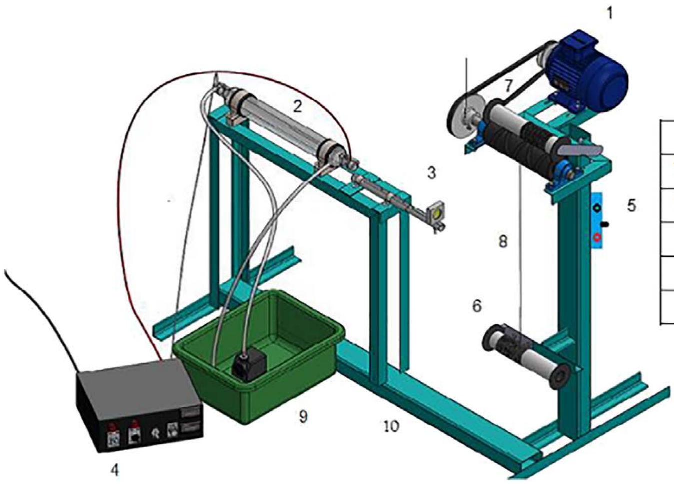
Among other recent researches performed on strengthening tire/textile adhesion we can refer to the followings:

UV laser operations on strengthening materials of rubber silicone matrix to increase rubber adhesion performed by Liu [21]; the chemical operations on the surface basalt cords and investigating their adhesion to the rubber by Li et al. [22]; performing heat treatments, UV and Epoxy Acrylate Biphenyl on polyester cords for strengthening adhesion to rubber by Yildiz et al. [23]. As a novel material, Lu et al. have investigated a composite made of carbon nanotube and introduced a long-time fatigue resistance tire [24].

In the present work, considering the fact that strengthening the adhesion of polyamide cord to the rubber compound is of great importance to reduce the tire failures, the main aim of this work is to follow further investigations in this field. Additionally, there has been lack of a general theory aligned with the effect of surface treatments on adhesion strength of rubber/cords; hence a model was introduced based on failure mechanisms to be applicable for any laser treatments.

2. Materials and methods

Two different cords were prepared in 1400/2 dtex and 1880/2 dtex made of nylon 66. The samples were fully oriented (FOY) and purchased from Zanjan Saba tire factory. After twisting, 390 and 330 twists per meter were obtained for 1400/2 and 1880/2 dtex cords respectively. Afterwards, the samples were placed under standard conditions up to 24 h (RH: %65 ± 2, T: 20 ± 2 °C) and then, covered in a black foil with silica gel to became appropriate for the initial tests such as laser treatment. The continuous system of CO_2 laser at Isfahan University of Technology and the basic parts are shown in Fig. 1.



part	number	part	number
Yarn Opener	6	Motor	1
Yarn Pickup	7	CO2 Laser	2
Yarn	8	Laser Jet	3
Cooler	9	Power Laser	4
Frame	10	Invertor	5

Fig. 1. Schematic of continuous system of laser apparatus used in this study.