Factors Affecting the Tearing Resistance of Textile Structures

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Introduction

Resistance to tearing plays a major role when evaluating the reliability of textiles used for example in protective clothing [1] and in composite materials [2]. Tearing in textile structures proceeds through the formation and propagation of a Del zone ahead of the crack. It arises from the stretching and slippage of longitudinal yarns along transverse yarns followed by the stretching and alignment of the transverse yarns [3]. Rupture takes place when the transverse yarns reach their maximum tensile strength. An additional phenomenon has recently been shown to occur: the slippage of transverse yarns along the longitudinal yarns [4]. It was associated with a decrease in the tearing energy.

In order to characterize the resistance to tearing of textile structures, a new criterion inspired from fracture mechanics and based on the tearing energy has been proposed [4]. The tearing energy G is provided by the expanded work ΔW necessary to increase the fracture surface area by ΔA according to the following relation:

$$G = -\left(\frac{\Delta W}{\Delta A}\right)_l \qquad \text{Eq. 1}$$

with l the applied displacement. This new criterion has been validated with fabrics of different types of weave and yarn material, different yarn linear density and yarn density values as well as with two sample configurations - tongue (trouser) tear and tensile central crack tear [4]. Compared to other methods using the measured force maxima and minima, this new criterion allows taking into account the contribution of the Del zone formation as well as the crack surface area, thus provides a more accurate description of the tearing phenomenon.

In this paper, this criterion is used to study the influence of textile and yarn characteristics on the tearing energy.

Experimental

Materials

Several plain weave and twill polyester fabrics with different values of filling yarn linear density and filling yarn density were used in this study (see Table 1). The warp yarn linear density and warp yarn density values were kept constant at 17.2 Tex and 48 yarns/cm.

Measurement Methods

Tearing measurements were performed on 5x10mm trouser-shaped samples tested along the warp direction at 100 mm/min. Loading/unloading cycles were carried out at several values of the maximum displacement. The tearing energy was computed using Eq. 1. The strain energy release rate was provided by the area delimited by the tearing and return force-displacement curve [4]. The tear crack surface area was measured in the undeformed state.

Tests were also conducted to characterize relevant properties of the fabrics and their constitutive yarns. Filling yarn slippage was measured by pulling a yarn out of a fabric sample subjected to a transversal preload following the method proposed in [5]. The slippage modulus was computed from the slope of the linear increase in the corresponding force-displacement curve. Tensile tests were also carried out on filling yarns.

Table 1. Characteristics of the fabrics

Weave	Filling yarn linear density (Tex)	Filling yarn density (yarns/cm)
Plain	33	10
	33	12
	33	15
	16.7	12
	15	12
Twill	33	10
	33	12
	33	15
	16.7	15
	12	15

Results and Discussion

Fig. 1 displays the variation of the tearing energy G with the filling yarn linear density for the two types of weaves (corresponding to different values of the filling yarn density). The observed increase in tearing energy with the filling yarn linear density can be attributed to a decrease in transverse yarn slippage due to reduced yarn mobility. Indeed, transverse yarn slippage corresponds to a lower value of the tearing energy compared to yarn breakage [4]. In addition, it may be noted that the variation in G is steeper below 16.7 Tex and more limited above that value. That behaviour can be linked to a change in the tearing mechanisms. For low values of the filling yarn linear density, tearing occurred without yarn breaking, i.e. solely through yarn slippage. On the other hand, both yarn breaking and yarn slippage took place for the 16.7 Tex samples and only transverse yarn breaking for 33 Tex fabrics.

An increasing trend was also obtained for the variation of the tearing energy with the filling yarn density. It can be attributed as well to the reduction in yarn mobility and yarn slippage with increased yarn density.

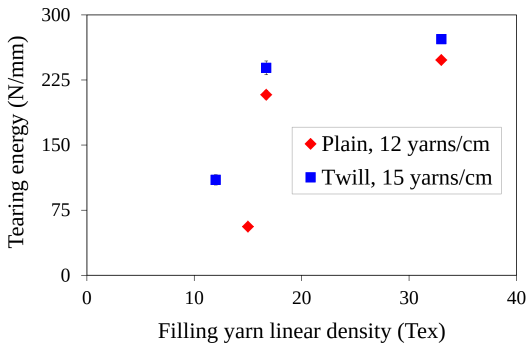

Fig. 1. Variation of the tearing energy as a function of the filling yarn linear density.

The relationships between the tearing energy and the yarn mechanical characteristics were also investigated. As shown in Fig. 2, the tearing energy increases with the filling yarn breaking force. It can be attributed to the contribution of the last step of the tearing process to the tearing energy, i.e. the failure of the transverse yarns in the Del zone. Indeed, as the filling yarn breaking force increases, the energy expanded in the successive failure of the Del zone outermost transverse yarns increases. An increase in the tearing energy as a function of the filling yarn Young modulus was also obtained. It can be linked to the linear relationship observed between the yarn modulus and its linear density. In the case of the elongation at break, the variation is non-monotonous. It may indicate the occurrence of a fibre mechanical damaging effect appearing for tightly packed structures.

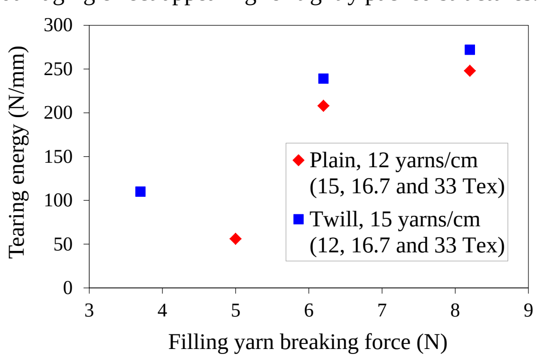

Fig. 2. Variation of the tearing energy as a function of the filling yarn breaking force.

Finally, when the tearing energy is expressed as a function of the filling yarn slippage modulus, an increasing trend is observed (see Fig. 3). Indeed, transverse yarn slippage has been associated with a lower value of the tearing energy compared to yarn breakage [4]. In addition, data for all tested fabrics, i.e. with different types of weave and filling yarn density and filling yarn linear density values, superimpose on a single master curve. This demonstrates the importance of the effect of slippage of transverse yarns along the longitudinal yarns on the tearing energy. This is a parameter which has been largely overlooked in previous works on tearing resistance of textile structures, which only considered longitudinal yarn slippage.

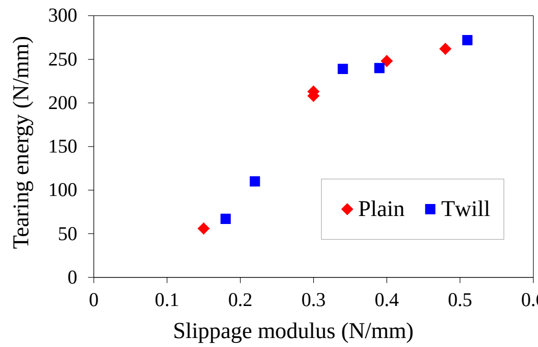

Fig. 3. Variation of the tearing energy as a function of the filling yarn slippage modulus.

Conclusions

In this work, a new tearing criterion based on the tearing energy has been used to study the effect of textile and yarn characteristics on the tearing resistance of plain weave and twill polyester fabrics with different filling yarn density and linear density values. An increase in tearing energy with filling yarn density, linear density, Young modulus and slippage modulus was measured. In addition, tearing energy data for all types of fabrics superimposed on a single master curve when expressed as a function of the filling yarn slippage modulus. This demonstrates the importance of transverse yarn slippage in the tearing process. An increase in tearing energy with filling yarn breaking force was also observed. These results build the path towards the development of a model for the tearing energy of textile structures.

Acknowledgments

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