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Investigation of fracture resistance of natural rubber/clay nanocomposites by *J*-testing

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ABSTRACT

The present work is aimed at studying the fracture behavior of a series of vulcanized natural rubber/organoclay samples obtained by melt blending. A fracture mechanics approach based on *J*-testing was adopted to evaluate the material resistance to crack initiation and propagation from a *J*-resistance curve as experimentally obtained by a single specimen procedure. The basis of the method and the experimental procedure adopted are described. Further, the effect of the organoclay content within the elastomeric matrix on the fracture properties is analyzed. It is found that the capability of the organoclay to improve fracture resistance is rate dependent indicating the viscoelastic character of the fracture process in such filled systems.

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1. Introduction

Filled rubbers are widely used in many industrial applications such as tyre treads, vibration dumpers and seals. Fillers, that typically consist in carbon black as well as silica particles, are added to impress to the elastomeric components suitable mechanical performances. In fact substantial amounts of such fillers should be incorporated within the elastomeric matrix to achieve the desired mechanical properties with particular reference to mechanical stiffness, as well as tearing and fatigue resistance.

In the last years the effects of the addition of nanoparticles to a polymeric matrix to tailor thermo-mechanical properties have attracted growing interest. In particular the effect of the addition of organomodified layered silicates, which are dispersed within the matrix as intercalated/exfoliated system of nanometric thick lamellae, were investigated. The possibility to obtain elastomeric nanostructured systems by introducing modified layered silicate in different types of elastomers has been investigated as well [1–3]. The mechanical properties of the mixtures, such as stiffness, tensile and tearing resistance, as well as dynamic properties, resulted strongly improved by the addition of such type of fillers, indicating that these materials can be considered very promising for the applications.

In a previous work by the authors the dynamic and viscoelastic behavior of natural rubber/layered silicate nanocomposites obtained by melt blending were studied [4,5] at the aim of understanding the mechanisms of the mechanical reinforcement referred to the static modulus and/or low amplitude storage modulus. In the present work, in order to extend the mechanical characterization of such materials to the fracture properties, their fracture behavior was investigated by a fracture mechanics approach based on the application of a *J*-testing methodology.

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Nomenclature

a	initial crack length (mm)
A	surface of the specimen ligament (mm^2)
B	specimen thickness (mm)
CTOD*	crack tip opening displacement (mm)
J	fracture resistance (J-integral) (kJ/m^2)
J_{IC}	J at fracture initiation (kJ/m^2)
L	specimen length (mm)
n	power law exponent
T	tearing energy (kJ/m^2)
T_J	tearing modulus (MJ/m^3)
u	displacement (mm)
U	area under the load–displacement curve (J)
u_i	displacement at fracture initiation (mm)
$\dot{u}$	cross-head rate (mm/min)
W	specimen width (mm)
Δa	crack advancement (mm)
η	geometry dependent calibration factor

For rubbers, the importance to characterize intrinsically the material resistance to crack initiation and propagation is justified by recent studies that evidence that the mechanisms of many failure processes can be frequently attributed to initiation and propagation of cracks [6,7].

The mechanics of crack initiation and propagation in an elastomeric material was firstly approached by Rivlin and Thomas [8] by introducing the tearing energy T, and successively by Andrews and Fukahori [9] who introduced a generalized approach to the fracture mechanics of highly extensible solids. More recently, the application of a fracture mechanics approach based on J-integral [10] was proposed and analyzed [11–14]. It is worth noting that on the basis of their definition T and J are formally identical, and hence they can be considered as equivalent. Further, experimental methodologies based on J-testing were developed [14–19]. Taking hint from a method recently proposed in literature [16], in the present work a single specimen J-testing experimental method was developed [19] and adopted to characterize the fracture behavior of samples of vulcanized natural rubber filled with different amounts of organoclay. The method allows the determination of a J-resistance curve providing the determination of the fracture resistance at crack initiation and propagation as described in the following. The effect of the organoclay amount incorporated within the natural rubber matrix on such properties, as well as the effect of rate are analyzed and discussed.

2. Experimental

2.1. Materials

The materials investigated were kindly prepared and supplied by Pirelli SpA (Milan, Italy). They were constituted by natural rubber (SMR-GP) filled with different amounts of an organoclay consisting in montmorillonite modified with dimethyl dehydrogenated tallow ammonium and with an organic content of 40 wt.% (Dellite 67G, produced by Laviosa Chimica Mineraria SpA (Livorno, I)). The formulations of the samples studied are detailed in Table 1, where the filler contents are given in phr and vol. fraction, respectively. This last parameter was calculated by taking into account that the percent of the inorganic material present in Dellite 67G is 55 wt.% calculated from the experimental value of ignition weight loss provided by the manufacturer. In this context, for the evaluation of the clay vol fractions, a density of 2.5 g/cm^3 for the inorganic part of

Table 1
Formulation of the rubber compounds.

Ingredient	Content	
	phr	Clay volume fraction[a]
Natural rubber (SMR-GP)	100	–
Organoclay (Dellite 67G)	0, 6.5, 14, 30	0, 0.011, 0.024, 0.047
Stearic acid	2	–
Zinc oxide	7	–
Sulphur	3	–
Resorcinol	1.5	–

[a] Clay volume fraction values refer to the clay inorganic component only.

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