# Friction of Nitinol Filaments Used in Knitting of Technical Fabrics

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**Abstract**

Nitinol filaments of 0.1 mm diameter are being evaluated to be used in the production of technical knitted fabrics, namely in socks or leggings with constant compression capabilities. For the knitting with these filaments it is necessary to evaluate the process and the tribological characteristics of the various materials involved. The assessment of the friction in these conditions is the main objective of this study based on the Amonton's law. An experimental set-up based on standard ASTM G143 (2009) was built and attached to a laboratory dynamometer working in tensile mode. This set-up could be adjusted to configure the tribological pair filament-needle or filament-yarn guide similar to those of the real knitting process. The experimental work that followed showed a considerable influence of the elastic characteristics of the filament, as well as the load, in the stability of the friction during the experiment. The average friction coefficient for the cylindrical bodies and needle when the applied load is above 2 N is 0.14 ± 0.005.

## 1. Introduction

Nitinol is a NiTi shape memory alloy that has been predominantly developed for applications for the biomedical and engineering industry [1, 2]. The range of applications has been increasing in recent years, such as multifunction textiles and garments to confer aesthetic attributes [3, 4, 5]. However, it is necessary to investigate the feasibility of processing these filaments in order to obtain products of good quality and efficiency in the manufacturing process.

During the knitting process yarns have to go through a complex trajectory touching yarn guides and needles. In these interactions friction is always present, playing an important role, both in the quality of the knitted fabric as well as in the wear of the machine elements [6, 7]. The basic apparatus to measure the yarn friction is the Capstan method.

In the attempt of measuring the friction coefficient in the apparatus based on standard D 3108 – 07 (Standard Test Method for Coeff. of Friction, Yarn to Solid Material) the pointer was oscillating with a very large amplitude making the reading impossible. This article shows the measurement results of the coefficient of friction of Nitinol filaments performed in an apparatus designed according to ASTM G143 (2009).

## 2. Experimental

The adopted measuring system is based on the Amonton's law, where the coefficient of friction is obtained by equation 1,

$$T = T_0 e^{\mu\beta} \qquad (1)$$

where T is the outlet tensile force, $T_0$ is the inlet tensile force, β is the angle of contact and μ is the friction coefficient.

The measuring device was attached to a universal laboratory dynamometer working in tensile mode, as represented in figure 1, in order to achieve a dynamic test.

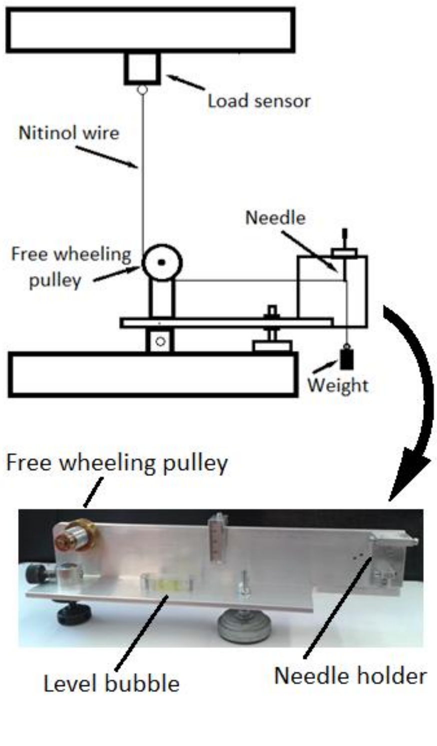



Fig. 1 - Set up of the experimental apparatus.

One end of the Nitinol filament is attached to the load sensor with a range from 0 to 100 N and a resolution of 0.001 N.

The filament passes around a freewheeling pulley that rotates on rolling bearings for low friction leaving it on a horizontal orientation. The filament goes then over the static reference body (needle or yarn-guide) with a contact angle of 90º having a tensioning weight at the other end that could be selected from 0.1 N, 0.2 N, 0.5 N, 1 N, 2 N, 3 N and 5 N. The test is carried out by a continuous dragging of the filament through 300 mm by the dynamometer.

The elements used in the experiments were a Nitinol filament SM495 (ASTM F2063) 0.1 mm diameter covered by a layer of titanium oxide, a knitting needle 0.7 mm diameter (95,7% Fe, 0,84% C, 0,37% Cr, 0,427% Mn, 1,21% Ni and 2,33% Si) and cylindrical elements of ASI 316 steel 7 and 14 mm diameter to simulate yarn-guides.

## 3. Results and discussion

Figure 2 represents graphical results of the friction coefficient obtained versus the length of filament dragged during the test. Figure 2a corresponds to tests for a load of 0.1 N and speeds of 0.05 m/min, 0.5 m/min and 1 m/min.

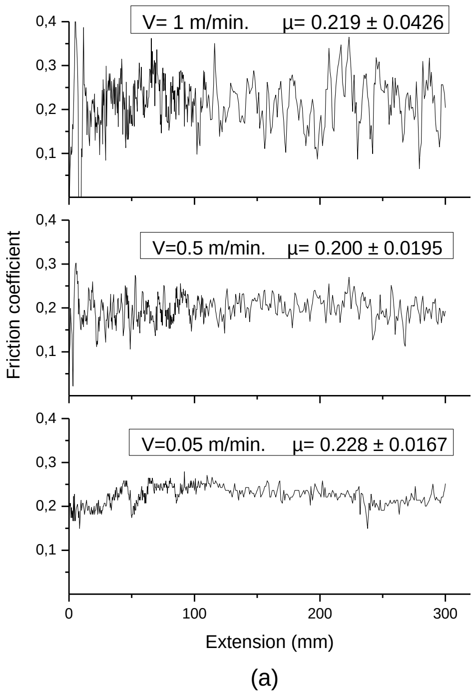



Fig. 2a - Friction coefficient versus filament travel on the needle for a load of 0.1 N and speeds of 1 m/min, 0.5 m/min and 0.05 m/min.

Figure 2b corresponds to tests for a speed of 1 m/min and loads of 0.1 N, 0.2 N and 2 N. It is possible to notice different patterns for the values of the friction coefficient.

In figure 2a it is clear that the fluctuation increases as the speed increases while in 2b the fluctuation decreases with the increase of the load. These fluctuations can't be seen as a stick-slip effect as the situation does not configure this phenomenon [8, 9, 10]. In this situation the Nitinol filament has a high elasticity, behaving like a spring, therefore resulting in the observed fluctuation.

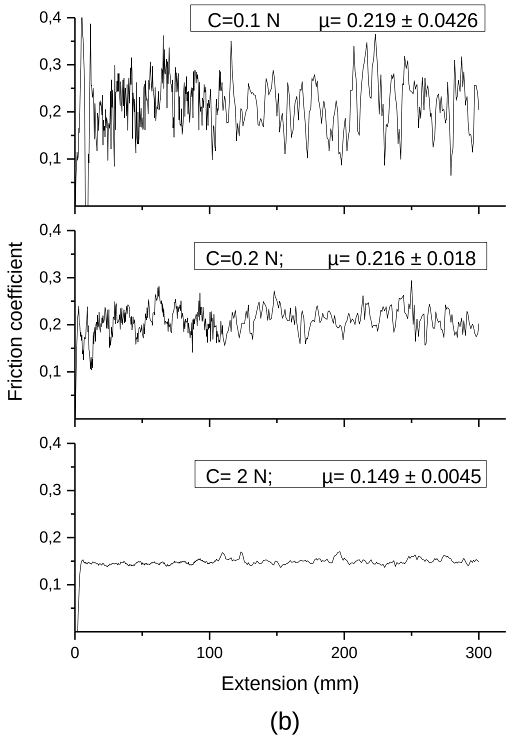



Fig. 2b - Friction coefficient versus filament travel on the needle for a speed of 1 m/min and loads of de 0.1 N, 0.2 N and 2 N.

Starting the test, the dynamometer applies an acceleration to the system filament-load initially static, until the desired testing speed is achieved. For the same testing speed, 1 m/min for example, the same acceleration is applied and therefore the same dragging force. When the same dragging force is applied to different loads, fluctuations of different amplitudes are obtained as observed in figure 2b.

The dragging force is applied upwards by the dynamometer to the filament and load, causing a vibration. This behaviour also occurs during the knitting process during the unwinding of the cones of metal filament or soon after the tensioners.

To simulate the tribological pair filament-yarn-guide the friction coefficient was measured in cylindrical bodies.

Figure 3 is a graphic display of the friction coefficient versus applied load to the Nitinol filament on the 1 m/min speed versus needle of 0.7 mm diameter and cylindrical steel bodies with diameters of 7 mm and 14 mm. It is observed that the friction coefficient varies with the applied load, decreasing as the load increases. However, the fluctuation decreases as the diameter of the cylindrical surface increases, suggesting that the diameter plays an important role and must be considered. In fact for the 14 mm diameter body the friction coefficient is approximately constant for all loads and for loads over 2 N the values obtained for the needle and the 7 mm diameter body are getting close. The average friction coefficient for the needle and steel cylindrical bodies of 7 and 14 mm diameter, for loads over 2 N was found to be 0.14 ± 0.005.

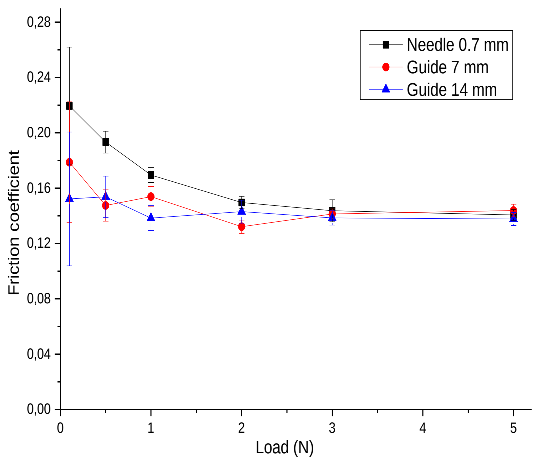
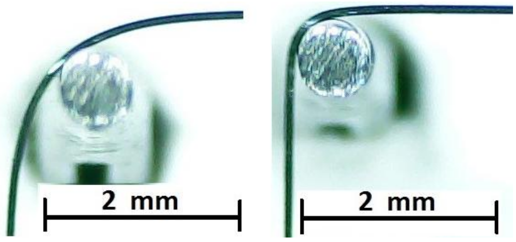



Fig. 3 - Friction coefficient versus applied load to the Nitinol wire for a speed of 1 m/min versus needle and yarn-guides of 7 mm and 14 mm diameter.

This variation of the friction coefficient with the applied load can be explained by the bending rigidity of the Nitinol filament.

As it can be observed in figures 4a and 4b, the contact between the surface of the needle and the filament changes with the load. As the load increases, the filament flexure increases, also increasing the angle of contact.




(a) (b)

Fig. 4 – Detail of the contact filament-needle for loads of 0.1 N (a) and 2 N (b).

## 4. Conclusions

Preliminary tests have shown that the developed instrument gives consistent results being a good representation of the model. The experimental work that followed showed a considerable influence of the elastic characteristics of the filament, as well as the load, in the stability of the friction during the experiment. The average friction coefficient for the steel cylindrical bodies and needle when the applied load is above 2 N is 0.14 ± 0.005.

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