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Micromechanisms of deformation and fracture of polypropylene nonwoven fabrics

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ABSTRACT

The micromechanisms of deformation and fracture in tension were analyzed in a commercial polypropylene nonwoven geotextile material in a wide range of strain rates. Two different loading scenarios (smooth and notched specimens) were considered to study how these mechanisms are modified in presence of a stress concentration. The nonwoven fabric presented significant deformability and energy-absorption capability, which decreased with the strain rate, together with a high level of strength, which increased with strain rate. In addition, the material was notch-insensitive as the stress concentration around the crack tip was relieved by marked nonlinear behavior, which induced crack blunting. Different experimental techniques (standard mechanical tests, in situ testing within the scanning electron microscope, digital image correlation, etc.) were used to establish the sequence of deformation and failure processes and to link these micromechanisms with the macroscopic behavior.

1. Introduction

In the current stage of technological development, the strongest materials are fabricated as structures of high aspect ratio and very small diameter (in the range of nm to μm). Nanotubes, nanofibers and microfibers are not used individually for engineering applications but in the form of bundles or as woven or nonwoven fabrics. The mechanical behavior of fabrics depends on the microstructure and on the dominant deformation and fracture micromechanisms, which are very different for woven and non woven materials. Most of the relevant work in this area has been carried out for woven fabrics, whose regular microstructure is easier to understand and analyze (Buet-Gautier and Boisse, 2001; Bahei-El-Din et al., 2004; Boisse et al., 2005; Lomov et al., 2007; Cao et al., 2008; Badel et al., 2008; Khan et al., 2010). Conversely, nonwoven fabrics tend to present a random microstructure as they are manufactured from a set of disordered fibers consolidated by bonds of different nature, such as simple entanglement, local thermal fusion or chemical binders. A typical example of this kind of material is paper, which is made up of cellulose fibers linked by hydrogen bonds, though the industrial applications of these materials have grown very rapidly in recent years with the incorporation of new fibers and consolidation processes. These include ballistic protection, thermal insulation, liquid-absorbing textiles, fireproof layers, geotextiles for soil reinforcement, etc. (Russell, 2007). In addition, new materials based on this concept have emerged recently as a consequence of its structural analogy with biological tissues and the advent of fibers with reduced manipulability. Good examples of these latter developments can be found in nanotube sheets (Berhan et al., 2004a,b, Berhan and Sastry, 2007) or in nanofiber felts directly produced by electrospinning (Dzenis, 2004).

The mechanical performance of nonwoven fabrics is quite different from their woven counterparts. In particular, they present lower stiffness and strength, but their deformation capability and energy absorption during deformation is far greater. This is due to the dominant deformation and failure mechanisms in nonwoven fabrics, which include straightening of curved fibers, large deformation and rotation of the fibers as well as bond breakage, fiber sliding and fracture. However, the detailed analysis of these processes has been limited to paper (Bronkhorst, 2003; Hägglund and Isaksson, 2006; Isaksson et al., 2006, 2004), which is an important albeit very particular type of nonwoven and, more recently, to glass-fiber felts (Ridruejo et al., 2010, 2011). In the case of nonwovens made up of polyolefin fibers, most of the results in the open literature on the mechanical behavior come from market-oriented manufacturers, which emphasize the material performance rather than the micromechanisms of deformation and fracture. Investigations into the relationship between the microstructure and the macroscopic properties were limited to assessing the influence of critical processing parameters (fiber orientation, bonding strength, density) on the macroscopic

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