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Preliminary Development of Laminated Nanocomposite from Nanocellulose-Kevlar for Military Application

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ABSTRACT. Generally, aramid fibre used in industries reportedly possesses high mechanical strength with high modulus, toughness and thermal stability. There is a high demand for eco-friendly, renewable and low cost materials. The demand also affects the production of Kevlar within Kevlar based industries. Previous studies found that cellulose has the capability to improve the performance of a composite. The objective of this study is to investigate the mechanical strength of cellulose micro or nano fibres (CMNF) in laminate cellulose or Kevlar reinforced epoxy resins. The composite material was fabricated manually using hand lay-up technique. The nanocomposite laminates were made using plain fibre (Kevlar 29). The laminates contained a minimum of 80% fibre with 1 wt.% CMNF powder loading in an epoxy resin. Tests were conducted on two types of sample: Kevlar/Epoxy (KE), and Kevlar/CMNF/Epoxy (KEC). The laminated composite material was found to have the highest stress-strain in Kevlar/CMNF/Epoxy (KEC). The material strength and tensile behaviour of the two types of sample are different where KEC (559.34 MPa) > KE. This study is a part of the exploration on potential applications of laminated composite in military applications.

Keywords: *Kevlar 29, Kevlar 29 reinforced epoxy, Laminate composite, Nanocellulose;*

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1. INTRODUCTION

Aramid fibre is a synthetic polyamide made up by the linkage of an amino group of one molecule and a carboxylic acid group of another. Nylon is an example of many synthetic fibres available in the market. Aramid is a super strong material which can stop bullets and knives from going through. The strength of aramid is five times stronger than steel at the same weight. Technically, aramid fibres are long-chain synthetic polyamides. These fibres have extremely high tensile strength, which is why they are commonly used in armor and ballistic protection applications.

Generally, aramid is mostly used in composite material form. It is mostly applied in the production of products such as sports equipment, vehicle parts, building materials, safety apparatus and military equipment. The various composite materials can be classified using several methods based on their usage. Several studies that focused on the type of composite materials have been conducted, such as the study on fibre-reinforced polymer composites, in which continuous thin Kevlar 29 as the aramid fibre are embedded in a polymer matrix [1]. The reinforcement is carried out to enhance the strength, stiffness, fatigue strength, resistance, or strength to weight ratio by incorporating strong and stiff fibres in a softer, more ductile matrix.

Based on previous studies, many researches were carried out on the usage of fibre reinforced polymer composite to improve the mechanical properties of the composite [2,3]. However, there is a lack of published information of cellulose reinforced fibre composites used in military applications. The objective of this paper is to uncover the mechanical properties of nanocellulose combined with Kevlar to be applied in the production of military helmet. In most of the previous studies, multiple layers of Kevlar were used in the helmet, making it heavy. The performance of the composite can be optimized and the behaviour of the sample can be enhanced using laminate or hybrid composites [4,5]. Hand lay up technique is used in the characterizations of the laminate. There are several studies available on the characterization of Kevlar or carbon combination fibre in sandwiched composite [6], cellulose nanofibres or epoxy composite [7], and woven jute or green epoxy composites [8]. Jabbar et al. [8] reported that nanocellulose has the potential in military applications because it can improve the performance of the composite thus increasing its mechanical properties.

2. MATERIALS AND METHODS

2.1 Materials. The materials employed in this study are nanocellulose prepared from rice straw (similar to our previous work [9]), Kevlar 29 fabrics and epoxy resin supplied by Oriental Option Sdn. Bhd. The cellulose and fabric used are shown in Figs. 1 and 2.

***Fig. 1** Cellulose from rice straw*

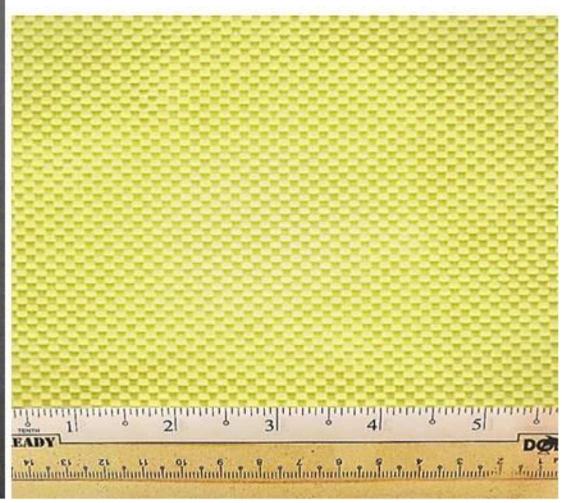


Fig. 2 Fabric of Kevlar 29

2.2 Preparation of Nanocellulose.

The micro or nano cellulose is extracted from rice straws which were collected from a local paddy field in Ulu Derdap, Perak, Malaysia. The rice straw sample is cut into small pieces of approximately 5 cm chips. The sample is weighed wet to ascertain its moisture content and dried in a vacuum oven at 30 °C for 24 hours. The extraction procedure involved swelling, acid hydrolysis, alkaline treatment and bleaching to obtain the final nano or micro cellulose.

2.3 ***Preparation of Nanocomposite Laminated Sample.*** The composite is prepared by hand lay up method. The polymer resin used is epoxy; the epoxy and hardener are mixed in a ratio of 2:1 by weight, according to the manufacturer's recommendations for hand lay up process. The nanocomposite laminate are made using plain fibre (Kevlar 29) and laminated with epoxy or nanocellulose matrix. The laminate comprised a minimum of 80% by weight of fibre and the nano or micro cellulose loading is 1 wt.%. The fabric is then cut into pieces of 200 mm x 200 mm in size to produce the composite laminate. The micro/nano cellulose are mixed with epoxy by using mechanical stirrer less than 1 hour before lay up at the fabric of Kevlar fibre. The laminated composite will hardened at least 24 hours.

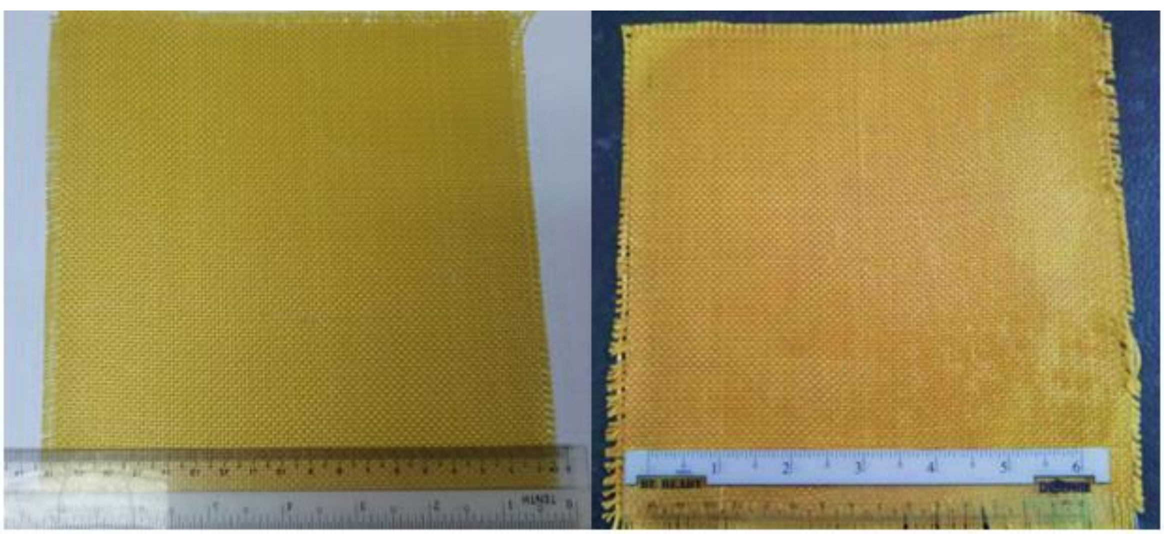
2.4 Tensile test setup.

Tensile test is performed following the ASTM D3039 test standard on a 160 mm x 25 mm x t (thickness of the laminate) sample, with a gauge length of 60 mm. The test is performed at a crosshead speed of 3 mm/min with 50 kN load. Five bone shaped samples are prepared for each composite laminates and each sample is tested in vertical direction.

3. RESULTS AND DISCUSSION

3.1 Laminated Composite. Two types of sample were prepared. The first type consists of Kevlar 29/Epoxy/micro-nanocellulose, and the second type is Kevlar 29/Epoxy, acting as a reference sample. The laminated composites are shown in Fig. 3.

3.2 Tensile test. The engineering stress-strain response of a material is shown in Fig. 4 and the tensile properties of the different composite laminates are given in Table 1 and Table 2. It showed that KE has lower tensile modulus compared to KEC. From the different types of composite laminate materials used, it was found that the composite reinforced with nanocellulose improved the strength of the laminate. It was proven in previous studies that even a minimal amount of cellulose is able to increase the mechanical performance of a composite [10].



(a) (b)

Fig. 3 Laminated composite (a) Kevlar 29/Epoxy composite and (b) Kevlar 29/Epoxy/Cellulose micro/nanocomposite

Table 1 Thickness of both fabricated composite laminates

Composite laminate	No. of layer	Thickness (mm)
Kevlar 29/Epoxy (KE)	1	0.44
Kevlar 29/Epoxy/1%CMNF(KEC)	1	0.46

Table 2 The mechanical strength of both fabricated composite laminates

Composite laminated	Tensile strength (MPa)	Elastic modulus (MPa)
KE	316.51	425.10
KEC	559.34	776.02

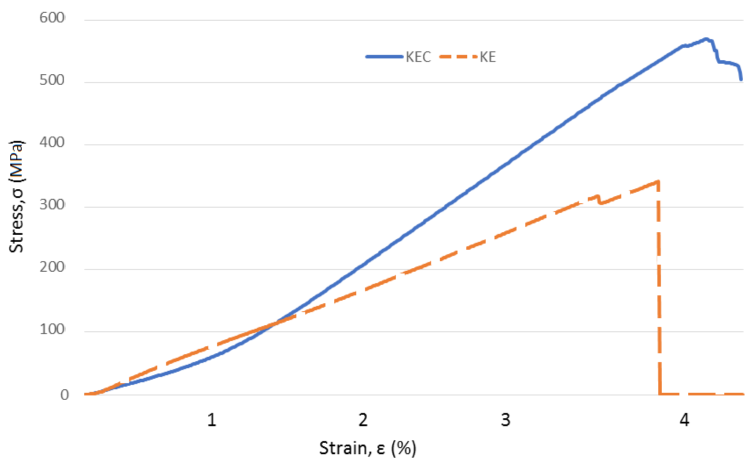


Fig. 4 The stress-strain curve composite laminates: Kevlar 29/Epoxy/micro-nanocellulose (KEC), and Kevlar 29/Epoxy (KE)The strength of various Kevlar 29 samples with varied composition matrix used in this study is shown in Table 2. It was observed from Fig. 4 that KEC showed the highest mechanical strength of 559.34 MPa tensile strength; and 776.02 MPa elongation at break. This is because the sample contained 1 wt. % of CMNF powder, which improved its strength compared to KE. By adding approximately 1 wt.% of CMNF powder in the KEC sample, the mechanical or tensile strength of the composite improved up to 559.34 MPa compared to the KE sample (without the addition of cellulose) with tensile strength value of 316.51 MPa. The tensile strength of the Kevlar 29 reinforced sample is 60% higher than non-reinforced samples. It is because of the CMNF powder as filler are fulfill the gaps between of the particles and fill in the porosity. From Table 2, it can be seen that laminated composite with CMNF has higher elasticity. It also shows the elastic modulus of KEC increased by 45% compared to the KE laminated composite.

In addition, the laminated composite materials can be differentiated by the crack length of its sample. The crack length of KE is 0.5 mm while KEC is 2.2 mm. Thus, it is proven that Kevlar 29 laminated composite reinforced resin can increase the time and displacement of the laminated composite crack.

Furthermore, for the nano or micro cellulose wt.% loading, the composite strength increases with decreasing particle size. Smaller particles have a higher total surface area for a given particle loading. This indicates that the strength increases with increasing surface area of the filled particles through a more efficient stress transfer mechanism.

4. SUMMARY

In conclusion, this study discovered that the inclusion of cellulose micro or nano fibres in laminated cellulose or Kevlar 29 reinforced epoxy improved the mechanical properties of laminate composite. This study explores the potential application of the laminated composite in high velocity impact applications. This research can also be directed to optimize the mechanical properties of the composite, making it higher in strength yet light in weight. The lay-up technique was used for the composite reinforcement sorting to obtain the most optimized result. In comparison with the other materials used, this research demonstrated the favorable potential usage of nanocellulose in a composite as the stress-strain result showed that it has improved the performance of the laminated composite.

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