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# ON THE NATURE OF MULLINS EFFECT IN SWOLLEN NITRILE RUBBER

M. S. Loo<sup>1</sup>, A. Andriyana<sup>1</sup>, J.-B. Le Cam<sup>2</sup>, G. Chagnon<sup>3</sup>, E. Verron<sup>4</sup> and A. M. Afifi<sup>1</sup>

<sup>1</sup> Faculty of Engineering, University of Malaya, Malaysia

<sup>2</sup> Université de Rennes 1, LARMAUR ERL CNRS 6274, Campus de Beaulieu, France

<sup>3</sup> UJF-Grenoble1/CNRS/TIMC-IMAG UMR5525, Grenoble, France

<sup>4</sup> LUNAM Université, Ecole Centrale de Nantes, GeM UMR CNRS 6183, 44231 Nantes France

## 1. INTRODUCTION

Nitrile rubber is well recognized for its strength and oil resistance characteristic. The resistance to swelling in hydrocarbon oils permits it to be widely utilized in the industrial and automotive field, such as seals, gaskets, rollers and packers. However, petroleum-based fuels are no longer dependable source of energy in terms of long term availability, increasing cost and environmental preservation. These undeniable issues have made biofuel a more attractive alternative energy source since it is known to have better sustainability and economic feasibility if compared to other choices of renewable energy sources [1]. Despite the many advantages of biofuel [2], the material compatibility, in particularly rubbers, in biofuel systems remains as a challenge till today [3].

In most of its applications, exposure to fluctuating loadings is usually inevitable. Nitrile rubber, like mostly any other elastomers, exhibits a non-linear mechanical response under static conditions. Meanwhile, under cyclic loading conditions, three basic phenomena are observed: hysteresis, permanent set and stress-softening. Among these three phenomena, stress-softening has attracted the attention of many researchers not only to describe it through physical interpretations but also by phenomenological approach. The magnificence is that, the research work on stress-softening is still on going since a hundred years ago and no concurrent studies are found on describing its origin until today [4].

Stress-softening can be affirmed through the cyclic stress-strain response. In the first cycle, a certain amount of stress is definite to deform the material. Yet, this amount does not preserve for the second and following cycles. Instead, a visible lower amount of stress is needed to deform the material after the first loading phase. This phenomenon is known as the Mullins effect [5]. The Mullins effect becomes an importance field of study especially under fatigue loading conditions [6] where the prediction of the lifetime of material is crucial. In the fatigue study, it is usually related to cyclic softening [7] due to its large amount of number of cycles.

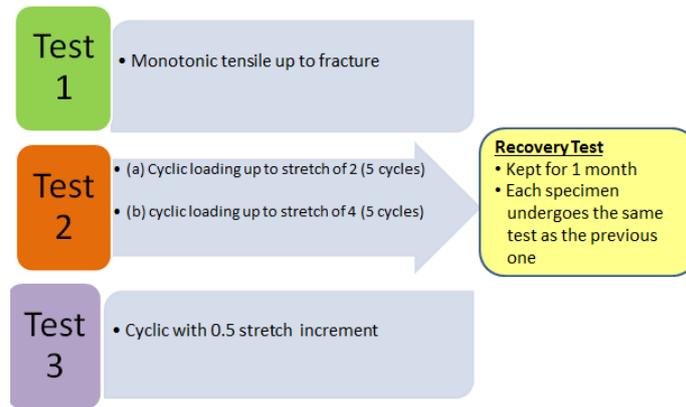
Even though the studies of Mullins effect has evolved over many years, studies conforming the presence of solvent, in particularly biodiesel, are not equally abundant [8-10]. The presence of biodiesel creates a hostile environment to the rubber and deteriorates the properties of rubber in the form of swelling [11]. These circumstances motivate even more the need to study the Mullins effect in swollen rubbers under cyclic loading.

## 2. EXPERIMENTAL PROGRAM

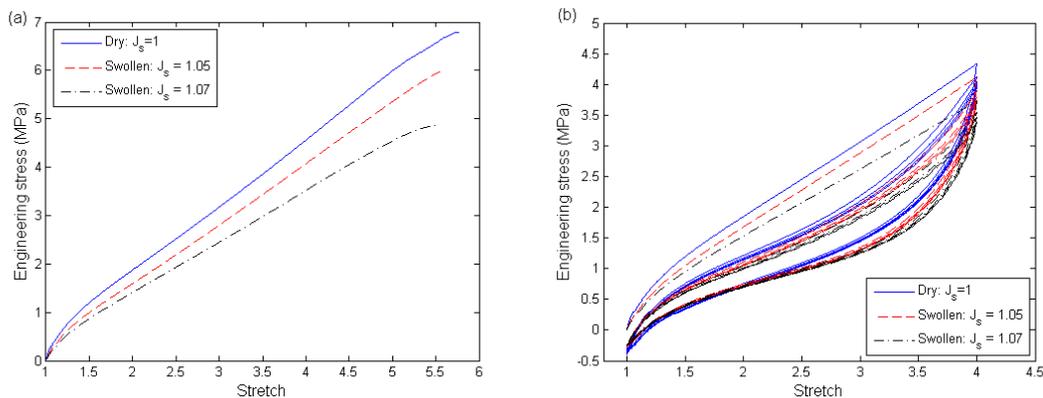
The nitrile rubbers investigated in this research are of hollow diabolo shape having the height, outer diameter and wall thickness of 55 mm, 25 mm and 6 mm respectively. Swollen nitrile rubbers are obtained through free swelling immersion in B100 (pure biodiesel) to attain two different degree of swelling. The three types of mechanical testing conducted on both dry and swollen rubbers are summarized in Figure 1. All of these mechanical testings are restricted to a strain rate of  $0.02s^{-1}$  to exclude the thermal effects.

## 3. SUMMARY OF RESULTS

The stress-stretch responses are investigated for both dry and swollen rubbers. The stress-stretch response for Test 1 and Test 2 are plotted in Figure 2(a) and Figure 2(b) respectively. It appears that no significant differences were observed in the nature of response. Similarly to the dry rubbers, the swollen rubbers exhibit non-linear behavior under monotonic uniaxial loading and Mullins effect persists under cyclic loading. However, the value of strain at fracture, permanent set and Mullins effect decreases with the degree of swelling. Moreover, swelling appears to increase the recovery of Mullins effect.



**Figure 1.** Types of mechanical testing



**Figure 2.** Result of the mechanical testing for (a) Test 1 (b) Test 2

#### 4. CONCLUSION

Under cyclic loading, both dry and swollen rubbers exhibit Mullins effect. It was observed that swelling reduces Mullins effect exhibited by the material.

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