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Mechanical properties of synthetic leather reinforced with woven, knitted and nonwoven fabrics

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In this research, synthetic leather samples have been produced using polyvinyl chloride film and three types of reinforcing polyester fibre fabrics, namely woven, knitted, and nonwoven, with similar areal weights. The samples are then subjected to tensile, trapezoid tear and bursting tests. The effect of structural parameters of the reinforcing fabrics on the mentioned properties has been analyzed and discussed. Based on the results, woven fabric reinforced leathers show the highest tensile and bursting strength, followed by knitted and nonwoven fabrics reinforced ones respectively. The highest tear strength value is observed in the nonwoven reinforced samples.

Keywords: Backing fabric, Laminated fabric, Mechanical properties, Synthetic leather, Nonwoven, Polyvinyl chloride film

1 Introduction

Laminated and coated fabrics are widely used in many applications and have established themselves as one of the important products in the global textile market. In these structures, the textile component provides tensile strength, tearing strength, and elongation control, and the polymeric laminating or coating material offers protection against the environment to which the structure is subjected. Synthetic leather, which is widely used as a substitute for natural leather, is a kind of laminated or coated textile in which a natural or synthetic fibre cloth (woven, knitted or non-woven) is bonded to or coated with polymers, such as polyvinyl chloride (PVC) or polyurethane (PU). Depending on the application, the polymeric material can be dense or foamed. Moreover, it is usually textured on the surface in order to resemble natural leather appearance. The benefits of synthetic leather over the natural one can be found in properties, such as resistance to color fading, crease resistance, washablity, ease of care, being odorless and uniform, and lower cost. They are used in many applications, such as shoes, bags, upholstery, tops of convertible cars, etc.

Mechanical properties of synthetic leathers or other laminated and coated fabrics with similar structures have been studied by some researchers. In the uncoated fabrics, it has been found that the fabrics with longer float lengths and lower sett (the number of yarns per unit length) have higher tearing strength due to higher thread mobility, which facilitates the grouping of threads during tearing[1, 2]. Coating process results in loss of tear strength, but the loss of strength varies with type of weave[1]. The factors that affect tear strength of uncoated fabric also apply to coated fabrics[2]. The trapezoid tearing behaviors of uncoated and coated woven fabrics in experimental and finite element analyses were investigated by Wang *et al.*[3]. Moreover, the influence of the coating on the trapezoid tearing properties was discussed.

The tensile properties of coated fabrics and laminates depend on the structural characteristic of their base layer, the polymer film and degree of its penetration into the base layer[4]. Ujevic *et al.*[5] analyzed chemical and physico-mechanical properties of artificial leather with polyurethane foam and woven and knitted fabric on the back side. According to the test results, sample of artificial leather with woven fabric on the back side have a higher breaking force than samples of artificial leather with knitted fabric on the back side for the vehicle interior. The shortcoming of the woven fabric is an irregular breaking force of the sample along the angles from 0˚ to 360, whereas the knitted fabric has more uniform breaking forces in all directions.

Matković and Skenderi[6] studied mechanical properties of polyurethane coated knitted fabrics. The elongation in the wale direction and breaking forces in the course and wale directions of the coated knitted

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fabric could be predicted and explained with the results of the elongation of knitted fabric. However, elongation in the course direction could not be clearly explained.

Kos *et al.*[7] showed that physico-mechanical properties of a woven fabric with different warp densities, differ from physico-mechanical properties of coated fabric with respectively different warp densities. Just minimal warp density reduction leads to significant change in the basic fabric properties, as well as the properties of multi-component material with appurtenant fabric. Changes in warp density provide significant correlation coefficients between the warp density and physico- mechanical properties of fabrics and multi-component materials.

Synthetic leather can be considered as a fibre reinforced flexible composite material. Aboshio *et al.*[8] studied the mechanical behaviour of neoprene coated nylon woven fabric composites using biaxial loading based on hydraulic bulge test method and uniaxial tensile method at varied environmental testing conditions. Results, indicating failure modes, ultimate strengths and strains from the uniaxial testing of the composites, were compared, and recommendations for application of the composite material in structural design are reported. In thermoplastic polyurethane (TPU)/polyester non-woven composite materials the fracture stress of composite materials is proportional to the resin content, but has very little to do with the layer order[9]. The mechanical behaviour of flexible composites made of mechanically bonded nonwoven preforms in a thermoplastic polyurethane (TPU) matrix was studied by Tausif *et al.*[10]. They showed that increasing the strength and degree of consolidation of nonwoven preforms did not translate to an increase in the strength of resulting fibre reinforced TPU-composites. The TPU composite strength was mainly dependent upon constituent fibre stress-strain behaviour and fibre segment orientation distribution. Guo and Lingxiao Jing[11] investigated Poisson's ratio of flexible PU-coated multi-axial warp knitted fabrics under uniaxial tensile. In another study, Guo *et al.*[12] showed that the coated multi-axial warp knitted fabric is anisotropic material, and the coating has a great influence on its mechanical properties.

Zhao *et al.*[13] produced a split microfibre synthetic leather using split microfibre nonwoven as the base and waterborne polyurethane（WPU）as the polymer coating. The results showed that the air permeability, tensile strength, elongation-at-break, tear strength, peeling strength and crease recovery angle of the split microfibre synthetic leather were better than knitted synthetic leather and real leather.

It is revealed from the literature that few studies have been done on mechanical properties of synthetic leather and similar coated fabrics with respect to their reinforcing fabric structure. Moreover, previous works have mostly focused on just one, or in some cases two fabric types and there is no comprehensive study on the behaviour of coated or laminated fabrics reinforced with three major fabric types, namely woven, knitted and nonwoven fabrics using the same testing conditions. Therefore, the aim of this study is to investigate the effect of backing fabric structure on the tensile, bursting and tear strength of artificial leather reinforced with the mentioned fabrics.

2 Materials and Methods

2.1 Materials

Three reinforcement structures (woven, knitted and needle-punched nonwoven fabrics) were produced in this study using the same type of material (polyester fibre) and nearly the same areal weights (in the approximate range of 130-140 g/m^2) for comparison. Magnified images of the fabrics' surfaces are shown in Fig. 1. Table 1 gives the characteristics of the fabrics.

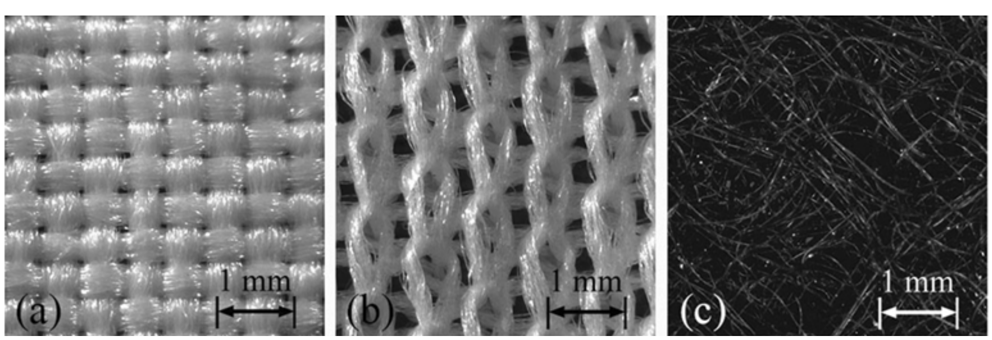

Fig. 1 — Magnified images of the reinforcing fabrics' surfaces (a) woven, (b) knitted, and (c) nonwoven

Table 1 — Characteristics of the reinforcing fabrics

Fabric code	Fabric type	Pattern	Thickness mm	Description
W	Woven	Plain	0.48	Filament yarn in warps and wefts (250 den), warp density 19/cm, weft density 23/cm
K	Knitted	Interlock (1×1)	0.85	Knitted with filament yarns (150 den), wale density 14/cm, course density 19/cm
N	Nonwoven	-	0.99	Needle-punched, fibres length 64mm, fibre fineness 3 den

A PVC film with thickness of 0.93 mm and areal weight of 47 g/m^2 was used as the matrix material. For producing synthetic leather samples, the PVC film was first cut into desired dimensions and the surface was manually covered with a thin and uniform layer of adhesive (Contact Premium "Pattex", made of polychloroprene rubber, by Henkel Co.). Approximately 100 g/m^2 of the adhesive was applied on the surface. The fabric pieces were then laid on the film surface and pressed. This process was done gently and carefully in order to prevent creasing or distortion of the fabrics. The laminates were then kept under pressure for 24 h at 22°C so that the adhesive is cured. The PVC film was coded "L" and the synthetic leather samples reinforced with woven, knitted and nonwoven fabrics were coded "WL", "KL" and "NL" respectively.

2.2 Characterization

2.2.1 Tensile Test

For measuring tensile strength of artificial leather, the samples were cut in the form of dumbbells, and tested according to ASTM D2209 standard method[14]. Tests were conducted on the universal testing machine Kardotech with a 1000 kgf load cell. The cross-head speed was kept at 300 mm/min and the distance between jaws at 100 mm. At least three tests were performed for each group of specimens and average values of maximum tensile force and tensile strain were reported.

2.2.2 Trapezoid Tear Test

For measuring Trapezoid tearing strength, samples were prepared and tested in accordance with ASTM D6077 standard method[15]. An outline of a trapezoid was marked on the specimens and the nonparallel sides of the trapezoid were clamped in the jaws of a tensile machine. A cut was made on the sample edge as the initial point for tear propagation . A continuously increasing load was applied to the specimen in such a way that the tear propagates across the specimens' width. The value of the breaking load of the specimen was obtained from the load-elongation curve and recorded autographically. Tests were conducted on the tensile testing machine Kardotech with a 1000 kgf load cell. The cross head speed of the machine was set at 300 mm/min and the distance between jaws at 25 mm. At least three specimens were tested from each sample. Average values of tearing force was calculated according to the procedure given in the standard method.

2.2.3 Bursting Test

For measuring bursting strength, samples were cut with the dimensions of 100 mm × 100 mm and tested in accordance with BS 3424 standard method[16]. The bursting strength was measured as the force required to penetrate a spherical plunger through a piece of leather clamped in a ring. Tests were conducted on the universal testing machine Kardotech with a 1000 kgf load cell and 100 mm/min cross head speed. The ball and the ring diameters were 25.4 mm and 45 mm respectively. Five specimens were tested from each sample and the average values of maximum force was reported.

3 Results and Discussion

3.1 Tensile Properties

Average values of tensile load and strain at break for raw materials and synthetic leather samples are compared in Fig. 2. ANOVA analysis was done on the results using SPSS software at 0.05 confidence level. It shows that structural parameters of the reinforcement fabrics have significant effects on the tested mechanical properties. W1 and W2 are referred to woven samples tested in warp and weft directions respectively. For the knitted fabric, K1 and K2 represent the samples tested in the wale and course directions respectively. As seen in Fig. 2, among the reinforcing fabrics the highest tensile load belongs to the woven sample (regardless to the direction), followed by knitted and nonwoven ones, which is technically expected due to structural differences among the three mentioned structures. In fact, in woven fabrics, one set of yarns are positioned parallel to the loading axis, and thus contributing much more effectively in carrying the load. However, in knitted fabrics the yarns are in the forms of stitches and not parallel to the loading axis. The nonwoven fabric is made of staple fibres not continuous yarns, and on the other hand, the fibres are oriented randomly. Therefore, their contribution in carrying the load is considerably low.

The highest strain at break is observed in the knitted sample (with much more extension in the course direction than in the wale one), followed by the nonwoven and then the woven samples. Knitted fabrics are famous for their extensibility due to their stitch structure, which allows the fabric to be extended to the point where the yarns are positioned straight in the stitch. Course-wise extensibility is higher than the wale-wise in most of weft knitted fabrics due to the form of the stitch. In the nonwoven fabric the high extensibility is attributed to the high mobility of staple fibres in such a structure. In the woven fabric, as stated before, one set of yarns are positioned straight and parallel to the loading axis and thus resisting effectively against extension, unless they are extensible in nature. The same trend is also observed in the synthetic leathers reinforced with the fabrics. It can be seen that the tensile properties of the reinforcing fabrics has a great influence on tensile properties of their synthetic leathers. It is generally observed that the synthetic leather has slightly higher tensile breaking load as compared to its reinforcing fabric, which is due to the marginal contribution of the polymeric film in carrying the load.

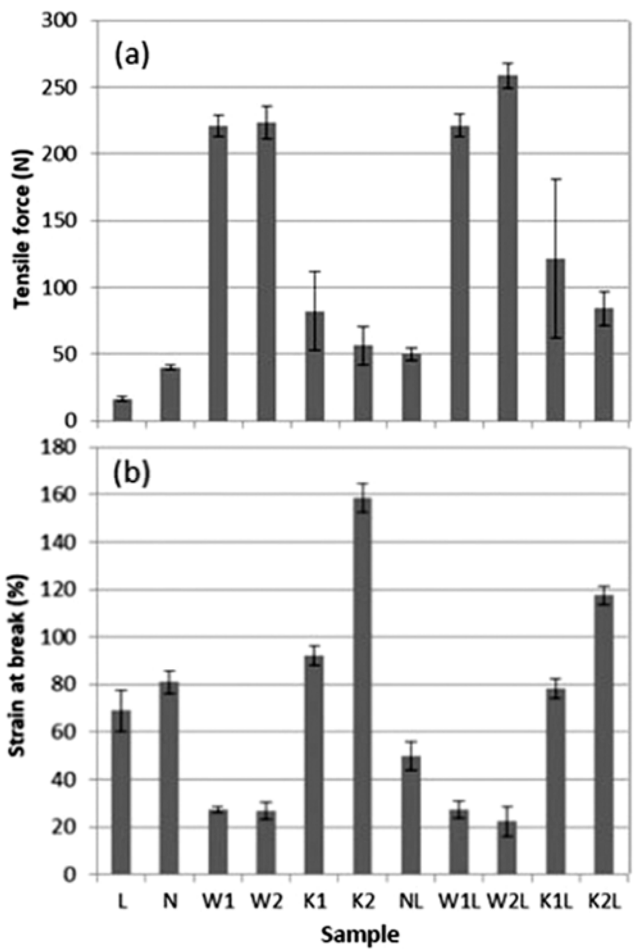

Fig. 2 — (a) Average values of tensile load and (b) strain at break for raw materials and synthetic leather samples

However, the breaking strain of synthetic leathers is found lower than those of their reinforcing fabrics, which is due to the effect of lamination process in confining the extension of the fabric. It is seen that the woven sample is less affected in this regard, as this is much less extensible in nature than knitted and nonwoven ones.

It can be generally concluded that, though knitted and nonwoven reinforced leathers have lower tensile strength as compared to the woven ones, their higher extensibility may be a positive feature in applications where higher flexibility is required, for example in clothing, upholstery, bags and other products with complex 3D shapes. On the other hand, woven reinforced leathers are ideal for products which require high dimensional stability and tensile strength.

3.2 Tearing Strength

The average tearing force of various samples is shown in Fig. 3. It is clear the lowest strength value belongs to the polymeric film "L". Regarding the reinforcement fabrics, the tearing mechanism is interesting. When woven fabrics are subjected to tearing loads, if the yarns have enough space, they first move away from the loading area. Consequently, the yarns gather behind the tearing point and result in

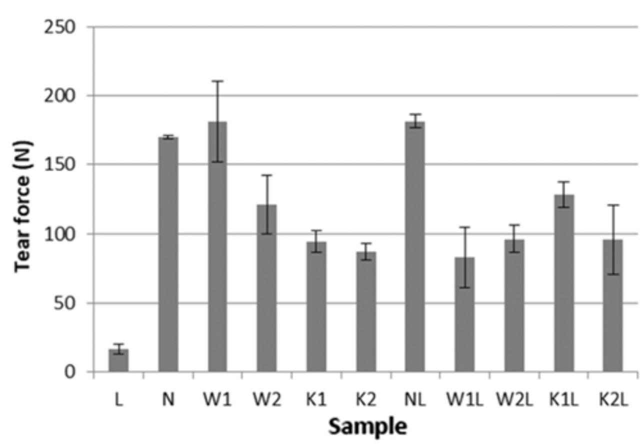

Fig. 3 — Average values of tear load for raw materials and synthetic leather samples

jamming state. The yarns then resist against the applied load in bundles (groups), resulting in a high tearing force than what they can resist individually.

Obviously, the less the fabric sett, the more is the ability of the yarns to move and gather in groups. Hence, it is observed that the woven fabric have higher tearing strength, when the warps (which have less density than the wefts) are subjected to tear. In fact, in W1 sample the yarns are more broken in bundles, than in W2 sample.

The other point is the high value of tear strength of the nonwoven sample. This observation can also be justified according to the above explanation. The nonwoven fabric provides higher degree of movement for the constituting fibres due to its loose and open structure. As a consequence, the fibres can move easily due to the applied force and form strong groups in the tearing region.

The lowest tear strength values are observed in the knitted fabric. This is because knitted fabrics are easily unraveled when some of the yarns are broken. The initial cut made on the sample and subsequent yarn breakages cause the fabric to fail at a lower tearing load as compared to the two other structures (woven and nonwoven), due to unravelling.

Regarding the reinforced synthetic leather samples, it is seen that the leather reinforced with the nonwoven fabric (NL) has the highest tear strength among the samples, due to the high tear strength of the nonwoven fabric.

It is also observed that the tearing strength of W1L is considerably lower than that of its reinforcement fabric (W1). It seems that the adhesive used in producing leather samples restricts the movement of yarns in the fabric, thus the yarns cannot form strong bundles and are broken individually, which leads to the loss in the tearing strength.

The strength loss in weft direction is much less than that in warp direction, as the yarns in W2 are broken in a rather individual manner due to their higher density. So, the adhesive has a less effect in changing the tearing mechanism.

Knitted fabric reinforced leather especially in the wale direction (K1L) show a higher tearing strength value than the woven reinforced samples (W1L and W2L), most probably due to more extensibility of the knitted sample and higher mobility of yarns in the sample. It is also seen that both K1L and K2L have slightly higher tearing strength values than their reinforcement fabrics (K1 and K2), which may be due to the effect of adhesive in restricting the run (unravelling) of the fabric when yarn breakage occurs.

3.3 Bursting Strength

Average bursting strength values for reinforced synthetic leathers are shown in Fig. 4 (a). Average curves of bursting load – displacement for the samples are shown in Fig. 4 (b). It is clear that woven fabric reinforced leather has the highest bursting load. Knitted and nonwoven reinforced samples possess the subsequent values respectively. Bursting loads may be applied to synthetic leathers in many applications, such as clothing, upholstery, etc. Therefore, it is important that they have acceptable resistance to such kind of loading. It is seen that regarding the bursting force, the order of the samples follows the same trend as in the tensile breaking force. In the case of bursting deformation, though the samples are different with regard to their resistance against deformation [Fig. 4 (b)], There is no statistically significant difference between their displacement values at break.

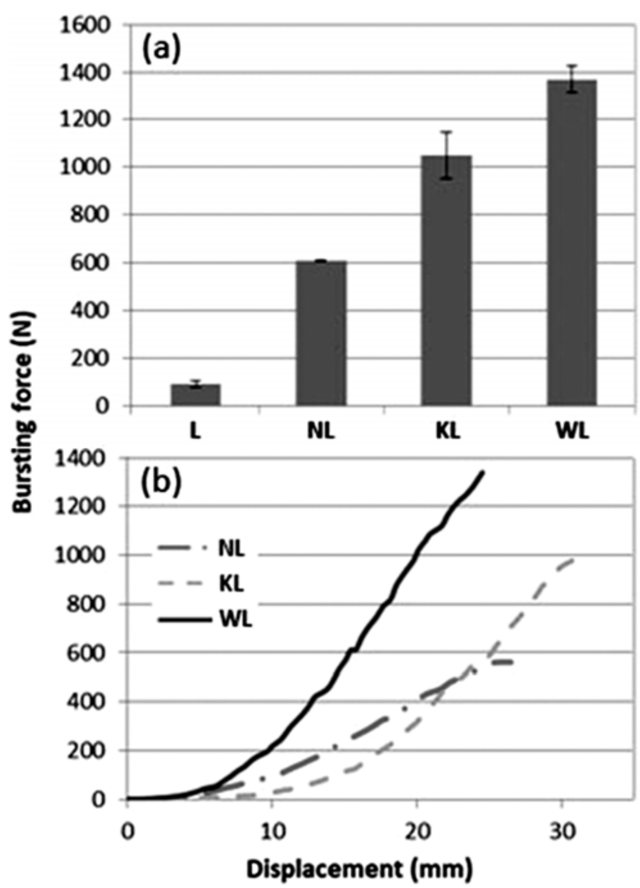

Fig. 4 — Average (a) bursting strength values and (b) curves of bursting load – displacement

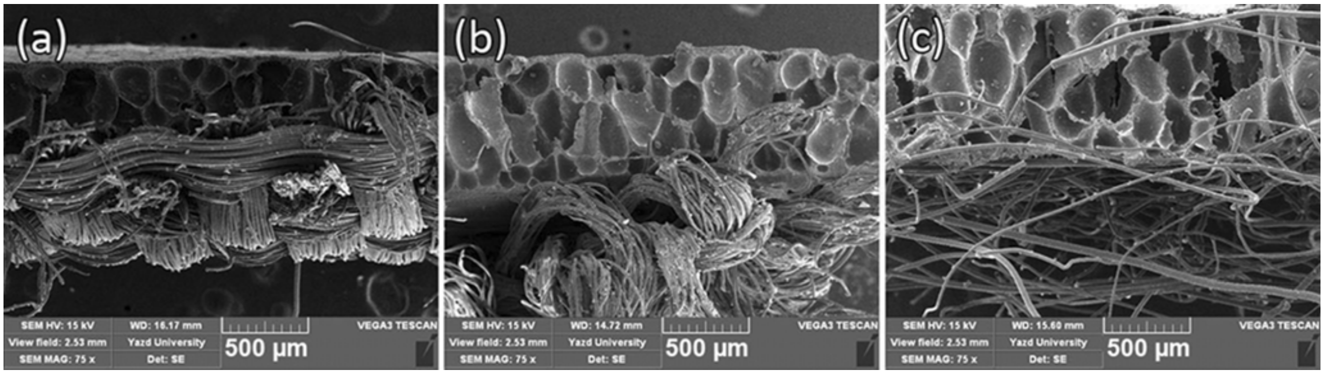

Fig. 5 — SEM images of fractured surfaces of the samples (a) WL, (b) KL and (c) NL

Table 2 — Characteristics of two commercial synthetic leathers

Property	Sample A	Sample B	
Reinforcement type	Nonwoven fabric	Knitted fabric	
Thickness, mm	0.93	0.96	
Direction of measurement	Longitudinal	Longitudinal	Transverse
Tensile breaking force, N	48.9	154.01	20.4
Tensile breaking strain, %	74.2	41.7	112.9
Tear strength, N	106.7	106.4	37.3
Bursting strength, N	334.2	547.5	

3.4 Quality Evaluation of Produced Samples

In order to check the effectiveness of the bond between reinforcing fabrics and the PVC film, fractured surfaces of the samples are scanned by scanning electron microscopy. SEM images (Fig. 5) show that the product is not delaminated after fracture and the parts are still bonded together. So, it can be concluded that the adhesive and the bonding procedures are effective in laminating the product and maintaining its structural integrity even after failure.

In order to have a rough view on the characteristics of commercial synthetic leathers in the market, two commercial leather types have been prepared and their tensile, tear and bursting properties are measured. The characteristics of the mentioned samples are given in Table 2. Although the properties cannot be compared with those of the samples produced in the current research work due to dissimilar parameters, the data can give some idea for our samples, since the properties of NL and KL are mostly in the same range or even higher than those for the commercial leathers.

4 Conclusion

In this research, tensile, trapezoid tear and bursting properties of synthetic leathers reinforced with woven, knitted, and nonwoven polyester fabrics have been studied. It is concluded that:

4.1 Samples reinforced with woven fabrics possess the highest tensile strength and lowest extensibility. Therefore, they are ideal for products which require high dimensional stability and tensile strength. Knitted and nonwoven reinforce samples have high values of extensibility, which may be a positive feature in applications where higher flexibility and formability are required.

4.2 Nonwoven fabric reinforced leather has the highest tear strength among the leather samples due to the high tear strength of the nonwoven fabric. Knitted fabric reinforced leather especially in the wale direction has a higher tear strength than the woven reinforced samples due to more extensibility of the fabric and more movement freedom of the yarns in the structure.

4.3 Tearing strength of woven reinforced leathers is considerably lower than that of its raw reinforcement fabric due to the effect of adhesive in restricting the yarns movement in the fabric.

4.4 Woven fabric reinforced leather has the highest bursting strength, followed by knitted and nonwoven reinforced samples.

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