
Proceedings Paper:

Gabriel, S, Chung Kim Yuen, S, Langdon, GS orcid.org/0000-0002-0396-9787 et al. (1 more author) (2022) Blast behaviour of natural fibre composites: Response of medium density fibreboard and flax fibre reinforced laminates. In: Zingoni, A., (ed.) Current Perspectives and New Directions in Mechanics, Modelling and Design of Structural Systems. Eighth International Conference on Structural Engineering, Mechanics and Computation, 05-07 Sep 2022, Cape Town, South Africa. CRC Press , pp. 201-202. ISBN 9781003348450

https://doi.org/10.1201/9781003348450-94

This is an Accepted Manuscript of a book chapter published by CRC Press in Current Perspectives and New Directions in Mechanics, Modelling and Design of Structural Systems on 5 September 2022, available online: http://www.crcpress.com/9781003348450

Blast behaviour of natural fibre composites: Response of medium density fibreboard and flax fibre reinforced laminates

S. Gabriel, S. Chung Kim Yuen
Blast and Impact Survivability Research Unit (BISRU), Department of Mechanical Engineering, University of Cape Town, Rondebosch, 7700, South Africa

G.S. Langdon
Department of Civil and Structural Engineering, University of Sheffield, Sheffield, S1 3JD, UK

C.J. von Klemperer
Department of Mechanical Engineering, University of Cape Town, Rondebosch, 7700, South Africa

ABSTRACT: Natural fibres are increasingly being used in the development of fibre reinforced polymer biocomposites for a range of applications, including construction. Additionally, medium density fibreboard (MDF) is a popular processed wood product, ideal for buildings and furniture. The interest in these materials is mainly because of their renewability, biodegradability, and low cost (compared to some synthetic counterparts). With their growing popularity, these materials could be exposed to a possible blast threat during their time of use. Thus, this study focuses on the effect to two natural fibre composites, namely medium density fibreboard and flax fibre reinforced epoxy composites, to air blast loading in order to understand the failure modes and failure progression of these materials. The use of an analytical model allowed the initial estimation of the required charge mass ranges. PE4 explosive charge masses between 2 to 11 g were moulded into cylindrical charges and placed at a constant standoff distance of 200 mm away, to generate a spatially uniform blast load onto the exposed area of the specimen. The transient deformation of the specimens was captured using high speed Digital Image Correlation. Through-thickness cracking was observed on the flax fibre reinforced composites, whereas in-plane cracking was found on the medium density fibreboards. Fragmentation also occurred in the medium density fibreboards which did not occur in the flax fibre reinforced composites within the charge mass range tested. The transient response of the specimens for both materials was elastic, with an initial steep rise in displacement followed by viscously damped oscillations.

1 INTRODUCTION

With growing concerns on sustainability and sustainable products, interest has been shown for materials based on bio-resins and plant fibres due to their favourable environmental impacts over synthetic materials (Bismarck et al., 2005). Additionally, natural fibres in particular have many advantages due to their biodegradability, abundance, availability, and low cost (Thiruchitrambalam et al., 2010). The use of natural fibres (such as flax, jute and other wood fibres) is extensively found in the production of composites for automotive interior linings, furniture, construction, packaging, and other applications (Luhar et al., 2020, Peças et al., 2018, Pickering et al., 2016). As popularity and usage of plant-based materials increases, so does the likelihood of the materials being exposed to a blast event. The effects of blast on structures and life can lead to devasting consequences. Yet, little is known on the blast resistant behaviour of natural fibre composites making it difficult to predict the associated costs and potential benefits in blast scenarios. Therefore, this paper reports the results of an experimental study on medium density fibreboard (a widely used wood composite) and flax fibre reinforced composite panels subjected to air-blast loading.

2 MATERIALS

Flax fibre was selected as a textile reinforcement along with epoxy to make a fibre reinforced polymer (FRP) panel suitable for experimental blast testing. The FRPs were manufactured using the vacuum assisted resin transfer method. A medium density fibreboard (MDF), of a similar mass to the flax FRP, was selected to be tested.

2.1 *Flax fibre*

Flax fibre reinforced composites have the potential for a wide range usage in maritime and automotive applications. A sized, balanced twill weave 550 g/m^2 flax fabric, produced by Lineo Belgium Limited (Lineo, 2010), was used. Nine layers of the fabric were required to manufacture a ~10 mm thick blast panel.

2.2 *Medium Density Fibreboard*

16 mm thick MDF, density 780 kg/m3, was purchased and cut to size using a router. The nominal composition of Supawood MDF is 82–84% wood, 8–10% UF resin, 5–8% water and a small quantity of paraffin wax (P. G. Bison, 2016).

2.3 *Prime 20 LV Epoxy Resin*

Prime 20LV is a marine grade epoxy infusion system manufactured by Gurit (Gurit, 2013). With its very low viscosity properties and long working times, this product is ideal for large panel infusions (Gurit, 2013). This resin system has been used in previous studies (Langdon et al., 2017, Langdon et al., 2018), giving consistent properties in the infused parts

3 MATERIAL PROPERTIES

Quasi-static tests were conducted to characterise the materials. These tests included flexural, tensile and, for the MDF only, through thickness testing. A results summary is shown in Table 1.

Table 1. Properties of the composites based on the quasi-static tests performed.

Property	Flax fibre reinforced epoxy	Supawood MDF
Flexural strength (MPa)	112	30
Effective flexural modulus (GPa)	6.3	27.6
Flexural strain at failure (mm/mm)	0.030	0.017
Tensile strength (MPa)	65 (0/90°); 40 (45°)	17
Elastic modulus (GPa)	4.3 (0/90°); 3.8 (45°)	2.7
Tensile strain at failure (mm/mm)	0.025 (0/90°); 0.022 (45°)	0.010
Internal properties	~	0.38 MPa (tensile) 115.5 MPa (comp)

3.1 *Flexural Properties*

Quasi-static flexural tests were performed in accordance with ASTM 7284 (ASTM International, 2015) where tests were performed on rectangular strips at a constant crosshead speed of 3 mm/min, a width: thickness ratio of 13:4 and a span: thickness ratio of 16:1. A primary concern for these tests was to confirm the manufacturing consistency as specimens were cut from the same large, manufactured composite panel for the blast panels. The results for each test series were considered consistent, confirming the regularity of the manufactured specimens and suitability for blast testing.

3.2 *Tensile Properties*

Quasi-static, in-plane, tensile tests were performed following the procedure in ASTM D 3039 (ASTM International, 2014), with specimens of 25 mm nominal width, 250 mm nominal length, and a 2.5 mm nominal thickness. Tensile tests were performed on specimens with their longitudinal axis at 0°, 45° and 90° relative to the woven fabric warp direction (or in the case of MDF, edge of the larger panel). The crosshead speed was kept constant at 1 mm/min and at least five tests per orientation were performed.

For the flax FRP, there were minimal differences between the 0/90° orientations, however the 45° orientation specimens exhibited greater ductility, lower elastic moduli and lower ultimate tensile strength. There were minimal differences in the between the different orientations tested for the MDF, hence a single averaged value was reported and presented in Table 1.

3.3 *Through thickness testing for MDF*

Both through thickness tensile and compression testing was conducted on the MDF to characterise the internal bonding of the material. SANS 6016 (South African National Standard, 2009) specification was used as a basis for the test procedures and geometries. As expected, the transverse strength was far greater in compression than tension. The low internal tensile bond strength could likely be attributed to the low-density structure of the material. Additionally, it appeared that the tensile failure occurred at the bond.

4 BLAST EXPERIMENTAL DESIGN

Blast tests were conducted to impart spatially uniform blast loads across the front faces of the panels. Using a horizontal ballistic pendulum, the blast impulse was inferred from its swing. A clamping frame, including a square tube, mounted onto the pendulum, was used to secure the panels, and directed a blast load uniformly onto the specimen. The size of the panels was 300 mm by 300 mm with an exposed area of 200 mm by 200 mm. Small quantities of plastic explosive PE4 were shaped into 20 mm diameter cylindrical discs and detonated at the other end of the clamping tube. Digital image correlation (DIC) was used on selected tests to obtain transient data that were recorded using two high speed cameras. A schematic of the blast test arrangement is shown in Figure 1.

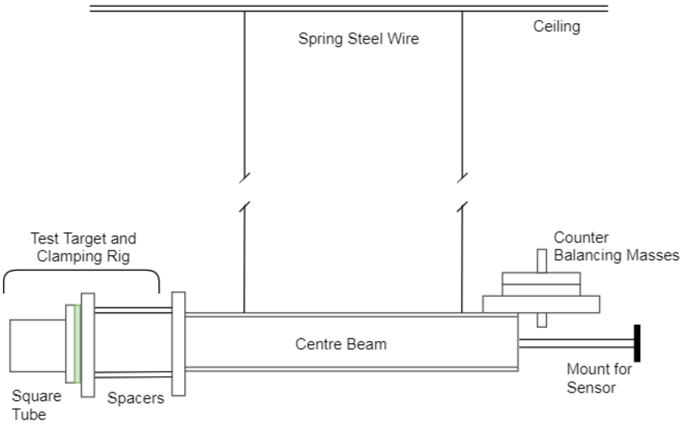


Figure 1. Schematic of the blast test arrangement showing the ballistic pendulum set up

Prior to testing, basic numerical ¼ symmetry computational simulations were used to help define design parameters and determine the approximate charge mass ranges for the different materials. The multi-material arbitrary Lagrangian-Eulerian (MMALE) approach was adopted on a geometry described in Figure 2. Only the exposed area of the panel was modelled while the clamped boundary was approximated by fully fixing the nodes along the appropriate edges. It was found that the charge mass limit for the composites would be around 10 g.

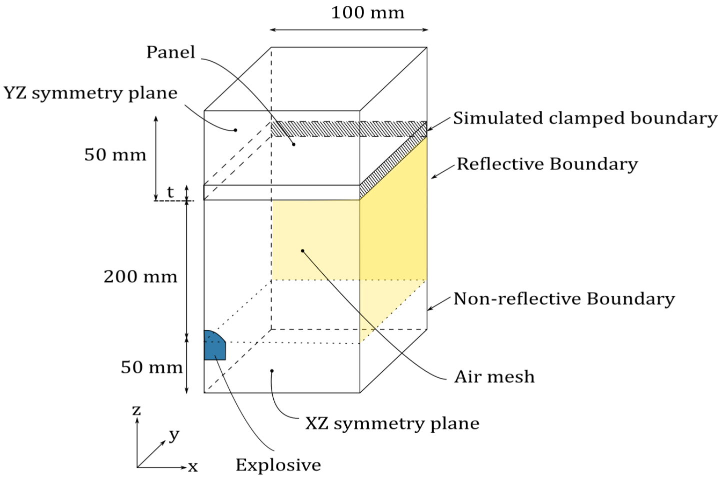


Figure 2. Schematic of basic geometry in mm of a panel subjected to an explosive detonation (where t = panel thickness; for flax FRP t = 10 mm, for MDF t = 16 mm).

5 RESULTS AND DISCUSSION

A summary of the blast results is shown in Table 2. Five (three for flax FRPs and two for MDF) of the experiments used the high-speed imaging system to obtain the transient response. For the MDF panels, the charge diameter was reduced to 20 mm for most of the experiments to allow for smaller charge detonations. A generally linear relationship was observed between the charge mass and calculated impulse as shown in Figure 3.

Table 2. Summary of the uniform blast test parameters and impulse.

	Flax FRP	MDF
Number of tests	5	9
Average thickness (mm)	10.06	16.14
Charge mass range (g)	5 - 11	2 - 4.5 (20 mm φ) 3.5 - 6 (30 mm φ)
Impulse range (Ns)	19.5 – 39.5	10.4 - 19.5 (20 mm φ) 17.2 - 20 (30 mm φ)

5.1 *Transient Response*

Images were taken from a central strip across the panel and displacements tracked optically. From these images, the mid-point displacement time history and horizontal mid-plane deformed profile evolution over time were generated using DIC.

The transient midpoint deflection time history for the flax fibre reinforced composite panels are shown in Figure 4. Peak displacements were found to be up to five times greater than the final deflection measured after testing. Viscously damped harmonic vibration behaviour was observed. A similar behaviour was observed for the MDF panels. At large enough deflections, cracks would form and cause decorrelation results in a loss of information.

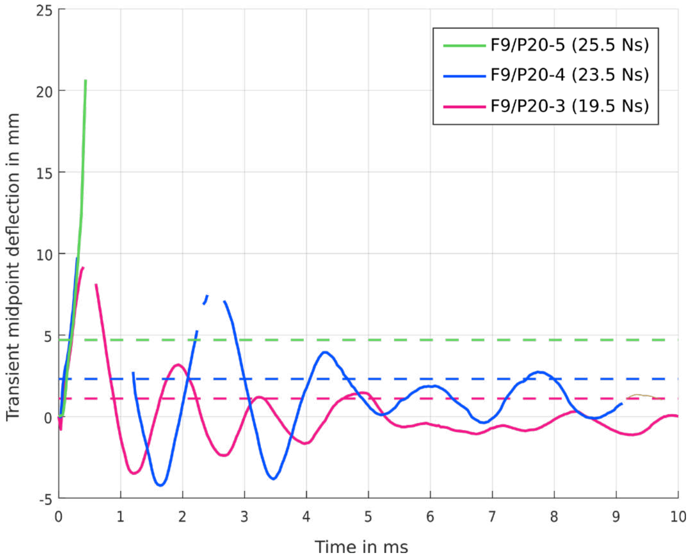


Figure 4. Midpoint deflection time history for flax fibre reinforced composite panels

The transient displacement profiles for a flax fibre reinforced composite and MDF panel shown in Figures 5 a and b. Prior to any significant damage occurring, dome-shaped profiles were observed However, after the damage (cracking) occurred, the profile deviates from the dome-shape and the sides appear to be straighter and revert as the crack closes.

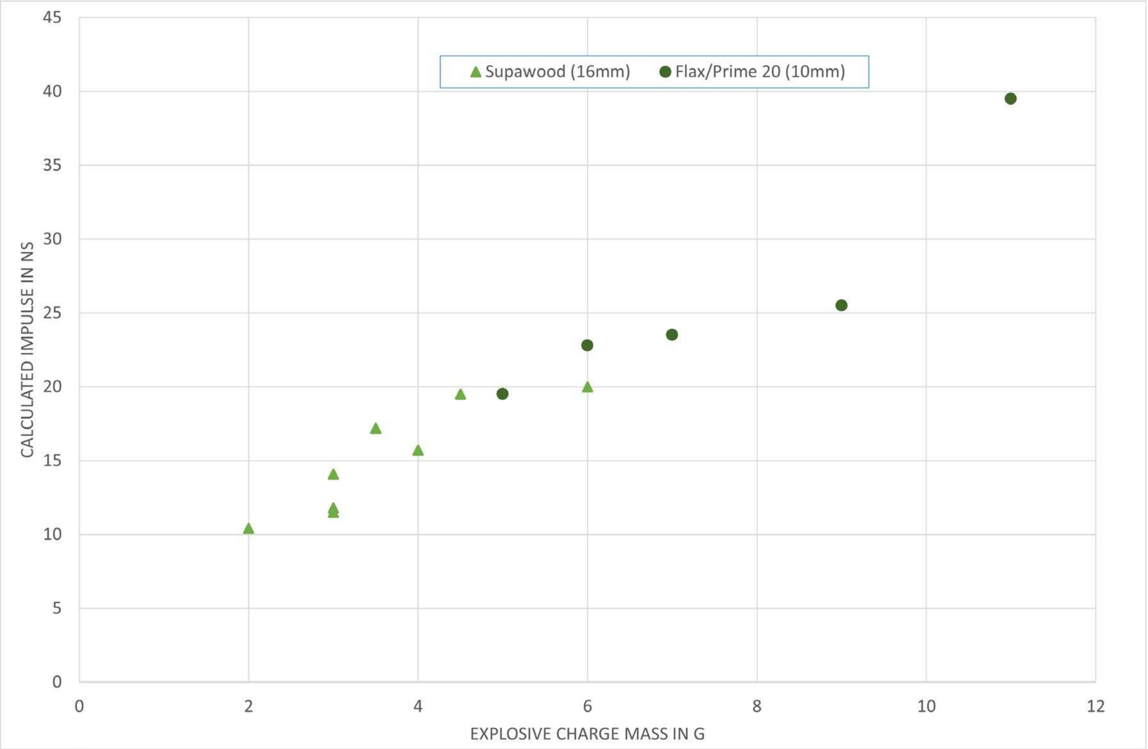


Figure 3. Graph of charge mass vs impulse for the blast tests

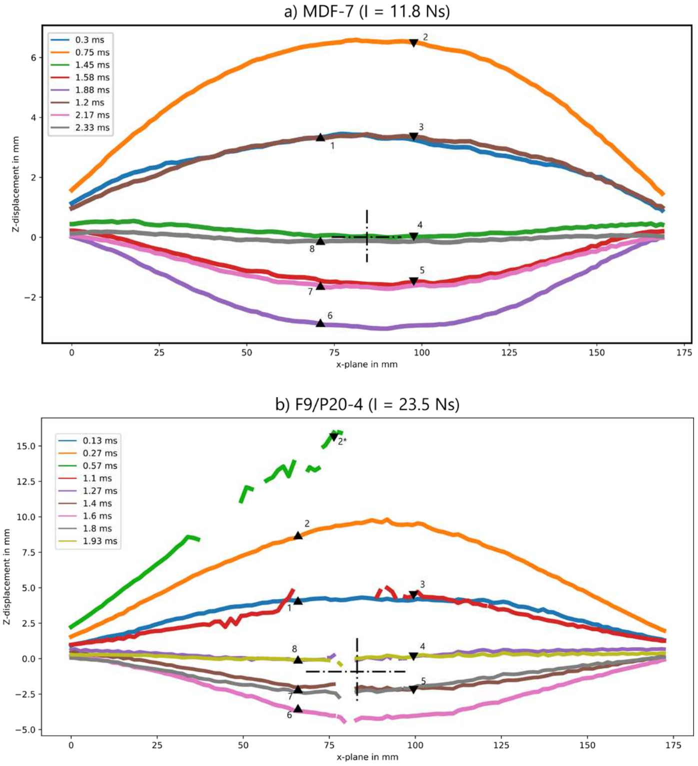
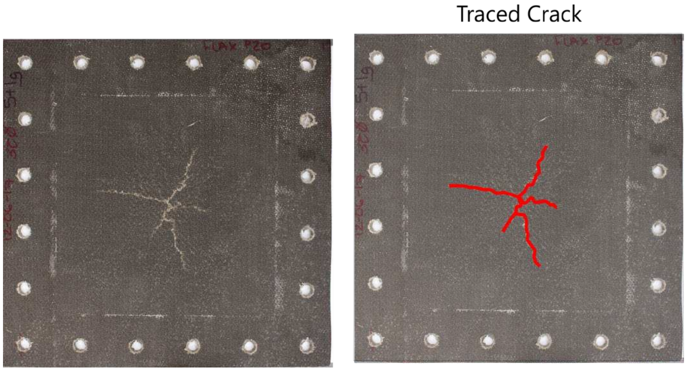


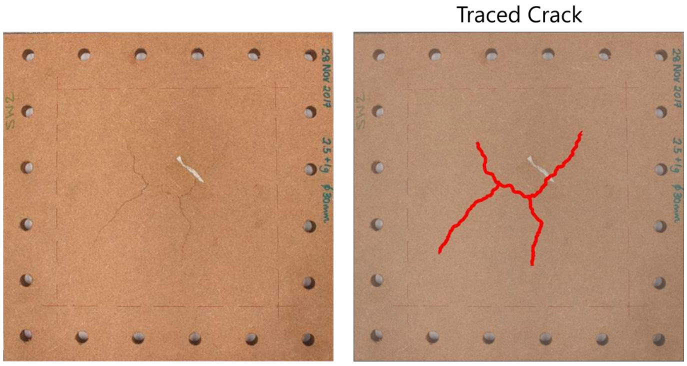
Figure 5: Midline displacement profiles for: a) MDF panel and b) flax FRP panel

5.2 *Surface and cross-sectional damage*

Inelastic deformation, in the form of cracking and permanent deflection, occurred on the blast loaded flax fibre reinforced composite and MDF panels. On both panels, cracks (typically only found on the back face) appeared to propagate from the centre of the panel towards the boundary. Images of the back surfaces for each type of blast loaded panel are shown in Figure 6. At an impulse of 20 Ns, an MDF panel was completely breeched, and fragmentation had occurred. It seemed at the 39.5 Ns, extensive cracks occurred on the flax fibre reinforced panel and that at a slightly higher impulse, fragmentation would likely occur as well.



a) Flax FRP, I = 22.8 Ns

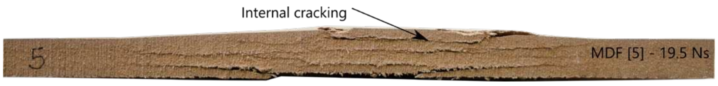


b) MDF, I = 17.2 Ns

Figure 6. Photographs of the back surface of blast tested panels

Through-thickness cracking was observed on the flax fibre reinforced composites, whereas in-plane cracking was found on the MDFs as shown in Figure 7 a and b respectively.

a) Flax panel, I = 39.5 Ns



b) MDF, I = 19.5 Ns

Figure 7. Photographs of the midline cross section of a) flax panel and b) MDF

6 CONCLUDING COMMENTS

The transient response and blast performance of flax fibre reinforced composite and MDF panel was investigated through a series of small-scale, carefully controlled explosive detonation experiments in air.

The MDF exhibited poorer blast resistance compared to the flax fibre reinforced composite which was consistent with its relatively low strength and ductility found in quasi-static tests. Cracking and fragmentation were found to be the main sources of damage. Transient measurements showed that the panels oscillated in a viscously elastic manner. Damage would, however, change the profile of the panels from a dome-to a more conical shape. While both materials are relatively weak in offering blast resistance compared to glass and carbon fibre composites, there may be some potential to consider hybrid composites reinforced with flax fibre to provide a better and sustainable blast resistance.

7 REFERENCES

ASTM INTERNATIONAL 2014. D3039/D3039M-17 Standard test method for Tensile Properties of Polymer Matrix Composite Materials. West Conshohocken, PA.

ASTM INTERNATIONAL 2015. D7264/D7264M-15 Standard Test Method for Flexural Properties of Polymer Matrix Composite Materials. West Conshohocken, PA.

BISMARCK, A., MISHRA, S. & LAMPKE, T. 2005. Plant fibers as reinforcement for green composites. *Natural fibers, biopolymers, and biocomposites.* CRC Press.

GURIT 2013. Prime(TM) 20LV. Document number: PDS-PRIME20LV-13-1215. Available: https://www.gurit.com/-/media/Gurit/Datasheets/prime-20lv.pdf.

LANGDON, G. S., VON KLEMPERER, C. J., SINCLAIR, G. & GHOOR, I. 2017. Chapter 6 - Influence of Curvature and Load Direction on the Air-Blast Response of Singly Curved Glass Fiber Reinforced Epoxy Laminate and Sandwich Panels. *In:* MOURITZ, A. P. & RAJAPAKSE, Y. D. S. (eds.) *Explosion Blast Response of Composites.* Woodhead Publishing.

LANGDON, G. S., VON KLEMPERER, C. J., VOLSCHENK, G. F., VAN TONDER, T. & GOVENDER, R. A. 2018. The influence of interfacial bonding on the response of lightweight aluminium and glass fibre metal laminate panels subjected to air-blast loading. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science,* 232**,** 1402-1417.

LINEO 2010. LINEO - Flax Fabrics Technical Fabrics made of Flax Fibers. Mont Saint Aignon.

LUHAR, S., SUNTHARALINGAM, T., NAVARATNAM, S., LUHAR, I., THAMBOO, J., POOLOGANATHAN, K. & GATHEESHGAR, P. 2020. Sustainable and Renewable Bio-Based Natural Fibres and Its Application for 3D Printed Concrete: A Review. *Sustainability,* 12**,** 10485.

P. G. BISON 2016. Panel Products DATA SHEET | TECHNICAL DATA | SUPAWOOD. Boksburg. Available: https://www.pgbison.co.za/pdownloads.

PEÇAS, P., CARVALHO, H., SALMAN, H. & LEITE, M. 2018. Natural Fibre Composites and Their Applications: A Review. *Journal of Composites Science,* 2**,** 66-66.

PICKERING, K. L., EFENDY, M. G. A. & LE, T. M. 2016. A review of recent developments in natural fibre composites and their mechanical performance. *Composites Part A: Applied Science and Manufacturing,* 83**,** 98-112.

SOUTH AFRICAN NATIONAL STANDARD 2009. SANS 540-1: 2009 Fibreboard products Part 1 : Uncoated fibreboard. Groenkloof.

THIRUCHITRAMBALAM, M., ATHIJAYAMANI, A., SATHIYAMURTHY, S. & THAHEER, A. S. A. 2010. A review on the natural fiber-reinforced polymer composites for the development of roselle fiber-reinforced polyester composite. *Journal of Natural Fibers,* 7**,** 307-323.