

Development of Textile Laminates for Improved Cut Resistance

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ABSTRACT

Fiber structures, yarn structures, and mechanical properties of fibers namely tensile modulus, tenacity, and elongation, are the key performance indicators of fabric cut resistance. *p*-aramid and UHDPE (Ultra High Density Polyethylene) based high performance fibers are most commonly used for protection against mechanical risks. Specially engineered composite yarns and fabrics enhance cut resistance. This paper discusses the influence of textile structure configuration on the performance of cut resistant textiles. A three tier laminate composite was made using knitted Kevlar fabric, (*p*-aramid) as the outer surface, polyurethane foam in the middle and a knitted nylon fabric as the skin contact layer. This specially engineered laminate showed a 20% increase in cut resistance when compared with the Kevlar fabric used for lamination. The combination of breathable PU foam and knitted fabric yielded high stretch with improved breathability and dexterity.

Key words: cut resistance, high performance fibers, Kevlar fabric, laminate, PU foam

INTRODUCTION

Injuries caused to people working in high mechanical risk areas result in loss of valuable human resources as well as damage to machinery and material. Age old warriors used shields to protect themselves from enemy's sharp weapons. The shield was a heavy metal plate and was difficult to handle. Now – a – days, operatives are protected by hazards posed by mechanized high speed operations of machines, handling of sharp or serrated objects, working in close proximity to revolving or reciprocating blades.

Particularly, hands and arms are always under high risk, which prompted development of protected gloves

and sleeves.. The conventional means of protection were wire mesh steel gloves, leather gloves and gloves made of some alloys. Many were uncomfortable at poor dexterity, and provided little protection.

After the invention of high performance polymers and materials, considerable research has focused on personal safety equipments, carried out initially for the military and later extended to occupational safety, has been done.

High modulus high strength polymers such as *p*-aramid, PBI, and ultra high density polyethylene have been introduced in personal protective devices in the form of fibers, yarns, fabrics or composite reinforcements¹. Their performance encouraged the technologists to design and engineer innovative personal safety equipment for protection against fire, ballistic, chemical, biological, nuclear, fall, and cut injury.

Higher strength to weight ratio of these polymers is the major advantage over conventional metals of steel, and alloys. Most of these polymers are pliable, flexible and possess textile characteristics making them easy to fabricate and ideal to wear.

Today's market for cut resistant gloves requires rising protection in combination with higher comfort levels. In general there are two types of cut hazards²: clean, sharp edge cuts such as knife blades and clean edge sheet glass and abrasive cut hazards caused by rough edge sheet metal; stamped or punched sheet metal and rough edged sheet glass. In order to make cut-resistant gloves for clean and sharp edge hazards, the following factors are the key elements in the design of yarns and/or fabrics

Tensile strength: The strength of the fiber is so great that it is difficult to break.

Abrasive action: The fiber is so hard that it will dull a passing metal blade.

Slippage: The blade actually slides across the yarn without catching to cut. Certain monofilament fibers have this advantage.

Gloves that are designed to resist clean edge cuts are usually made with core yarns. Core yarns are manufactured by wrapping different yarns around a center or solid fiber core. Each wrap provides a factor of cut resistance.

Abrasive cut hazards do not just cut, they tear and abrade and consequently require a different type of glove for protection. Gloves used in these areas must provide cut resistance, along with the additional requirements for abrasion resistance and tensile strength. They also tend to be much thicker, in order to resist the rougher edges, and are used in direct contact with the hazard rather than as a liner. Factors that are necessarily incorporated into the design of these gloves are:

Stretch: This allows the glove to move ahead of the cutting edge. This is why most cut-resistant gloves are knit and not woven.

Rolling: The yarn fibers roll as the edge passes across. An analogy would be cutting a carrot with a knife. If the carrot rolls it will not cut, but when held stationary it cuts very easily.

Loft: A soft thickness in the glove that resists a cutting edge. We can cut a piece of paper very easily with a sharp blade. However, if we place the paper on top of a pile of shaving cream, the task becomes more difficult because we lack the pressure required to cut. This paper discusses the cut resistance and utility performance of a newly engineered fabric/foam laminate.

MATERIALS AND METHODS

Materials

Rib knitted fabric composed of 94% Kevlar and 6% lycra was used for laminating foam. Areal density of the fabric was 400 grams per square meter. This fabric acts as a protective layer of laminate.

A single jersey knit 100% nylon fabric was used as bottom layer or skin contact layer of the laminate.

Courses and wales per inch of fabric were 100 and 44 respectively with area density of 110 grams per square meter.

Breathable polyurethane-polyester open cell foam was used as a middle layer of the laminate. The density of foam was 7lb/cu.ft. and the thickness used was 2mm.

Methods

Lamination process

The structure of laminate is as shown in *Figure 1*. The laminated structure was developed by the flame lamination process. The fabric layers were bonded to the foam surface by flame heating the foam surfaces and subsequent application of pressure. A lamination speed was 10 meters per minute while the temperature was maintained at 140° C. The laminate was allowed to cure and relax for 24 hours. The resultant thickness of laminate was 1.94 mm.

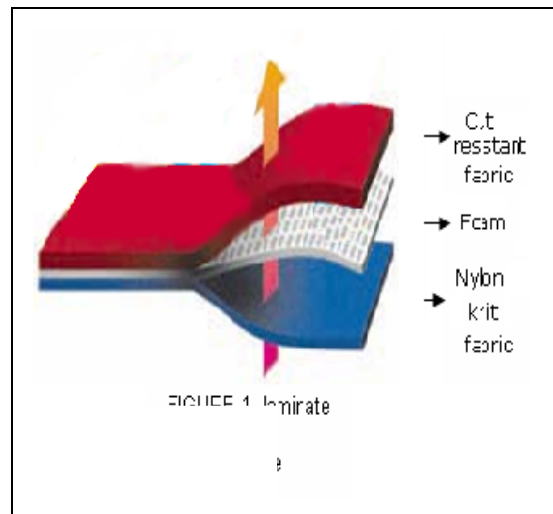


FIGURE 1. Laminate Structure

Testing for cut resistance

Widely used test methods for the determination of the cut resistance of fabrics are: DIN EN 388, ISO 13997 and ASTM F 1790-04. Alternatively, developing application oriented test method are of paramount importance to better meet the performance requirements. A test method devised on the concept of tension-shear loading is a useful tool in designing slash-resistant gloves and clothing³. Following are the brief descriptions of each test methods and

justification was made to choose ISO 13997, the most appropriate method for testing laminates.

DIN EN 388: Protective Gloves against Mechanical Risks (Cut resistance Index)

This Coupe Tester comprising a circular blade loaded at a constant force of 5 N. The recorded number of cycles needed to cut the specimen is used to calculate a cut index. The result is classified into cut protective levels 0 to 5, with 5 representing the highest performance level.

ASTM F1790-04: Cut Protection Performance

As an alternative to the Coupe Tester method, the load versus distance concept was developed. This concept relates the applied force to the cutting-through distance. ASTM F 1790-04 introduces both CPP (Cut Protection Performance) tester and TDM (Tomo Dynamo Meter) tester for the determination of cut resistance in order to harmonize with the ISO standard.

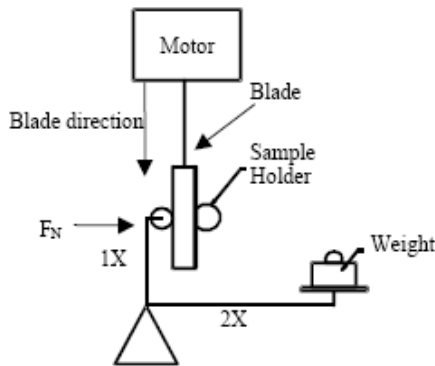


FIGURE 2. Schematic representation of ASTM 1790

Figure 2 represents the working principle of ASTM 1790.

ISO 13997: Protective clothing – Mechanical properties-Determination of resistance to cutting by sharp objects

This standard describes the test method using the TDM (Tomo Dynamo Meter) tester. The standard defines three classes of cut length. For each class, cuts have to be made using a chosen weight. Based on the results, the force needed to cut 20 mm is obtained.

Cut resistance testing of fabrics and laminate was carried out as per ISO 13997 using the TDM (Tomo Dynamo Meter) tester. Though each test method has its own merits and limitations, ISO 13997 method using TDM eliminates occurrence of errors due to

frictional characteristics of surface and the thickness of cut resistant materials besides maintaining force equilibrium⁴. Figure 3 below demonstrates how the force equilibrium is maintained by watts mechanism.

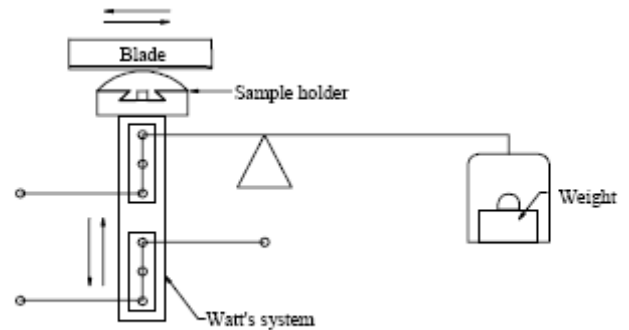


FIGURE 3. Schematic representation of ISO 13997

RESULTS & DISCUSSION

Cut resistant performance

Five different cut resistant fabric samples made of Kevlar fabric with different knit construction were chosen and tested for cut resistance force value as per ISO 13997. The range of cut resistance force for different fabrics was varied from 450g to 650g. A fabric showing higher cut resistance of 650g was chosen for lamination.

Test condition:

Sample conditioned at 21° and 65% R.H.

Apparatus used: Tomo Dynameter TDM – 100 (by IRSST)

Cut direction: 45 degrees

Length calibration (cut length of neoprene), mm: 22.933

Blade sharpness correction factor, mm: 0.8721

Totally, 26 readings were taken from three specimens randomly chosen at three different places of laminate. Figure 4 is the graphical representation of cut resistance force and correlation coefficient obtained from testing of laminate.

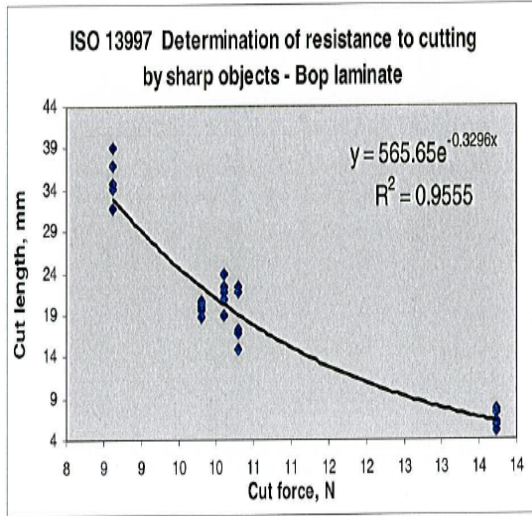


FIGURE 4. Graph representing cut resistance of laminate

Figure 4 shows that force required to cut through a distance of 20 mm is 10.1N (1034.1g) for the laminate and the R^2 value is 0.9555. It is evident from the above results that the cut resistance force value of laminate has increased considerably to the extent of 60% when compared with fabric. The increase in cut resistance is attributed to the addition of the foam layer since PU foam exhibits good stretch, compression set, cushioning and softness.

Physical testing of laminate

To determine the utility performance, tests were also conducted on laminate and the results are summarised below in *Table I*:

The differences in test values of the laminate between length and widthwise direction obtained with regard to tensile strength, elongation, stretch and growth are due to the directional effect caused by the knit structure of fabrics used for lamination. The increased stretch percentage of the laminate is a useful property for better dexterity. The air permeability of the laminate is found to be good because of the use of open cell PU foam, hence, the laminate has good breathability and improved wear comfort. The growth factor shows a minimum value which indicates that the dimensional stability of laminate is good.

TABLE I
Test results of laminate

S No	Test Standard	Result	
		Lengthwise (wales)	Widthwise (course)
1	Tensile strength, kg: ASTM 5034	59.13	58.08
2	Elongation at break, %: ASTM 5034	139.86	176.43
3	Stretch: %: ASTM 6614	26.53	42.86
4	Growth %: ASTM 6614	0.80	0.80
5	Air permeability, cc/sec/cm ² : ASTM D737	9.21	
6	Abrasion resistance: ASTM D 4970	No change	

SUMMARY AND CONCLUSIONS

1. Five cut resistant fabrics were made with a cut resistant range of 450g to 650g.
2. Laminated structure made out of Kevlar fabric and breathable open cell PU show a higher cut resistance force of 1034.1 g.
3. It is concluded that the laminated structure made out of Kevlar fabric and breathable open cell PU foam can be used to manufacture devices to protect against mechanical risks caused by sharp objects.
4. In general all of the developed textile/foam laminates with improved dexterity and wear comfort can be employed for applications such as protective helmet liners, safety pads for athletes, bike racing, sleeves for hand protection, cut protection gloves, and chain saw aprons.

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