Engineering Science and Technology, an International Journal xxx (2018) xxx–xxx

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Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

journal homepage: www.elsevier.com/locate/jestch

Review

Effect of carbon content and drawing strain on the fatigue behavior of tire cord filaments

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ARTICLE INFO

Article history:
Received 8 March 2018
Revised 3 April 2018
Accepted 16 April 2018
Available online xxxx

Keywords:
Steel tire cord
Carbon content
Pure bending fatigue
Fracture surfaces

ABSTRACT

In this work we aim to investigate fatigue strengths of the steel filaments in diameter of 0.25 mm with three different Carbon (0.70%C, 0.80%C and 0.90%C) and with four different drawing strains (3.25, 3.37, 3.71 and 3.76) by the pure bending test method. All fatigue tests have been carried out at room temperature and at a frequency of 10 Hz via a custom manufactured pure bending testing machine of which the fully reserved strain value, $R = \varepsilon_{min}/\varepsilon_{max}$, is −1. The applied value of cyclic deformation, ε, has been chosen from the range 0.20%–1.07% as bending strain. The plots of S-N (Strain–Cycle) curves are based on high cycle fatigue (HCF) life is greater than or equal to 10^4 cycles. The fatigue deformation limit values have been determined as 0.55% units and 0.20% units for the steels of the 0.25NT-70C and 0.25UT-90C quality, respectively. The increase in hardness resulting from the microstructural thinning (due to drawing strain) increases the fatigue deformation limit of the steels containing 0.80%C. Despite the increase in the drawing strain, carbon content and hardness, the fatigue deformation limit decreased with increasing inclusion content. Fractured surfaces of the samples, which have been broken at both high fatigue life and fatigue deformation limit values, are inspected via SEM. The SEM inspection has demonstrated that the fatigue fracturing of the steel filaments are similar to that of baseball bat cracking.

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1. Introduction

Steel filaments and steel filaments products create significant part in group of plastically treated articles. These products often work with high external loads and find wide application in situations where high reliability of working is required, like different kinds of machines and devices [1]. The intensification of the drawing process changes the deformation conditions forcing producers to use new technological solutions in the field of surface treatment, lubrication and drawing process [2]. The steel filaments are generally produced via several steps of cold drawing from steel filaments containing 0.6 wt%C to 0.9 wt%C and patenting to produce a fine pearlite microstructure [3]. Sensitive fatigue life estimation in the design of structures subject to variable load conditions is critical when human life is particularly at stake. As steel cord filaments are the most important building blocks of a tire, their fatigue life values exhibit parallels with the life time of the tire. Thus, a tire with a high fatigue strength meets the needs such as long life, bet-

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Peer review under responsibility of Karabuk University.

https://doi.org/10.1016/j.jestch.2018.04.010
2215-0986/

ter fuel economy, and in particular safety. Tire cord filaments are being produced in diameters varying from 0.15 mm to 0.40 mm and production of tire cords are carried out by meshing certain amount of filaments together. Changes in the intensities of force and/or deformation of a tire cord sustaining repeated loads in addition to road conditions such as obstacles and speed bumps exhibit variability when a tire is in motion. Accurate estimation of fatigue properties of cord steel during its service is of vital importance because of this variable repeated loading [4]. Fatigue tests of these filaments are carried out via a custom produced pure bending fatigue machine. The fatigue tests of steel filaments in air were performed on the pure bending fatigue machine under the frequency of 10 Hz [5]. Two distinct fatigue regions were observed – a low-cycle regime ($\leq 5 \times 10^4$ cycles) and a high-cycle fatigue regime [6]. Fatigue test is realized in this test method by bending steel filaments with diameters up to 1.60 mm by 180° or 90° and then rotating the filament around its own axis. Pure bending test method is most commonly applied to dental braces [6] and while there is no international publication on 180^0 alternating pure bending fatigue of tire cord filaments, there exist publications only employing fatigue test method under repeated axial pull-pull loading on tire cord filaments [7].

The purpose of this study is to compare the fatigue behaviors of the 0.25 mm diameter steel filaments with 0.7 wt%–0.9 wt% C content and drawing strain between 3.37 and 3.71 applied to the steel filaments containing 0.80 wt% C. All investigated steel filaments were tested on pure bending testing machine under fully reserved strain conditions, at varying bending deformation values in a cyclic interval of 0.20% to 1.07%.

2. Experimental

Steel cord filaments with carbon contents of 0.70 wt%, 0.80 wt% and 0.90 wt% which are procured from Bekaert have been employed in this work. Their chemical compositions and mechanical properties are given in Table 1. The number 0.25 in the material codes of Table 1 indicates the filament diameter and the letters T, N, H, S, and U stand for Tensile, Normal, High, Super and Ultra, respectively.

Samples of 4 different qualities as given in Table 1 have been taken into bakelite, positioned longitudinally and vertically to the axis of drawing, for metallographic examination and after a fine grinding with sandpapers of 1000 and 3000 grit sizes, they have been polished with diamond abrasives.

Inspections of inclusion on the sample surfaces fine grinded and polished and microstructure examination of the sample surfaces following an etching via 4% nital have been carried out with a Carl Zeiss Ultra Plus Gemini Fesem SEM device. An image analysis was performed to quantify inclusions by software Image J analyser. Five hardness measurements for each sample fine grinded and polished longitudinally and vertically have been taken via a QNESS Q10 brand microhardness tester employing a diamond square pyramidal tip with an apex angle of 136° by applying a 3 kg of load for 15 s.

In this work, pure bending fatigue tests of the steel cord filaments have been realized via a fatigue testing machine, as exhibited in Fig. 1a. Fatigue testing machine was designed and produced to apply ASTM E2948-14 standard test method. The fea-

Table 1
Chemical and mechanical properties of the investigated steel cord filaments.

Grade Code	Chemical Composition					Tensile Strength* (N/mm²)	Total Elongation* (%)
	C % avg.	Mn % avg.	Si % avg.	P % max.	S % max.		
0.25 NT-70C	0.72	0.53	0.22	0.025	0.025	2755.50	1.97
0.25 HT-80C	0.83	0.53	0.22	0.020	0.015	3149.11	2.07
0.25 ST-80C	0.83	0.53	0.22	0.020	0.015	3400.89	2.17
0.25 UT-90C	0.92	0.35	0.22	0.020	0.015	3797.49	2.21

* Manufacturer's data.

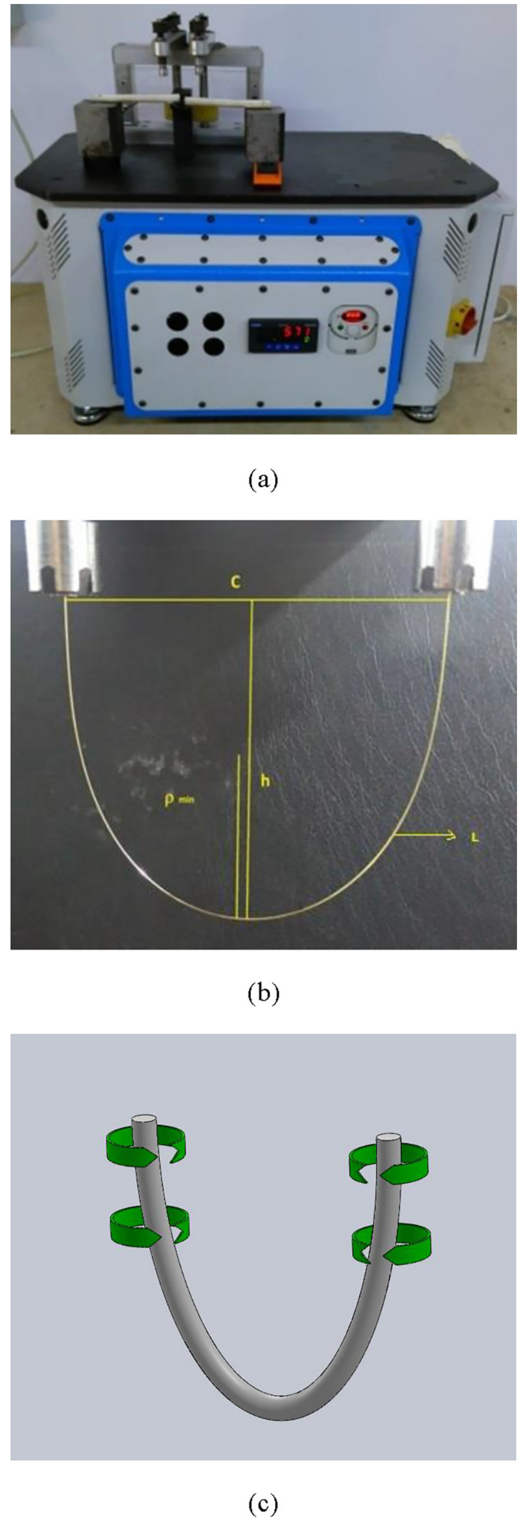

Fig. 1. (a) Pure bending fatigue testing machine designed and produced for this work (b) actual sample installed in chucks and (c) motion of the filament during test.

Please cite this article in press as: H. Koymatcik et al., Effect of carbon content and drawing strain on the fatigue behavior of tire cord filaments, Eng. Sci. Tech., Int. J. (2018), https://doi.org/10.1016/j.jestch.2018.04.010