A Flexible Laminate Composite based on Natural Rubber Wood Fibres

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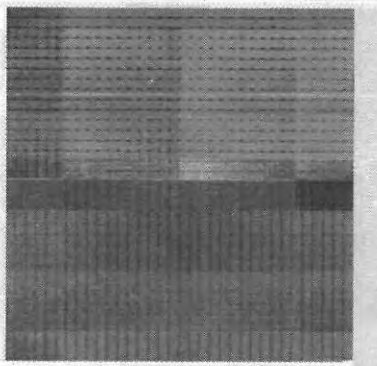
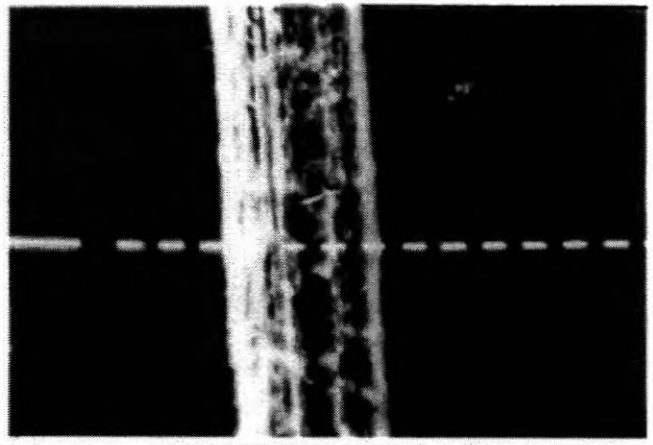
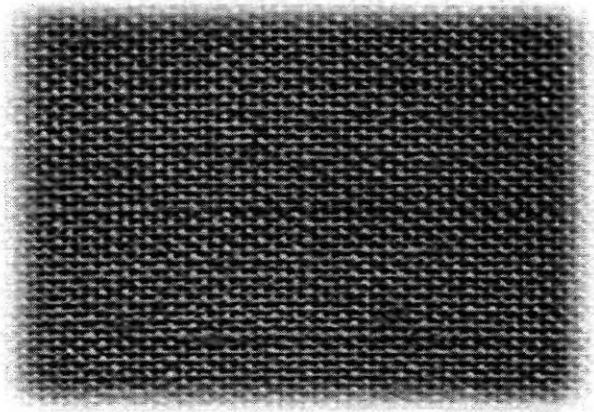


1. INTRODUCTION





1.1 Main Objectives

- To produce high impact strength, flexible composite materials (based on ≥70 wt % of 'green' and sustainable raw materials)

- To identify the most potential type of composite material (produced via lamination technique) for anti-stab body amour application.

1.2 Background

- Usage of natural fibres has increased recently due to lower cost if compared to synthetic ones (e.g. glass and polyaramid fibres).

- Natural fibres are also recyclable, light weight and have reasonable good strength.

- Natural fibres have comparable strength and modulus with glass fibres (but not as strong as polyaramid and carbon fibres).

Carbon > Polyaramid > Glass > Natural fibres

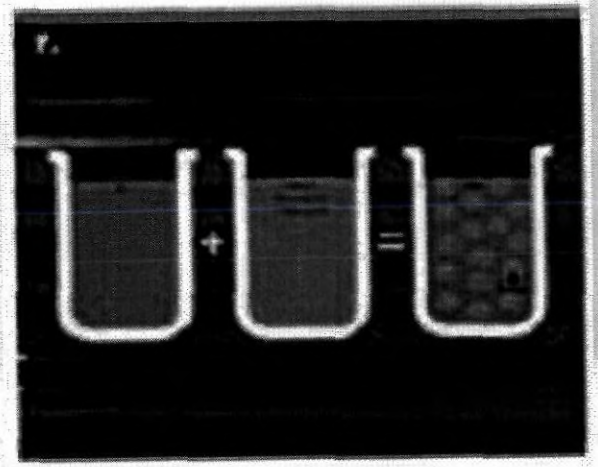
1.3 Prior Arts and Problems

❖ Lamination is a simple and highly practical technique to acquire high strength composite materials.

❖ Poor interfacial adhesion (between the rubber and fibre layers) is a major problem for preparing laminate composites.

❖ However, adhesion strength can be enhanced via using of a suitable adhesive system (to improve bonding strength between the rubber and fibre layers).

2. EXPERIMENTAL



2.1 Test Methodology

- Stab resistance test (US NIJ-Standard 0115.00).

- Adhesion strength studies via:
  - Shear failure test,
  - Solvent swelling test.

- Basic tensile properties (i.e. tensile strength & elongation at break %) test.

- Intersectional surface study by using scanning electron microscope.

2.2 Preparation of Test Samples

- Natural rubber (*Hevea Brasiliensis*) wood fibres were used.
- Cellulose content was 75.0 ± 5.0 wt %.
- Wetted fibres were compressed (5 tonnes) and dried sufficiently to produce fibre mats.

Example of Fibre Mat in Random Orientation

2.2 Preparation of Test Samples (cont……)

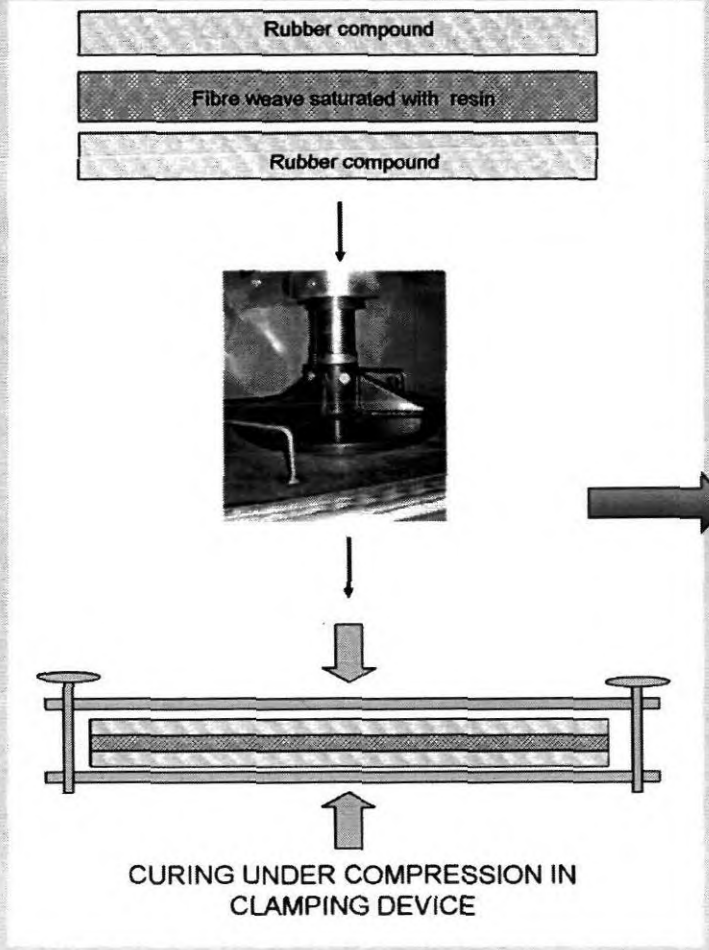
General Formulation of Rubber Compound used for laminating with Fibre Mat:

Raw Ingredient	Content (p.p.h.r.)
Natural rubber	100.0
Filler (Silica)	20.0
Sulfur	2.0
Accelerator	1.8
Activator	7.0

- An open mill was used to produce the rubber compound (sheet in 1 mm thickness)

2.2 Preparation of Test Samples (cont……)

❖ Natural rubber latex-lignin based adhesive system (in house grade) was used:



Numbers of alternate layer of different test sample:

Tensile and shear failure tests = 2 rubber layers + 1fibre layer

Stab resistance test = 6 rubber layers + 5 fibre layers

Flow of the Rubber-Fibre Composite Lamination

2.3 Measurement of Tensile Properties

- Test performed according to BS ISO standard.

- Each test piece consisted of one layer of fibre sandwiched by two layers of rubber compound (total thickness, ~3 mm).

- Six test pieces were used to repeat each measurement in order to obtain the mean value.

2.4 Determination of Adhesion Strength

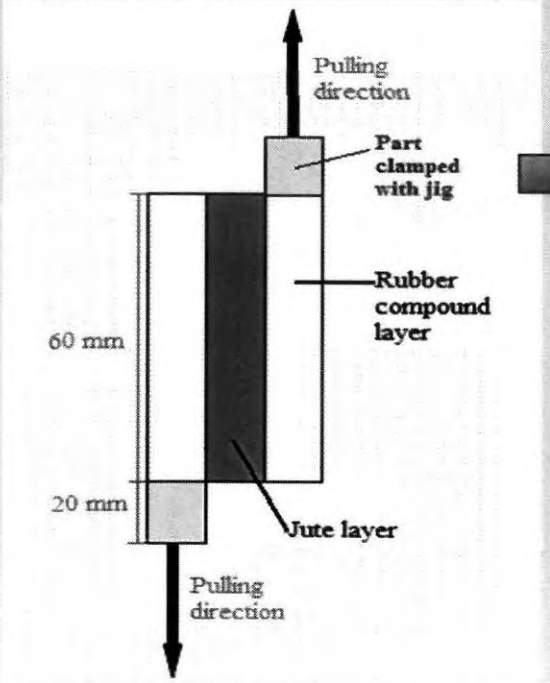
- For the solvent (toluene) swelling test:
  - Cylindrical shaped test piece (diameter 22 mm x thickness 11 mm) used,
  - 5 test pieces repeated to obtain mean degree of volume swelling % (at 23°C for 72hr),
  - The degree of volume swelling % (Q%) was calculated using the following equation:

$$Q\% = [(W1-W2)/W2] \times 100$$

Where; W1 is the weight of sample after swelling (gram) and W2 is the weight of sample before swelling (gram).

2.4 Determination of Adhesion Strength (cont……)

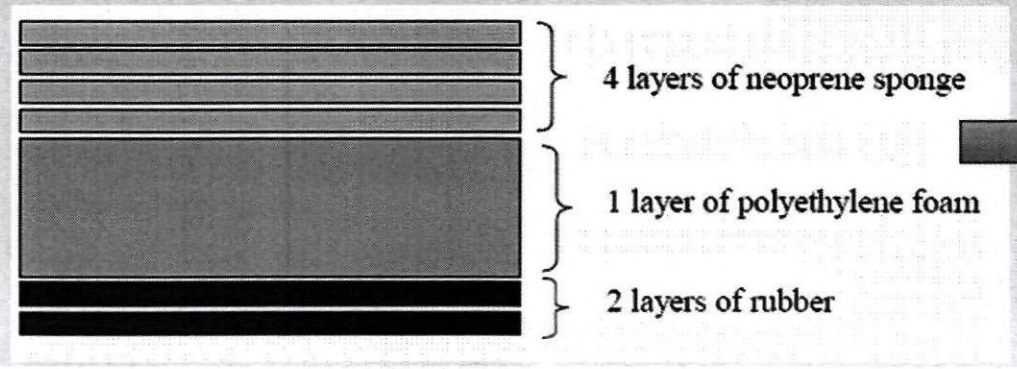
- For shear failure test:
  - A tensile machine used,
  - 5 test pieces repeated to obtain mean value,
  - Same test piece as used for tensile properties measurement,
  - Shear strength at full delamination occurred was recorded.



A Simple Schematic of Shear Failure Test for Laminate Composite

2.5 Stab Resistance Test

- Compiled with US NIJ-Standard 0115.00.
- A backing material (neoprene + PE foam + rubber) was used for each test.
- Two different protection classes, i.e. 'edged blade' (P1 knife & S1 knife) and 'spike'.
- Three different threat levels, i.e. level I (24 joules), level II (33 joules) and level III (43 joules).



Construction of Backing Material

2.5 Stab Resistance Test (cont……)

Stab resistance test series for 'edged blade' and 'spike' protection classes:

Number of test	Angle of incidence	Threat weapon
1	0°	P1 knife blade
1	0°	S1 knife blade
1	45°	P1 knife blade
1	45°	S1 knife blade
1	0°	Spike
1	45°	Spike

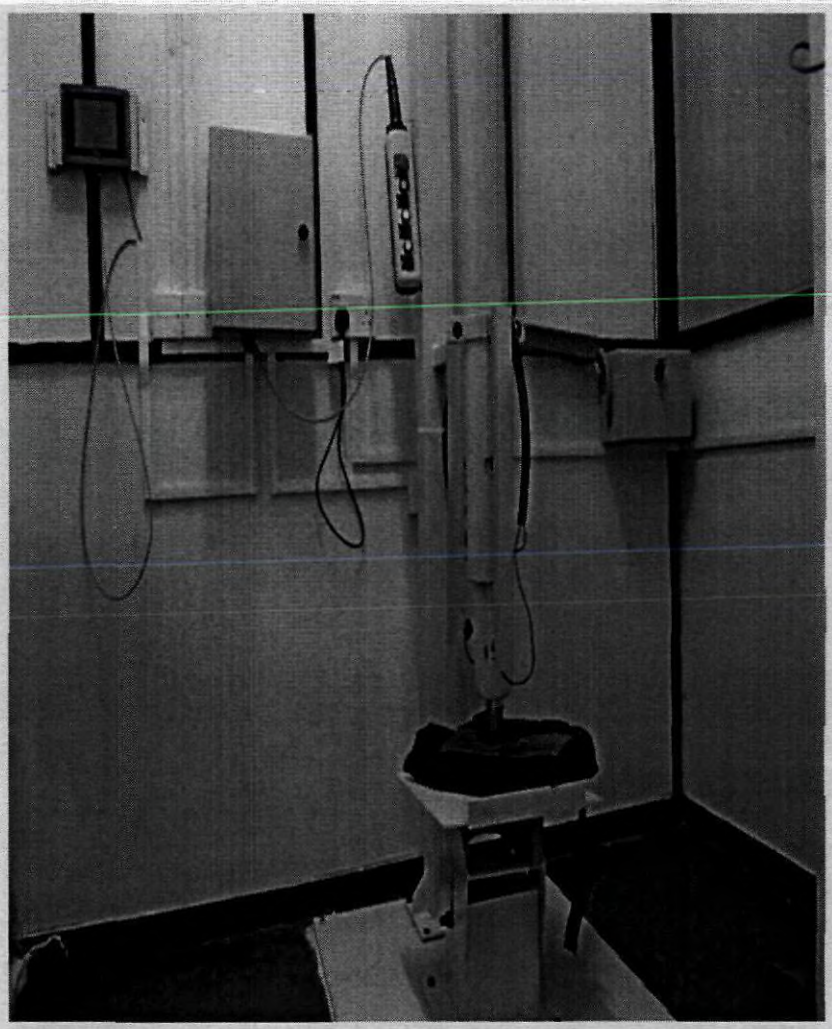
Test Passing Criteria:

≤ 7.0 mm of penetration depth for either 0° or 45° angle of incidence

4 duplications for 'edged blade' class

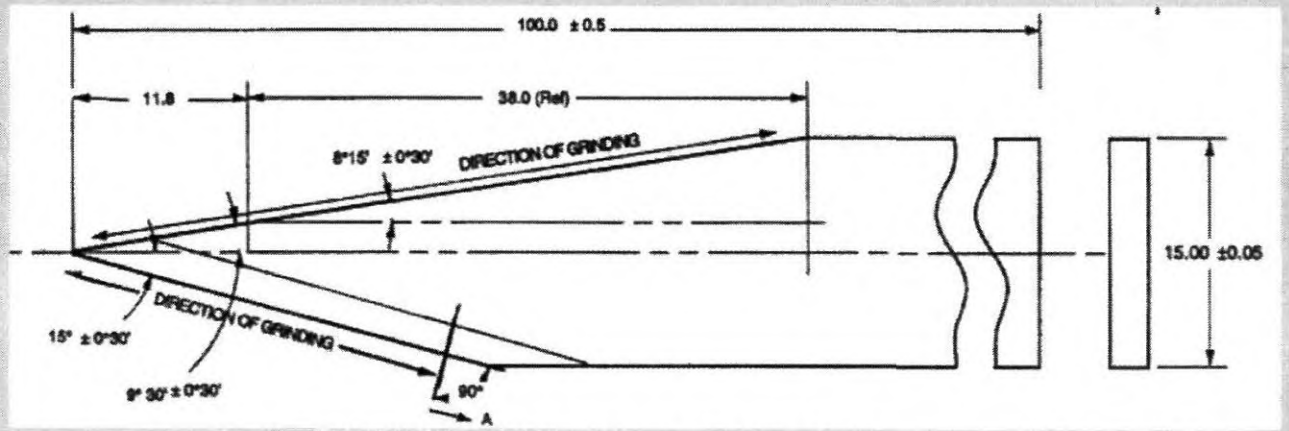
No duplication for 'spike' class

2.5 Stab Resistance Test (cont……)

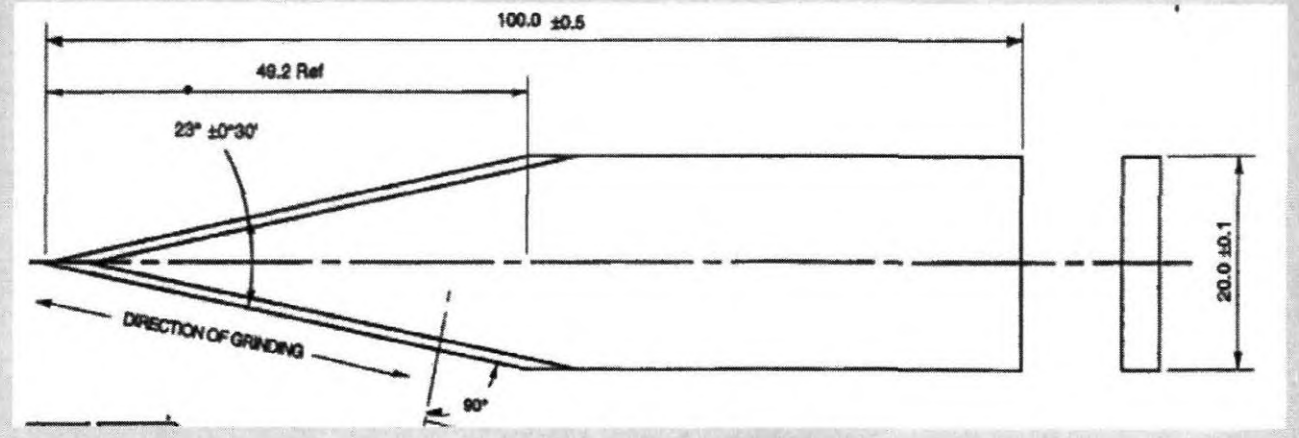


An US NIJ-Standard complied Stab Resistance Testing Machine developed by MRB

2.5 Stab Resistance Test (cont……)



P1 Knife Blade

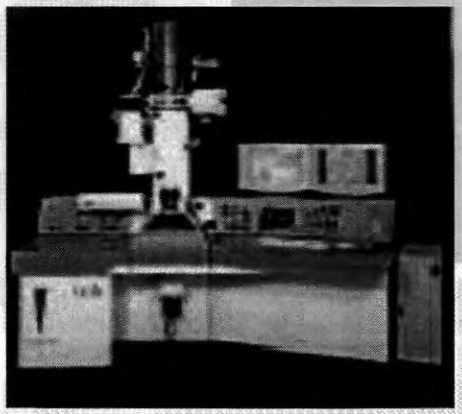


S1 Knife Blade

2.6 Microscopy Study

- A field emission scanning electron microscope (*FESEM*) was used (magnification = 100 times).
- All samples were nitrogen-frozen before fracture (without any prior coating) to obtain a perfect intersectional surface for the examination purpose.

3. RESULTS & DISCUSSION



3.1 Measurement of Tensile Properties

❖ High fibre loadings (~33.0 wt %) achieved via lamination technique contributed to tensile reinforcement of laminate composite.

Tensile Properties of Laminate Composite based on Natural Rubber Wood Fibres:

Tensile property	Mean value
Tensile strength	15.6 ± 0.5 MPa
Elongation at break %	639.3 ± 50%
M100	10.7 ± 0.5 MPa
M300	12.5 ± 0.5 MPa

3.2 Determination of Adhesion Strength

❖ An increment of mass % value (mean = 10.6 ± 0.5) was recorded for all laminate test pieces.

❖ High shear strength at the full delamination (mean = 14.0 ± 0.5 MPa) was also observed for all laminate test pieces.

❖ A reasonably strong adhesion bonding was successfully achieved via the application of natural rubber latex-lignin based adhesive system.

3.3 Stab Resistance Test

Example Results of Stab Resistance Test for "Edged Blade" Protection Class (Energy Levels I-III) :

Energy Level	Angle of Incidence	Threat Weapon	Penetration Depth (mm)	Pass/ Fail
I	0°	P1	3.4	Pass
	0°	S1	4.1	Pass
	45°	P1	3.7	Pass
	45°	S1	4.5	Pass
II	0°	P1	4.9	Pass
	0°	S1	5.4	Pass
	45°	P1	5.1	Pass
	45°	S1	5.8	Pass
III	0°	P1	7.2	Fail
	0°	S1	7.5	Fail
	45°	P1	7.9	Fail
	45°	S1	8.1	Fail

100% pass for levels I & II only

3.3 Stab Resistance Test (cont……)

Stab Resistance Test Results for "Spike*" Protection Class (Energy Levels I-III)

Energy Level	Angle of Incidence	Threat Weapon	Penetration Depth (mm)	Pass/ Fail
I	0°	Spike	6.0	Pass
	45°	Spike	7.2	Fail
II	0°	Spike	7.3	Fail
	45°	Spike	8.1	Fail
III	0°	Spike	9.0	Fail
	45°	Spike	9.8	Fail

100% failure for levels II & III

****Spike simulated an extreme sharp and pointed weapon attack***

3.4 Microscopy Study

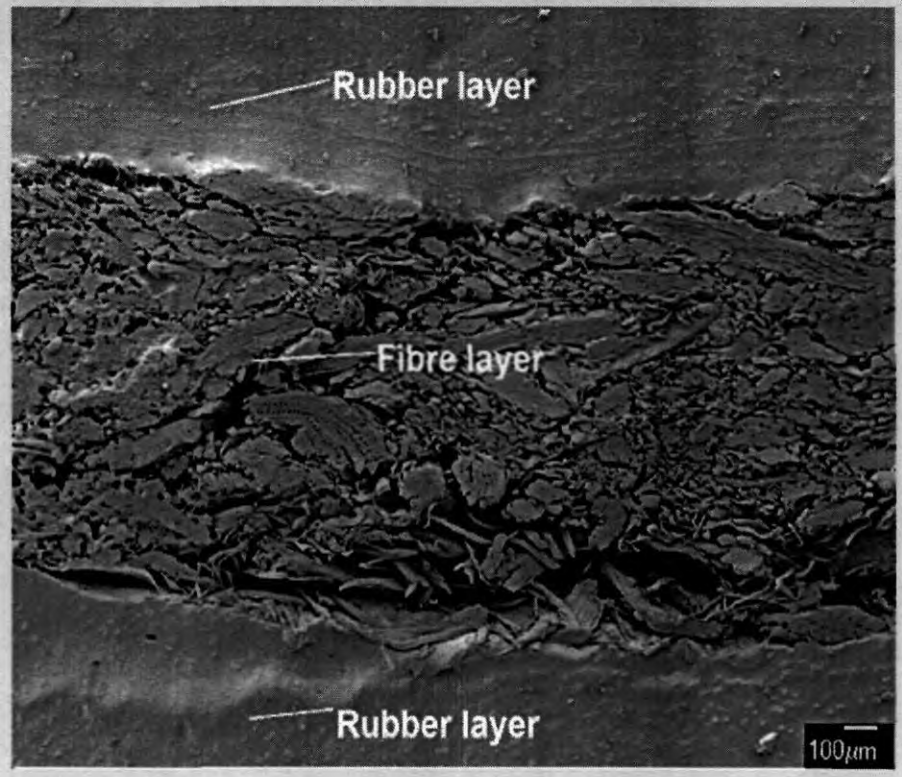
- All laminated samples exhibited compact and highly interacted rubber wood fibre layers in a random orientation.

- It is due to the high compatibility between rubber wood fibres and the applied adhesive system.

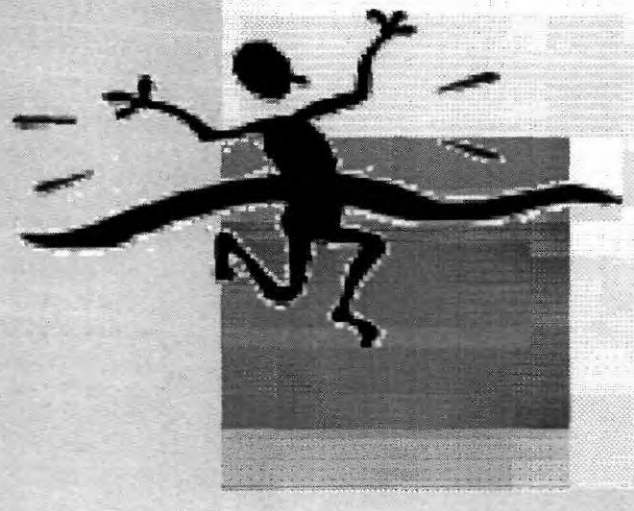
- This kind of structure could also enhance the tensile properties as discussed before.

3.4 Microscopy Study (cont……)

An Example of Intersectional Surface Micrograph of Laminate Composite based on Natural Rubber Wood Fibres:



4. CONCLUSION



4.1 Overall Conclusion

❖ Composites based on natural rubber wood fibre were successfully produced via the simple yet practical lamination technique.

❖ It exhibited high flexibility and good adhesion strength (with the application of natural rubber latex-lignin based adhesive system).

❖ It showed medium level of stab resistance strength (particularly for 'edged blade' protection class).

❖ Good commercial potential for the anti-stab body-armour application.

Related Publications and Patent

1. Malaysian Patent Pending (*Application No.: PI 2013002984*).

2. Journal of Rubber Research, *Volume 17(1), pg. 1-12.*

3. Polymer and Polymer Composites, *Volume 22(4), Article in press.*

Acknowledgement

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Thank you for your attention

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