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Material Behaviour

Compressive-tensile fatigue behavior of cords/rubber composites

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Cord/rubber composites are used to build complex structures which may be submitted to cyclic loads, sometimes leading to critical fatigue failure. The focus of this study is to investigate the cyclic compressive/tensile strain behavior of polyester, polyamide and hybrid polyaramid/polyamide cords. For that, the cords were embedded in rubber belts to be used in a specially designed rotating pulley equipment that allows monitoring and controlling of tensile force, frequency and strain level. All fatigue tests were performed using stress-control mode, and tensile residual strength of the cords was measured as a function of material type, number of cycles and compressive/tensile strain level. The results show that compressive and tensile cyclic strains decrease residual properties. Hybrid cords showed higher residual strength than polyester and polyamide cords when subject to high compressive strain or high number of cycles. Moreover, morphological evaluation indicated failure to be associated with micro-buckling and extensive fibrillation.

1. Introduction

High performance fibers as cords embedded in a rubber matrix have been used in several industrial applications such as tires [1], conveyor belts [2], hoses [3] and offloading hoses [4–6]. In the case of offloading hoses, the cords are inserted as fabrics into the elastomer, producing a composite structure with good flexibility and high strength [7], and several layers are wound on top of each other until the desired wall thickness is reached [4].

The fibers used to produce the cords present distinct characteristics and suitability. Polyester cord has high modulus and low shrinkage characteristics in comparison to polyamide (nylon 6 and 66), and thus provides excellent dimensional stability. Polyester also has better retention of relaxation modulus under constant strain and exhibits greater elasticity at room temperature than polyamide, but nylon 66 has excellent fatigue resistance even at high strain [8]. Nevertheless, polyester and polyamide cords present low static strength, leading to increased hose weight due to the large number of layers required to fulfill design requirements.

Aramid fibers consist of aromatic polyamide and exhibit an interesting combination of properties including higher strength and modulus, toughness and thermal stability compared to more traditional fibers such as polyester and polyamide. They are being extensively used in low weight composite structures for various applications [9]. However, there are few studies focusing on analyzing the fatigue performance of these materials, which is an important loading condition considering that cord-rubber structures are used in hoses that undergo constant dynamic loading. An early investigation on the fatigue strength of polyaramid cords (Kevlar 29) with the Flex test (test device that provides compression in cords) [10] reported Kevlar to have good flexural fatigue characteristics although not as good at a given strain level as nylon and polyester, which are regarded as low modulus and more tough fibers.

New technologies have been developed to increase compressive fatigue strength of high modulus cords. Onbilger et al. [11] reported an improvement in fatigue properties by changing the way the 4-yarn cord was constructed. A nylon core with 200 denier showed residual strength of 1200 N after 6 h cycling at 15% compression, whereas a nylon core with 1000 denier showed 1450 N because it was able to distribute the compressive loads more evenly, minimizing contact with the other yarns. The authors also reported advantages in the use of hybrid cords. A 3-yarn Kevlar cord showed elongation at break of 4.6% and residual strength after compressive fatigue (disc fatigue, 15% compression, 6 h) of 21%, whereas the hybrid cord (2 Kevlar yarns and 1 Nylon yarn) showed an elongation at break of 7.6% and residual strength after compressive fatigue

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of 48%.

Shi et al. [12] investigated the evolution of the dynamic fatigue of the adhesion in a tire carcass compound reinforced by polymer cords under cyclic loading, using a self-developed fatigue test. They found several relations between the adhesion life and stress/strain amplitude for tensile mode. Valantin et al. [13] investigated interfacial damage of polyamide cord/rubber composites under tensile fatigue load and identified higher fatigue strength for samples with coating treatment when compared to samples without coating. These studies focused on fatigue analysis of cord/rubber composites under tensile load. Severe damages was found when the cord/rubber composites were subjected to compression load. Leal et al. [14] described that kink band formation was found in cords of high-performance organic fibers under compression using a loop test.

There are many reports in the literature concerning fatigue of advanced composite materials, but only a few on cord/elastomer composites, especially using hybrid cords. Hence, in this study, a pulley/bending fatigue test was designed and built to investigate compressive/tensile fatigue properties of cords/rubber composites and the behavior of polyester, polyamide and hybrid polyaramid/polyamide cords was investigated under various experimental conditions.

2. Experimental

2.1. Materials

Three types of reinforcement cord were investigated, which were produced using three yarns of polyester fiber (4222 dtex), three yarns of polyamide (12200 dtex) or two yarns of polyaramid and one yarn of polyamide (4733 dtex). Cords were spaced 1.2, 1.9 and 1.2 mm for polyester, polyamide and the hybrid, respectively, in the manufacture of fabrics. Butadiene-acrylonitrile elastomer with two layers of unidirectional cords was wound onto a 406 mm mandrel and transferred to an autoclave for curing. Later, the belts were cut to produce 21 mm wide strips for testing.

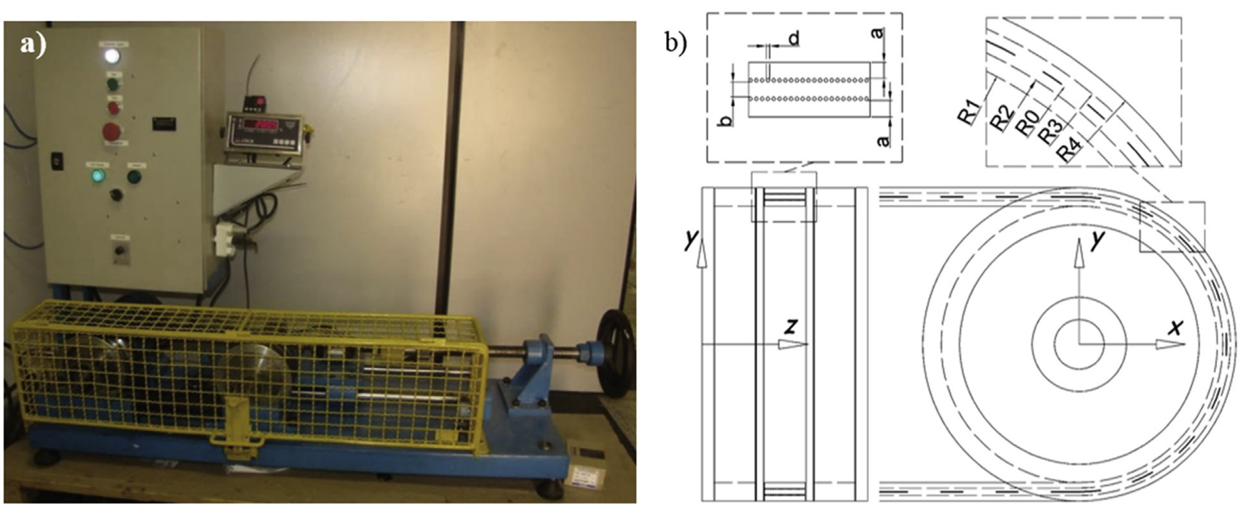

Fig. 1. Fatigue test equipment using pulleys detailed on the right.

Table 1
Belt dimensions and fatigue test conditions.

Belt/cord	a (mm)	b (mm)	Belt thickness (mm)	Compressive strain level (%)	Tensile strain level (%)	Tensile load (N)	Number of cycles
Rubber + polyester	3	2.3	9.9	−2.3	0.5	669	1×10^4
or							1×10^5
Rubber + polyamide							1×10^6
		12.0	19.6	−6.9	0.5	836	1×10^4
							1×10^5
							1×10^6
Rubber + hybrid polyaramid/polyamide	3	2.3	9.9	−2.3	0.5	982	1×10^4
							1×10^5
							1×10^6
		12.0	19.6	−6.9			1×10^4
							1×10^5
							1×10^6
							5×10^6
		16.5	24.9	−8.3			1×10^4
							1×10^5
							1×10^6
							5×10^6
		24.0	32.4	−10.8			1×10^4
							1×10^5
							1×10^6
							5×10^6