VOL. 13, NO. 3, FEBRUARY 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

EXPERIMENTAL INVESTIGATION ON CHARPY IMPACT RESPONSE OF KENAF BAST FIBRE REINFORCED METAL LAMINATE SYSTEM

D. Sivakumar[1], S. Kathiravan[1], L. F. Ng[1], M. B. Ali[1], M. Z. Selamat[1], S. Sivaraos[2] and O. Bapokutty[1]
[1]Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Durian Tunggal, Melaka, Malaysia
[2]Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, Durian Tunggal, Melaka, Malaysia
E-Mail: sivakumard@utem.edu.my

ABSTRACT

Natural fibre triggers the researcher's interest due to its advantage over synthetic fibres as it is inexpensive and eco-friendly. The objectives of this study is to investigate the effect of fibre length, loading and chemical treatment of kenaf bast fibre reinforced polypropylene metal laminate under Charpy impact loading. The kenaf bast fibre loading of 50wt%, 60wt% and 70wt%, fibre length of 3 cm, 6 cm and 9 cm and chemical treatment of 0% and 5% NaOH are considered. Aluminium, 5052-O is employed as the skin for the composites in this research. The composite and FML were fabricated using hot compression moulding method. Specimens were extracted from the prepared FML panels using water jet cutter and tested in accordance to ASTM E-23 using INSTRON CEAST 9050 pendulum impact tester. The results show that the alkaline treated kenaf fibre with fibre loading 70wt% and length 9 cm absorbed the highest impact energy at 157.04 kJ/m^2 compared to other fibre metal laminate compositions.

Keywords: fibre metal laminate, impact strength, charpy impact test, kenaf bast fibre, natural fibre.

INTRODUCTION

Natural fibres have gained the attention of researchers and industries in the past decades due to their favourable characteristics compared to synthetic fibres as it is biodegradable and low cost. The increasing environmental concerns pressed the development of alternative materials to replace the conventional synthetic materials such as glass fibre and carbon fibre based composites. Therefore, natural fibre based composites were explored as they are environment - friendly and have high specific strength.

Kenaf (Hibiscus cannabinus) is a type of natural fibre originated from Africa which is now commercially grown in many countries such as Malaysia, Bangladesh, Thailand, United States and China. Kenaf fibres demonstrate the most potential among other natural fibres as reinforcement to utilise in designing engineering materials by replacing synthetic fibres. Kenaf fibres have low density and high strength to weight ratio which results in good performance for the structural application (Ng *et al*. 2017). Kenaf poses good flexibility which able to resist impact forces (Salman *et al*. 2017). However, kenaf fibres are not free from drawback such as the existence of hydrophilic nature. The presence of hydroxyl (-OH) group in the lignocellulosic fibre attracts moisture which may disrupt the fibre/matrix adhesion consequently lead to the poor mechanical performance of the composite. Several methods have been handed to reduce the water affinity such as fibre surface modification and using compatibiliser to the composite (Ramesh 2016). There have been a number of studies on thermoplastic based composite involving kenaf fibre as reinforcement that has been reported (Sameni *et al*. 2003; Thirmizir *et al.* 2011; Taib *et al*. 2014; Sivakumar *et al.* 2017; Sivakumar *et al.* 2017).

Poor damage tolerance of fibre reinforced polymers (FRP) and low fatigue strength of monolithic aluminium inspired researchers to the development of fibre metal laminates (FML) (Vogelesang & Vlot 2000). FML is a class of hybrid structure consisting of thin metal layers sandwiching fibre reinforced polymers as shown in Figure-1. Initially, Fokker Aero-structure of Netherlands found such laminate structure able to resist rapid crack growth efficiently than the conventional monolithic metals (Chai & Manikandan 2014). These bonded structures with a combination of composite and metal provide excellent impact damage tolerance as well fatigue strength while having a low weight. Vlot *et al.* (1999) found FML displays excellent damage threshold energies compare to the conventional composite and metals in an impact study.

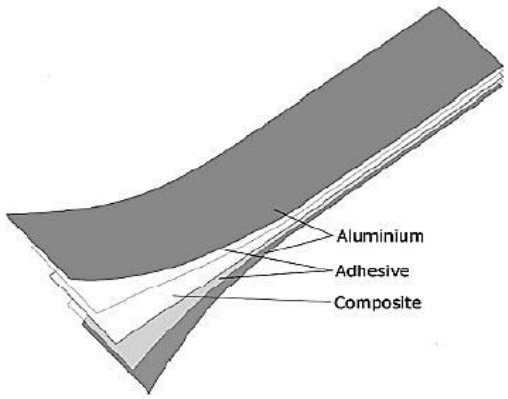


Figure-1. Illustration of a sample FML (Source: Dharmalingam *et al*. 2009).

Longer processing cycle to manufacture thermoset based FMLs increases the overall FML production cost. Thus, thermoplastic based FML are introduced which offers shorter processing cycle time which leads to low-cost production and with improved toughness (Morrow *et al*. 2010). A number of studies have been reported on natural fibre based thermoplastic FML in the past decades (Kuan *et al*. 2011; Sivakumar *et al*. 2016;

Sivakumar *et al*. 2017;Subramaniam*et al.* 2017; Ng *et al.* 2017; DharMalingam *et al.* 2017).

To date, only a few studies have been conducted to investigate the Charpy impact response of FML. Sivakumar *et al*. (2016) conducted a study to investigate the effect of fibre loading on the Charpy impact response of oil palm fibre based FMLs. The test was carried out on flatwise and edgewise orientation. It was found that the natural fibre FML able to absorb impact energy efficiency due to the layer by layer resistance towards impact where the aluminium and FRP resist the impact individually. In another study, Vieira *et al.* (2017) conducted a comparative Charpy impact assessment between composite and FML based on woven sisal fibre reinforced epoxy. The result shows that the FML can absorb impact energy up to 536% higher than the plain composite due to the higher modulus aluminium as skin. Farsani *et al*. (2014) also revealed similar outcome where the Charpy impact resistance of basalt fibre reinforced aluminium and steel is higher compared to the respective composites. This work will investigate the Charpy impact response of kenaf fibre reinforced polypropylene metal laminate. The effect of kenaf fibre loading, length and chemical treatment are evaluated under Charpy impact loading.

MATERIALS ANDMETHOD

Materials

Innovative PultrusionSdn. Bhd. supplied the kenaf bast fibre with a density of 1.4 g/m^3. The Polypropylene (PP) matrix with a density of 0.946 g/m^{3}was provided by Basell Asia Pacific Ltd, Malaysia. Aluminium alloy 5052-O with 0.5 mm thickness was used as the skin for the composite. The aluminium sheets were prepared to dimensions of 200 mm x 200 mm.

Composite fabrication

The treated kenaf fibres were prepared by soaking in 5% of Sodium Hydroxide (NaOH) solution at room temperature for 4 hours to remove the lignin, hemicellulose and other contaminants and to improve the interfacial bonding with the polymer. The treated fibres were filtered and washed out several times with tap water until the NaOH residues were removed. Then the treated fibres were dried overnight at room temperature and later dried in an oven at 40°C for 24 hours. The kenaf fibres were prepared with 3 different lengths which are 3cm, 6cm and 9cm. The PP was prepared into sheets with the size of 200mm × 200 mm × 1 mm (Length × Width × Thickness) by using compression moulding method. Kenaf random fibre mats were prepared by pressing the fibres for 2 minutes at temperature of 180°C according to the composition shown in Table-1. The composite assembly was prepared by stacking the fibre mats and PP sheets alternatively in a picture frame mould size of 200mm × 200 mm × 3 mm (Length × Width × Thickness). The assembly was subjected to compression moulding with preheating for 2 minutes at temperature 180°C. Later it was pressed at 5MPa while maintaining the temperature for 8 minutes and removed upon cooled to room temperature. The consistent thickness of kenaf fibre reinforced polypropylene composite was obtained as shown in Figure-2.

Figure-2. Randomly distributed kenaf fibre reinforced polypropylene composite.

FML Fabrication

The aluminium alloy 5052-O was mechanically roughen using sandpaper grit size 80 and later cleaned with ethanol. 2/1 configuration of kenaf fibre metal laminate (KFML) assembly was prepared by placing a kenaf fibre reinforced composite in between two aluminium alloy plates as shown in Figure-3. Modified PP adhesive film was placed in between the composite and metal interface. The prepared FML assembly was stacked in a picture frame mould of 200mm × 200 mm × 4 mm (Length × Width × Thickness) and undergoes hot compression moulding process at temperature 170°C and pressure 0.4 MPa for 10 minutes. The FML were removed upon reaching room temperature. Table-1 shows the code for the prepared KFML composition for this work.

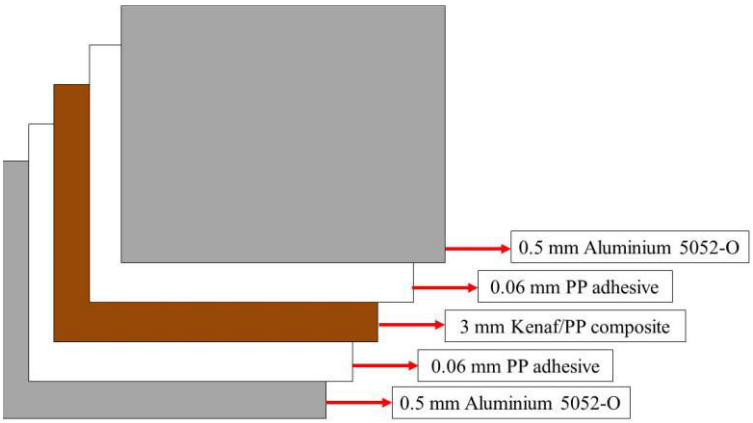


Figure-3. Stacking sequence of KFML.

Table-1. Fabricated KFML specification.

Specimen code	Fibre weight (%)	Fibre length (cm)	Fibre treatment
UT-50(3)	50	3	Untreated
UT-60(3)	60		
UT-70(3)	70		
UT-50(6)	50	6	
UT-60(6)	60		
UT-70(6)	70		
UT-50(9)	50	9	
UT-60(9)	60		
UT-70(9)	70		
T-50(3)	50	3	Treated
T-60(3)	60		
T-70(3)	70		
T-50(6)	50	6	
T-60(6)	60		
T-70(6)	70		
T-50(9)	50	9	
T-60(9)	60		
T-70(9)	70		

Experimental setup

The specimens for Charpy impact test was cut from the FML plates using water jet cutter in accordance to ASTM E-23. The impact properties of the KFMLs were calculated by using INSTRON CEAST 9050 pendulum impact tester. A 50 J Charpy hammer calibrated according to ASTM E-23 was employed to test the KFML specimens at an ambient temperature of (25± 3°C) and relative humidity of (30±2%). The KFML specimens were tested on flatwise orientation as shown in Figure-4. The impact test was repeated three times for each FML composition to obtain the average impact energy.

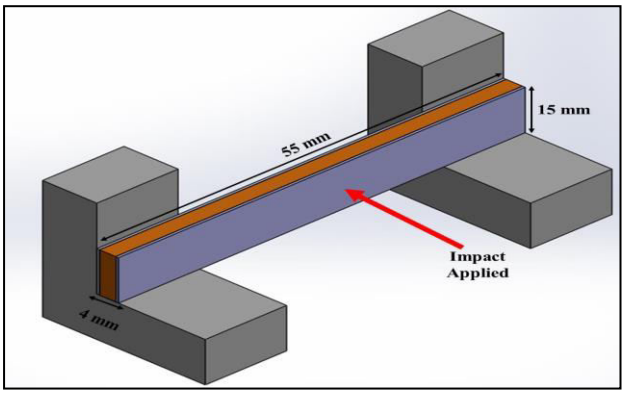
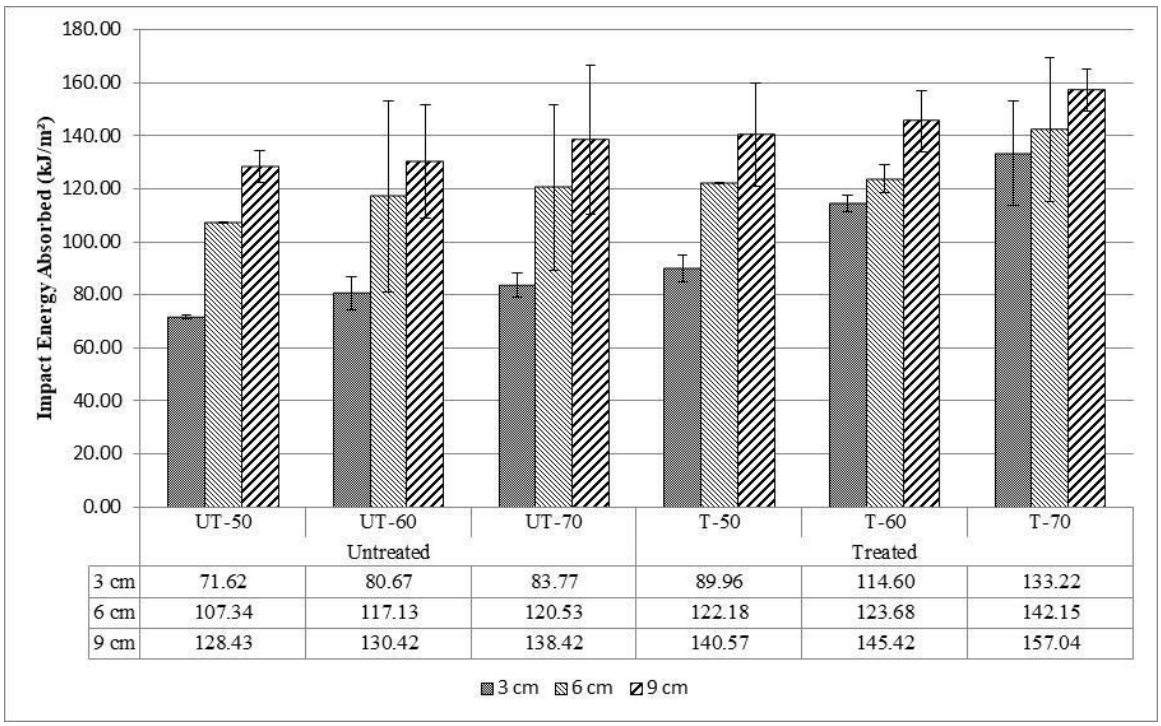


Figure-4. Schematic illustration of KFML specimen dimension at Flatwise impact orientation.

RESULTS AND DISCUSSIONS

Flatwise impact test

Figure-5 presents the average impact energy absorbed by the KFML specimens on flatwise orientation with different compositions. The impact energy absorbed by the KFML specimens were determined by dividing the total energy absorbed by the impacted cross-sectional area of FML. Overall, the impact energy absorbed by the KFMLs increases as the fibre length increases for both NaOH treated and untreated fibre. The impact energy absorbed by the untreated 50wt% fibre loading (UT-50) and NaOH treated 50wt% fibre loading (T-50) KFML exhibits an average increase of 25.6% and 9.4% respectively when the fibre length was increased from 3cm to 9 cm. It is evident that the impact energy absorbed by the shorter fibre length of KFML specimens decreases which may be due to the poor stress transfer by the short fibres upon impact. Shorter fibre tends to have higher number of fibre ends which act as crack initiation point that induces early fibre breakage results to the decrement in impact energy absorption of KFML (Farahani *et al.* 2012).



	UT-50	UT-60	UT-70	T-50	T-60	T-70
	Untreated			Treated		
3 cm	71.62	80.67	83.77	89.96	114.60	133.22
6 cm	107.34	117.13	120.53	122.18	123.68	142.15
9 cm	128.43	130.42	138.42	140.57	145.42	157.04

Figure-5. Comparison of impact energy absorbed at flatwise orientation.

The impact energy absorbed by the KFMLs with NaOH treated kenaf fibres is higher compared to untreated kenaf fibres regardless fibre length and loading. The impact energy absorbed by KFML with fibre loading 60wt%, NaOH-treated and 9 cm length kenaf fibre, T-60(9) shows an improvement of 11.5% compared to the KFMLs with fibre loading 60wt% untreated 9 cm kenaf fibre, UT-60(9). A similar trend was observed for KFML with kenaf fibre length 9 cm at fibre loading 70wt% where the impact energy absorbed by the T-70(9) is 13.5% higher than the UT-70(9). This is in agreement with the result presented by Bakar *et al.* (2010) that highlighted the improvement in mechanical properties of chemically treated kenaf fibre reinforced composites. The NaOH treatment on kenaf fibres removes the lignin and other impurities on the fibre surface and enhance the interlocking between the fibre and matrix which consequently increases the impact energy absorption in treated KFMLs. The alkaline treatment provides better interfacial bonding compared to untreated kenaf fibres in KFMLs.

It is observedthat the overall impact energy absorption of KFML increases as the kenaf fibre loading increase for both untreated and alkaline treated fibres. The impact energy absorbed by the treated kenaf fibre length of 9 cm KFML recorded an increment of 3.4% when the kenaf fibre loading increased from 50wt% to 60wt% and further increase by 8.0% as the fibre loading increased to 70wt%. This shows that higher fibre loading able to absorb more impact energy through the fibres.

Figure-6 shows the damaged KFMLs with different compositions. Figure-6(a) and (c) shows the untreated KFML with fibre loading 70wt% and 50wt% respectively. A visible intra-laminar delamination takes place due to the poor interfacial bonding of untreated kenaf fibres with the matrix compared to treated KFMLs as shown in Figure-6 (b) and (d). The untreated fibres display poor bonding with the matrix which results in poor impact energy absorption. According to Caminero *et al.* (2016) the impact energy mostly dissipates through delamination and fibre/matrix debonding. However, due to a high strain rate of impact,it 's hard to identify the sequence of damage. Most commonly the matrix failure occurs followed by fibre failure and aluminium failure by considering the strength of the constituents.

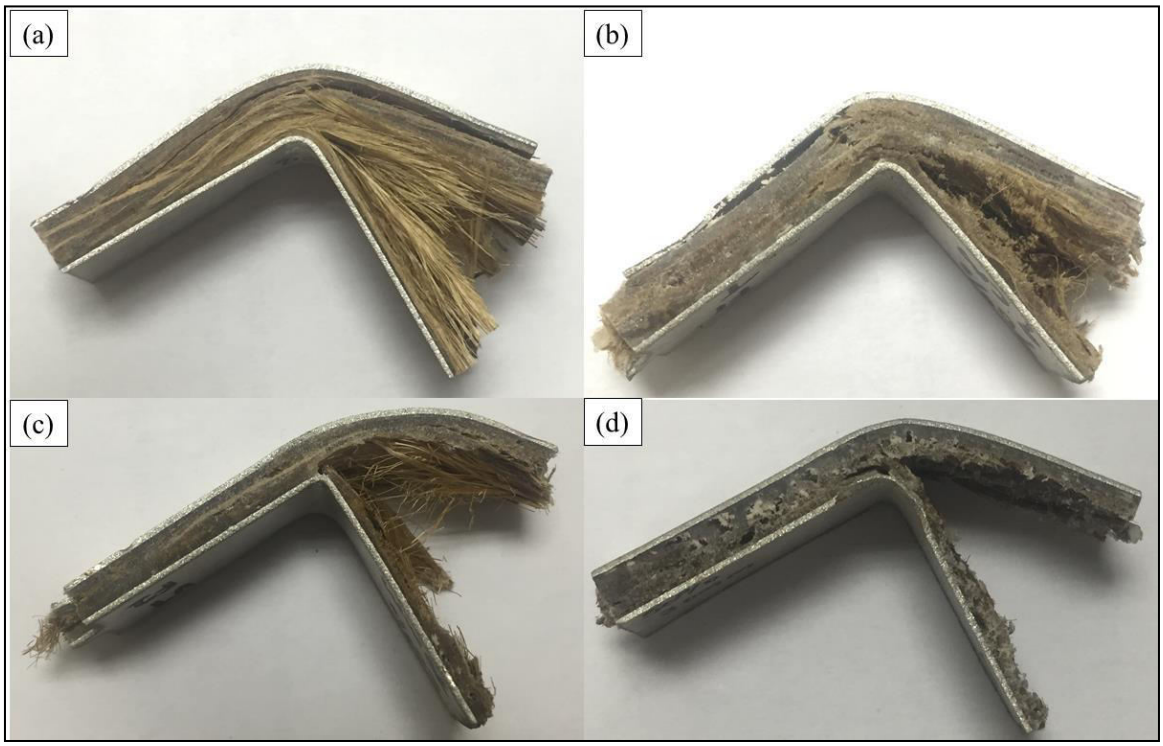


Figure-6. Damaged KFMLs in flatwise orientation (a) UT-70(9), (b) T-70(9), (c) UT-50(3) and (d) T-50 (3).

CONCLUSIONS

The effect of fibre length, loading and treatment of kenaf bast fibre reinforced polypropylene metal laminates were investigated by conducting Charpy impact test on flatwise orientation to evaluate the impact energy absorption.

Overall, the kenaf fibre length 9 cm exhibits an average improvement of 22.4% impact energy absorption compared to 3 cm KFML. Moreover the KFML recorded an average increment of 10.1% impact energy absorption with the increase of kenaf fibre loading. The treated kenaf fibres shows an average increment of 22.05% in impact energy absorption compared to the untreated kenaf fibre reinforced FML. NaOH treatment FML with highest fibre loading and length T-70(9) exhibits the highest impact energy absorbed which is 119.3% higher than the UT-50(3) KFML.

REFERENCES

Caminero M. A., Rodríguez G.P. & Muñoz V. 2016. Effect of stacking sequence on Charpy impact and flexural damage behavior of composite laminates. Compos. Struct. 136: 345-357.

Chai G.B. & Periyasamy M. 2014. Low velocity impact response of fibre-metal laminates–A review. Compos. Struct. 107: 363-381.

Dhar Malingam S., Compston P. & Kalyanasundaram S. 2009. Process Variables Optimisation of Polypropylene Based Fibre-Metal Laminates Forming Using Finite Element Analysis. Key Eng. Mater. 410: 263-269.

Dhar Malingam S., Jumaat F.A., Feng N.L., Subramaniam K. & Ab Ghani A.F. 2017. Tensile and impact properties of cost-effective hybrid fiber metal laminate sandwich structures. Adv. Polym. Technol. doi: 10.1002/adv.21913.

Farahani G.N., Ahmad I. & Mosadeghzad Z. 2012. Effect of fiber content, fiber length and alkali treatment on properties of kenaf fiber/UPR composites based on recycled PET wastes. Polym. Plast. Technol. Eng. 51: 634-639.

Farsani R. E., Khalili S.M.R & Daghigh V. 2014. Charpy impact response of basalt fiber reinforced epoxy and basalt fiber metal laminate composites: Experimental study. Int. J. Damage Mech. 6: 729-744.

Kuan H. T. N., Cantwell W.J., Hazizan M.A. & Santulli C. 2011. The fracture properties of environmental-friendly fiber metal laminates. J. Reinf. Plast. Compos. 30(6): 499-508.

Morrow C., DharMalingam S., Venkatesan S. &Kalyanasundaram S. 2010. Stretch forming studies on thermoplastic composite. In: Proceedings of 6th Australasian congress on applied mechanics, Perth, Australia.

Ng L.F., Sivakumar D., Zakaria K.A. & Selamat M.Z. 2017. Fatigue Performance of Hybrid Fibre Metal Laminate Structure. Int. Rev. Mech. Eng. 11 (1): 61-68.

Ng L.F., Sivakumar D., Zakaria K.A., Bapokutty O. & Sivaraos. 2017. Influence of kenaf fibre orientation effect on the mechanical properties of hybrid structure of fibre metal laminate. Pertanika J. Sci. & Technol. 25 (S): 1-8.

Feng N.L., Dhar Malingam S., Zakaria K.A., & Selamat M.Z. 2017. Investigation on the fatigue life characteristic of kenaf/glass woven-ply reinforced metal sandwich materials. Journal of Sandwich Structures & Materials. 0(0). doi: 10.1177/1099636217729910.

Ramesh M. 2016. Kenaf (Hibiscus cannabinus L.) fibre based bio-materials: A review on processing and properties. Prog. Mater. Sci.78 : 1-92.

Salman S.D., Leman Z., Ishak M.R., Sultan M.T.H. & Cardona F. 2017. Quasi-static penetration behavior of plain woven kenaf/aramid reinforced polyvinyl butyral hybrid laminates. J. Ind. Text., Epub ahead of print 6 February 2017. DOI: 10.1177/1528083717692593.pp. 1-20.

Sivakumar D., Ng, L.F., Chew R.M. & Bapokutty O. 2017. Investigation on Failure Strength of Bolted Joints Woven Fabric Reinforced Hybrid Composite. Int. Rev. Mech. Eng. 11(2): 138-143.

Sivakumar D., Ng L.F., Lau S.M. & Lim K.T. 2017. Fatigue life behaviour of Glass/Kenaf Woven-Ply polymer hybrid biocomposites. J. Polym. Environ.,Epub ahead of print 24 February 2017. DOI: 10.1007/s10924-017-0970-0. pp. 1-9.

Sivakumar D.,Kathiravan S., Selamat M.Z., Said M.R. & Sivaraos. 2016. A study on impact behaviour of a novel oil palm fibre reinforced metal laminate system. ARPN J. Eng. Appl. Sci. 11(4): 2483-2488.

Subramaniam K., Dhar Malingam S., Feng N.L. & Bapokutty O. 2017. The effects of stacking configuration on the response of tensile and quasi-static penetration to woven kenaf/glass hybrid composite metal laminate. Polym. Comp. doi: 10.1002/pc.24691.

Taib R. M., Hassan H.M. & Ishak Z.A.M. 2014. Mechanical and morphological properties of polylactic acid/kenaf bast fiber composites toughened with an impact modifier. Polym. Plast. Technol.Eng. 53(2): 199-206.

Thirmizir M.Z. A., Ishak Z.A.M., Taib R.M. & Leong Y.W. 2011. Mechanical, water absorption and dimensional stability studies of kenaf bast fibre-filled poly (butylene succinate) composites. Polym. Plast. Technol. Eng. 50(4): 339-348.

Vieira L.M.G., Santos J.C., Panzera T.H., Rubio J.C.C & Scarpa F. 2017. Novel fibre metal laminate sandwich composite structure with sisal woven core. Ind. Crops Prod. 99: 189-195.

Vlot A., Vogelesang L.B. & De Vries T.J. 1999. Towards application of fibre metal laminates in large aircraft. Aircraft Engineering and Aerospace Technology. 71(6): 558-570.

Vogelesang L. B. & Vlot A. 2000. Development of fibre metal laminates for advanced aerospace structures. J. Mater. Process. Technol. 103(1): 1-5.