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BALLISTIC IMPACT RESISTANCE OF FLEXIBLE COMPOSITES

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Abstract The study investigates the ballistic resistance of high performance fabrics coated with natural rubber (NR). Ballistic Twaron fabrics were coated with high modulus prevulcanised NR. Samples were then tested for ballistic impact resistance by firing them with standard fragment simulation projectiles to determine the velocity at which there is fifty percent chance that the sample is completely penetrated by the projectile. A series of 2-, 4-, 6-, and 8-layer fabric samples were tested for ballistic resistance through combination and arrangement of neat and coated layers. The results suggest that alternate layers of neat and coated fabrics in the fabric system would lead to higher ballistic limit as compared to neat samples.

KEYWORDS: Ballistic impact resistance, ballistic limit, natural rubber, coated fabrics

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Introduction

In general, any type of coating or finishes will alter the inter fiber and yarn to yarn friction of a fabric. Higher friction is needed among the yarns in order to improve the energy absorbing characteristics. Many studies (Briscoe and Motamedi, 1992; Lee *et al.*, 2003; Tan *et al.*, 2005) had shown that higher friction between projectile-fabric and yarn-yarn restricts the mobility of the yarns upon impact. The projectile will be required to engage more yarns, which result in higher energy absorption.

Early work on the effect of friction on ballistic performances was done by Briscoe and Motamedi (Briscoe and Motamedi, 1992). The authors found that fabrics with the highest coefficient of friction and apparent yarn modulus, gave the highest ballistic performance at both high impact and static experiments. The used of silica particles as coating have been reported (Tan *et al.*, 2005) to improve the ballistic impact performance of ballistic fabrics. Lee *et al.*, (2003) studied the ballistic resistance of Kevlar KM-2 fabrics impregnated with silica particles dispersed in ethylene glycol (shear thickening fluid, STF). Overall, the STF coated fabrics gave higher impact velocity measurements (at low velocity impact especially against fragments and stab threats) with reduced depth penetration but with some increased in the sample weight. In another study, Tan *et al.*, (2005) also used silica particles but the particles were suspended in water (silica-water suspension, SWS) before impregnating the fabrics. The study found that the ballistic limit for some samples increases as high as 65% compared to uncoated fabric samples but with the expense of about 42% increase in the areal density of the samples.

In this study, NR was explored as the coating material. NR has been extensively used as coated fabrics in many technical textile applications due to its high energy absorbing characteristics together with its high flexibility, excellent puncture and tear resistance, and good adhesion. However, little is known on the performance of NR as ballistic impact materials. This paper reports the ballistic limit of NR coated Twaron fabrics.

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Experimental Details

Twaron CT 709 Microfilament fabric was used in the study. The fabric is made up of 930 dtex yarns of plain woven construction. It has an areal density of 202 g/m^2 with 27 warp and weft per inch respectively. Prevulcanised NR (Revertex Malaysia Sdn. Bhd.) of high modulus type was used in the study. The coating technique applied was single dipping and samples were dried at room temperature.

The ballistic tests (also known as V_{50} test) were conducted to determine the ballistic limit of the samples. The test was conducted in accordance to NIJ Standard 0101.04 (NIJ Standard-0101.04, 2001). The target sample, measuring 350 mm x 350 mm in size, was clamped at all four edges and positioned at 5 meters away from the muzzle of the test gun. NATO standard fragment simulation projectiles (FSP) were fired from a Universal Test Gun System. This projectile is a 0.56 mm diameter cylinder with a blunt chisel shaped nose weighing 1.1 grams. At least 6 shots were fired at each target sample so that the arithmetic mean of 6 shots (3 complete penetration and 3 partial penetration velocities) can be calculated for the ballistic limit. The impact and residual velocities were measured using two pairs of shooting chronographs (CED Millennium), placed at the front and back of the target. The ballistic test set-up is shown in Fig. 1. A series of 2-, 4-, 6-, and 8-layer fabric samples were tested for ballistic resistance through combination and arrangement of neat and coated layers.

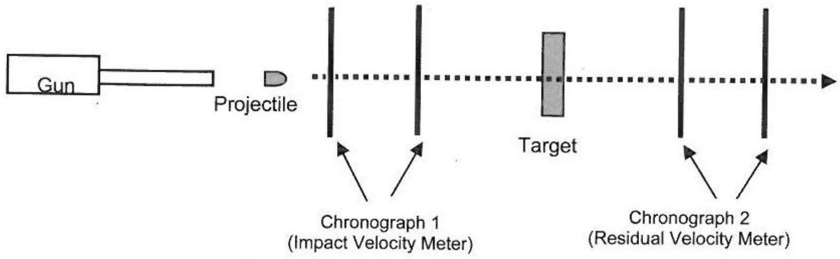

Figure 1. Ballistic impact test set-up

Results and Discussion

The ballistic results for the 2-, 4-, 6-, and 8-layer fabric systems are given in Table 1 and illustrated in Fig. 2 - 3. Except for the 2-layer fabric system, all other fabric systems with the combination of neat and coated fabric layers are arranged alternately (for example: neat layer/coated layer/neat layer/coated layer, for the 4-layer system). In general, the ballistic limit and energy absorption increases with higher number of fabric layers. For all systems, the combination of neat and NR coated layers gave higher ballistic impact resistance than the all-neat sample.

The ballistic limit and impact energy absorbed by the 2-layer coated fabric system was found to be higher than the neat system. For the 4-layer fabric systems, replacing two neat fabrics with two coated fabrics increase the energy absorption of the system by 58 % compared to the neat system. Although the combination of 2 neat and 2 coated fabrics have higher areal density than the neat fabric system, the increased in sample weight was not significant as compared to the specific energy absorption of the samples. The combined layer samples indicated above have higher specific energy absorption than the 4-neat fabric system as well as the 6-neat fabric system. This indicated a reduction of fabric layers for equivalent or higher ballistic impact performances.

Similarly, for the 6- and 8-layer fabric systems, combined layers of neat and coated fabrics gave higher ballistic impact performances. However, compared with the 4-layer fabric systems, the differences between the ballistic limits and energy absorption reduced with these respective fabric layers. Compared to the neat fabric system, there was only 18% and 14% difference in the energy absorption of the combined layers in the 6- and 8-layer fabric systems respectively. Thus, with higher number of fabric layers, the inclusion of NR coated fabric layers would reduce the specific energy absorption of the system due to the increased in the weight of the system.

Table 1. Ballistic results of multiple fabric layer systems

Fabric system	Ballistic Limit (m/sec)	Energy Absorption (J)	Fabric system density (g/m^2)	Specific Energy Absorption (J/g/cm^2)
2 Neat	149	12.2	404	302
2 Coated	190	19.9	676	295
4 Neat	200	22.0	808	272
2 Neat + 2 Coated	252	34.9	1078	324
6 Neat	241	31.9	1212	264
3 Neat + 3 Coated	261	37.5	1617	232
8 Neat	316	54.9	1616	340
4 Neat + 4 Coated	338	62.8	2160	291

The results obtained in this study supported previous studies on fabric coating and friction (Lee *et al.*, 2003; Tan *et al.*, 2005). It can be said that due to friction effects, the NR coated fabric layers help to increase the energy absorbed by the system. The NR coating would have restricted the movement of the yarns upon impact which would result in more yarns in each fabric layer to be involved. This effect has been shown to reduce the number of layers penetrated by the projectile at a certain impact velocity (Table 3). For the 4-layer fabric system, the fabric system is completely penetrated at impact velocity of about 209 m/sec. However, when 2 neat layers are substituted with 2 layers of coated fabrics, only the first layer is damaged when shot at about the same velocity. The projectile rebound from the system can also be said as partial penetration. Less number of penetrated fabric layers was also observed for the 6- and 8-layer fabric systems for about the same impact velocity with the respective neat fabric system.

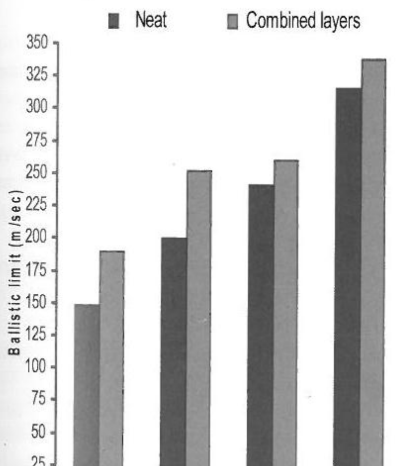

Figure 2. Ballistic limit of multiple layer fabric systems

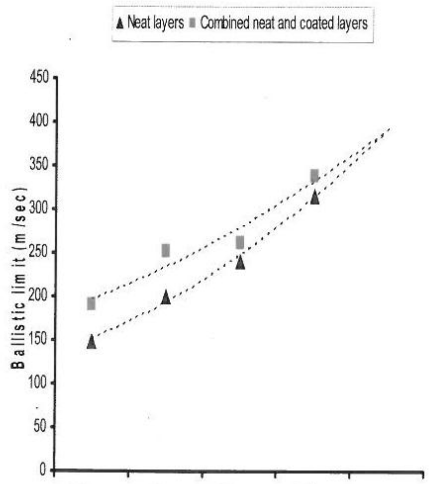

Figure 3. Impact energy absorption of multiple layer fabric systems

Table 2. Comparisons on number of penetrated layers in multiple layer fabric systems

Fabric system	Impact reference velocity (m/sec)	No. of penetrated layers	Remarks
4 neat	209	4	Complete penetration
2 Neat + 2 Coated	201	1	Projectile rebound
6 Neat	243	6	Complete penetration
3 Neat + 3 Coated	249	1	Projectile rebound
8 Neat	325	7	Projectile embedded in sample
4 Neat + 4 Coated	321	5	Projectile embedded in sample

Conclusion

This study was done to investigate the potential of NR, on high strength fabrics, for ballistic impact applications. It was found that in multiple layer fabric systems, the combination of neat and NR coated Twaron fabrics gave higher ballistic impact resistance than all-neat fabric systems. This shows the higher energy absorbed by the NR coated fabrics in the fabric systems. The coated fabrics also resulted in less number of layers penetrated by the projectiles.

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