SLICING CUTS ON TRIAXIAL FABRIC USING ROBOTIC- CONTROLLED RAZOR BLADE

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2 authors:

Magdi Elmessiry
Alexandria University

Shaimaa Youssef El-Tarfawy
Alexandria University

SLICING CUTS ON TRIAXIAL FABRIC USING ROBOTIC-CONTROLLED RAZOR BLADE

Magdy El Messiry [1] and Shaimaa El-Tarfawy [2]
[1,2]*Textile Department, Faculty of Engineering, Alexandria University, Alexandria, Egypt.*
E-mail of the Presenting Author: Shaimaa_youssef2001@yahoo.com

ABSTRACT

The cut resistance is the most important property of the fabrics used for protective gloves, anti- stabbing and bulletproof fabrics. A newly designed apparatus for measuring the fabric cut resistance under various loading is developed. Several triaxial fabrics were examined, Polyester, Vectran and Kevlar-29, with different fabric weights. The effects of cutting load, speed and fiber type were explored. Analysis of the model of the cutting force of triaxial fabric was investigated. Cutting resistance force noticed 2.21N, 5.10N, and 8.23N for Polyester, Vectran and Kevlar-29 triaxial fabrics respectively. The Kevlar-29 triaxial fabric demonstrated to have the highest fabric cut resistance.

Key Words: Triaxial fabric; Cutting resistance; Cutting speed; Kevlar-29; Vectran

1. INTRODUCTION

The fabric cutting resistance depends on the yarn cutting resistance, the fabric structure, fabric specifications and the methods of its gripping during cutting. In the case is designed to cut the fabric which is supported by a fixed surface the cutting force is equal to the shear stress for all fibrous material cut by the cutter [1]. Other situation when the fabric can deform under the cutting force then the fabric will fail under shear stress and tension stress. ASTM F1790-05, "the property that hinders cut through (the penetration of the cutting edge entirely through the material) when a material or a combination of materials is exposed to a sharp-edged device". According to the European standard EN388 which defines the cut resistance as the number of times a dead weight must be applied to a cutting edge before the fabric is cut through. In the ASTM F1790 / F1790M – 15, a cutting edge is placed under a specified load and moved across a fabric sample fixed on a mandrel [2]. Several types of cut-resistance testers were developed such are: NFPA Cut-resistance apparatus, Tocodynamometer Cut Resistance TDM-100 Tester-ISO 13977, Mandrel used in the TDM-100 Cut-resistance tester, IRRST Cut Resistance Testers, ITF Cut Resistance Tester, the ASTM develop Cut Protection Performance Tester to evaluate the cutting resistance of the fabric CCP to cut 25 mm then protective performance tester (CPPT) was developed to determine the cutting force of the fabric under a certain applied load. The primary test method for cut resistance in EN 388 The blade of the COUPTEST is circular and applies a counter-rotating motion under a fixed load of 5 N. The blade is passed repeatedly over the sample, and the number of cycles to produce a cut through are determined. A cut index is calculated that determines the classification level of the product. The cutting length varied from 20-25.4 mm according to standards ISO 13997- ASTM F1790-14. The shape of the blade cutting edge determines the distribution of the cutting force on the contact surface between the blade and the cutting material [3]. The cutting force distribution profile determines the sharpness of a blade. It can be observed from both the computation and experimental results that the cutting force is proportional to the contact length [4]. Blade sharpness is another factor that affects the cutting forces. Contact between the cutting object and the blade is an area, which can be shown from the microstructure of a knife [5-7]. In the field of protective clothing, many different materials are used to provide cut, tear and puncture resistance. The key for yarns or fiber additions to provide each of the required performances [8-9]. For most materials, frictional forces due to lateral gripping could be several times greater than the friction due to the applied normal force. Thus, the cutting energy required for breaking molecular chains is much smaller than the energy dissipated for friction. The elastic modulus, the structure of the material as well as the sliding velocity have a significant influence on the friction. Therefore, all these properties can affect the cutting resistance results [10-11]. The design of the robotic-controlled razor blade required the knowledge of the value of the normal load and the cutting speed suitable for each type of fabric according to it aerial density in order to perform a clear cut of the fabric. In this work, the cut resistance of high-performance yarns, including Polyester, Vectran, and Kevlar-29 has been studied the cutting force of triaxial fabric was analyzed and experimental as a function of fabric material and areal density as well as the cutting speed.

2. MATERIAL AND METHODS

2.1. Materials

Several materials are used in the form of triaxial fabrics from Polyester yarns with 144 tex, yarn tenacity 80 cN/tex, strain to failure 0.145, Vectran yarns with 140 tex, yarn tenacity 203 cN/tex, strain to failure 0.038 and Kevlar-29 yarns with 167 tex, yarn tenacity 233 cN/tex, strain to failure 0.036. In this work several samples were made of the following fabrics with the following specifications given in Table (1):

Table 1. Triaxial fabric specifications

Fabric samples	**Polyester**		**Vectran**		**Kevlar-29**	
	Density Hexagon units per cm	**Fabric weight (g/m^2)**	**Density Hexagon units per cm**	**Fabric weight (g/m^2)**	**Density Hexagon units per cm**	**Fabric weight (g/m^2)**
Low fabric density	3	140	3	166	3	163
Normal fabric density	3.6	166	3.6	200	3.6	196.5
High fabric density	4	185	4	222	4	218

2.2 Design of cut test apparatus

2.2.1 Fundamentals of cutting resistance testing device

The device described in this paper must have at least two mechanisms in order to apply the normal load on the test specimen and the motion of the blade over the workpiece in order to proactive the forces during the cutting process. The blade holder can rotate to change the cutting angle as well as to reciprocate over the test specimen at different cutting speed during the cutting process. All blade motions are controllable to remove any human error affects the test results. To ensure that the motions are accurate and smooth to assurance and a high level of repeatability. The device must be able to support a cutting load of 6000 N which was chosen based on the standards ASTM F1790 / F1790M – 15 of cutting hazards that are related to a cutting action by a smooth sharp edge across the surface of the material. The cutting speed is controlled up to 660 mm/min. A fabric test sample – which can be rectangular or round, is placed outside the plastic cylinder mandrel of diameter 50 mm clamped with enough force to keep the sample in place but not cause any residual stresses within the area to be cut which is a groove on the surface of the fabric holder with a length 25 mm and width 3 mm. The angle of the blade can be set before starting the test of the cutting process. The sample holder is firmly fixed on the table and pressed to the blade holder by the predetermined load. Figure (1) gives a sketch of the fabric holding device. Test apparatus may test materials with any thickness greater or having a high frictional coefficient such as elastomers.

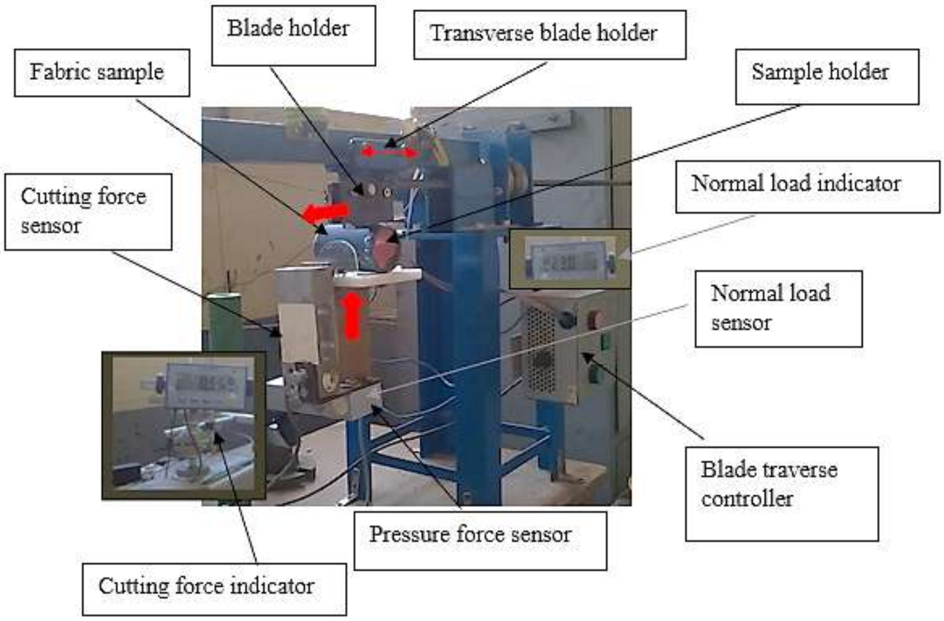


Figure 1. Cutting resistance Testing set up

A stainless-steel razor blade (Lord) was found to provide the consistent cut forces variation and was selected for all subsequent systematic cut investigations, each test using a new blade for each test. The test starts with the determination of the critical value of the normal load which is capable to cut the fabric for a distance of 25 mm. This value of the load will be fixed to all the samples of this type of fibers. With the change of the fabric, areal density new value of critical load should be found. The average of 3 samples are tested in each case was calculated.

3. RESULTS AND DISCUSSIONS

3.1 Mechanism of fabric cutting

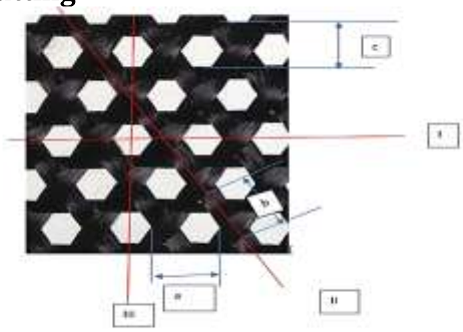
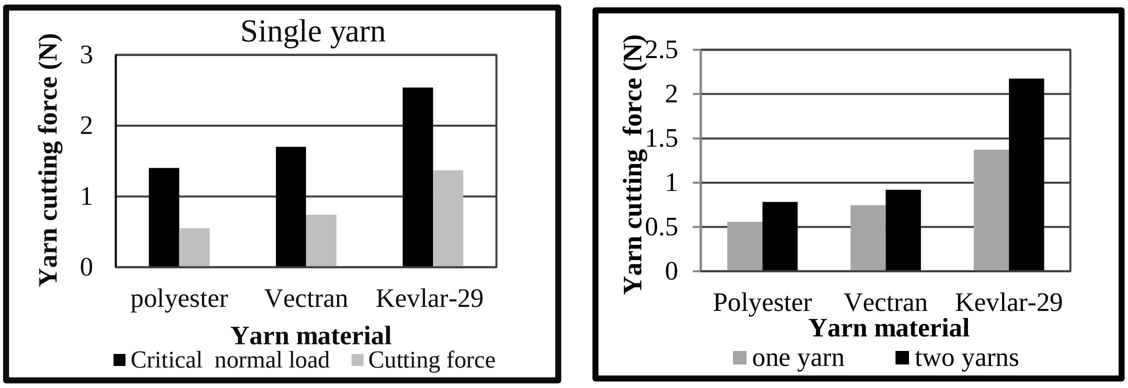


Figure 2. Triaxial fabric cutting resistance possibilities

The fabric is interlacements of yarns in a certain sequence according to the fabric design. In the case of triaxial fabric Figure (2) the possible lines of fabric slicing with the blade of thickness are less than yarn thickness. The value of the cutting force is different depending cutting angle and the shear stress of the yarns and that under the cutter path which can be classified as Interlacements cut (I, II and III), mixed cut longitudinal and Interlacements cut. The value of cutting force in longitudinal can be neglected for multifilament yarn. Figure (3 a-b) illustrates yarn cutting resistance for single and two crossed yarn for different types of fibers at speed 470 mm/min. It is clear that the Kevlar-29 yarn has the highest yarn cutting resistance force. Two crossing yarns give a high value of cutting resistance force than one yarn but not the twice value of one yarn, it is due to the interlacing and crossing between yarns.

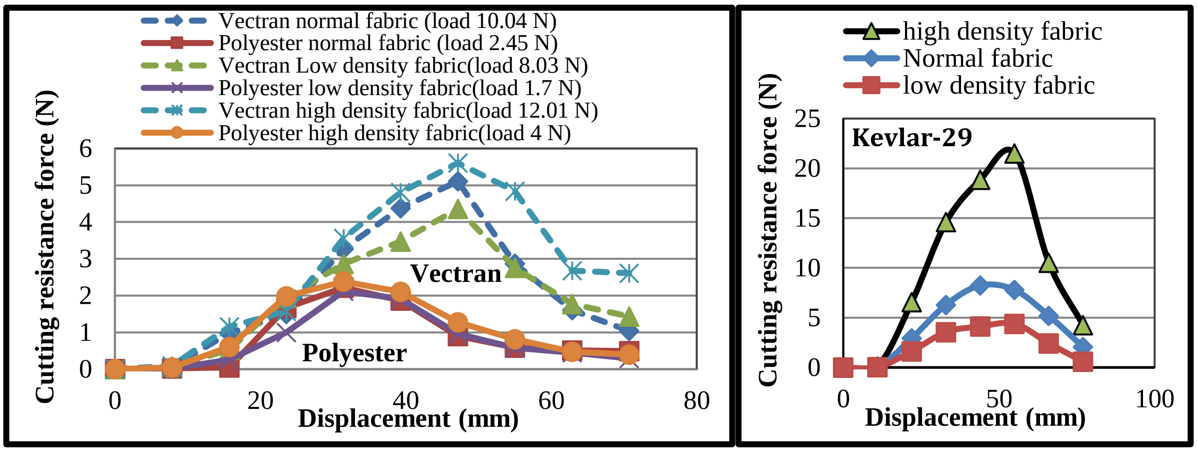


a. Single yarn cutting resistance b. One and two crossed yarns cutting resistance

Figure 3 - a, b. Yarn cutting resistance

3.2 Effect of fabric areal density of the cutting resistance

For each type of fabric three liner density fabric were tested. Vectran and polyester are tested at 470 mm/min and Kevlar-29 at 660 mm/min. The results of the cutting force are given in figure (4 a-b) which indicates that the Kevlar-29 fabric at normal load 27.44 N has the highest values of the cutting resistance force, which is a function of the fabric areal density.



a. Fabric cutting resistance for Vectran and Polyester fabrics **b.** Fabric cutting resistance for Kevlar-29 fabric

Figure 4 – a, b. Cutting resistance versus displacement for different fabric weights

3.3 The relation between the cutting resistance force and cutting speed

As the increase of the cutting velocity, the cutting resistance force of the fabric reduced significantly. Figure (5) gives a change of the cutting force-displacement diagram for low-density Kevlar-29 fabric with two different cutting speed 470 and 660 mm/min. From the analysis of the results of the different fabrics the following equation (1) can be concluded:

$$\textbf{Cutting resistance coefficient} = (P * W * E)/ (V) = K \qquad \textbf{(1)}$$

Where K is material cutting resistance coefficient, E is Young's modulus of the yarn (cN/tex), V is the cutting speed (mm/min), W is fabric weight (g/cm^2), P is a critical normal force (N). Figure (6) indicates that the above equation is valid for different types of fibers.

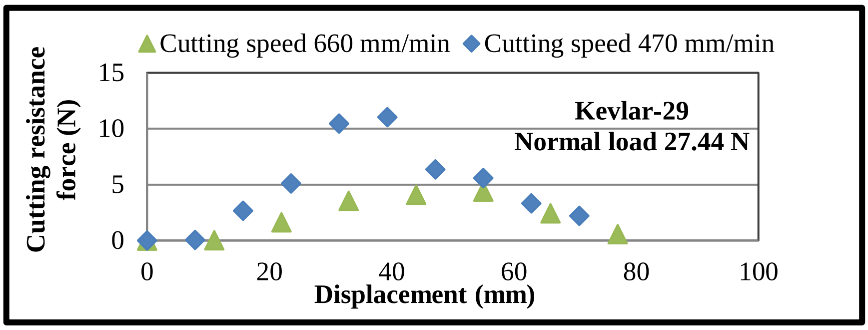


Figure 5. The effect of the cutting speed on the cutting force

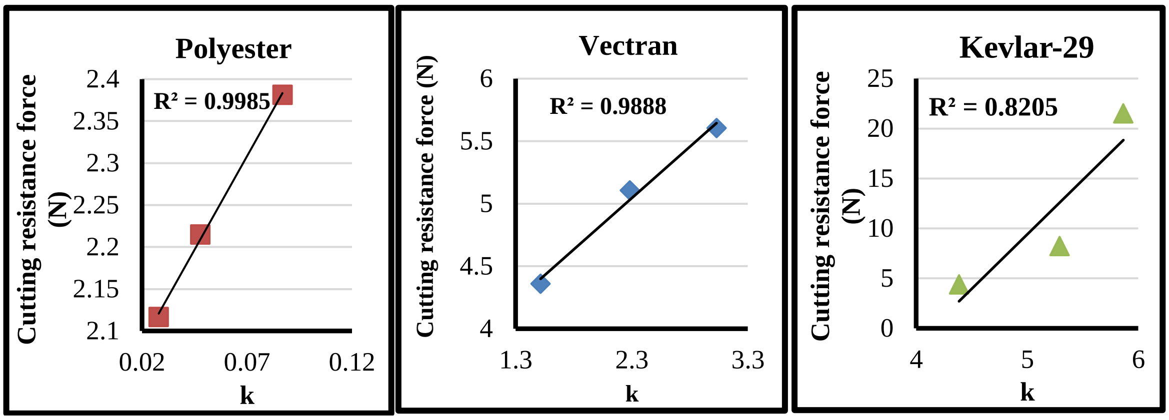


Figure 6. Cutting force versus material cutting resistance coefficient for Polyester, Vectran and Kevlar-29 fabric

The material cutting resistance is in relation with the value of critical load required to initiate the cutting of the fibers and which depends on Young's modulus of the fibers. Materials with the high values of the critical normal load will increase the friction between the blade and the sliced material resulting in a higher value of cutting resistance coefficient.

3.4 The cutting energy for different fabrics

Cutting energy (EC) represents the energy required to complete fabric cut for distance 25mm at the critical applied load and perform a complete slicing of all yarns under the cutter path. Figure (7) illustrates the effect of the fabric material, areal density and the cutting speed on the cutting energy. As the fabric density increases, the cutting energy rises. Vectran requires more cutting energy than Polyester for the same fabric density. Kevlar-29 has the highest cutting energy, most likely due to its relative hardness and expected higher transverse mechanical properties as well as the friction properties of the fibers-blade material.

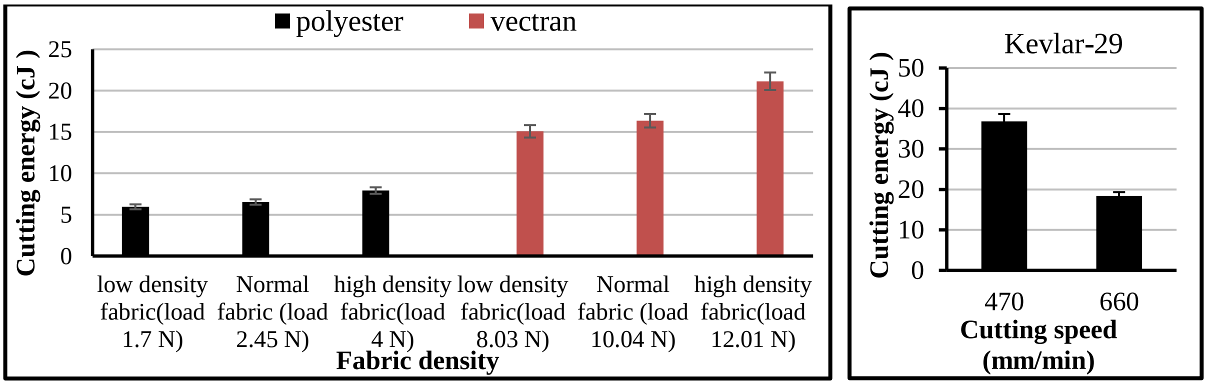


Figure 7. Cutting energy for different types of fabric, fabric areal density and cutting speed.

The cutting energy (EC) is linearly proportional to the fabric areal (W) density(g/cm^2),

$$\textbf{The specific cutting energy (SE) = EC/W} \quad (2)$$

It was found that (SE) for Polyester, Vectran and Kevlar-29 fabrics, at the same cutting speed (470 mm/min), is 424, 911 and 1706 cJ/($gm.cm^{-2}$), respectively.

4. CONCLUSION

Fiber material, fabric areal density, the normal load, and the cutting speed effects were explored. Cutting resistance force of Polyester, Vectran, and Kevlar-29 fibers triaxial fabrics indicates that the Kevlar fabrics have the highest values and required a high value of the normal critical load. The analysis of the cutting force model of triaxial fabric reveals that the cutting force value depends on the relative direction of the cutter to the yarn's axis. The cutting resistance of the fabric was found to be a function of the applied critical load to perform a complete cut of the yarn, and it was found to be 0.55, 0.74, and 1.37 N for Polyester, Vectran and Kevlar-29 yarns, respectively. Cutting resistance force of the fabric was found to be linearly dependent on the fabric areal density and inversely proportional to the cutting speed. The Kevlar fibers demonstrated higher average cut resistance than other fibers, due to their relatively higher transverse mechanical properties. An equation to express cutting resistance coefficient was driven. The value of specific energy is found to be of highest value for Kevlar-29 Triaxial fabric.

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