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ORIGINAL ARTICLE

Strain rates effect of dynamic compression properties of E-glass / jute composite

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ABSTRACT – Presently, the application of natural fibres widely gains attention from academia and industries as an alternative material in the composite system. The introduction of the hybrid composite using natural and synthetic fibres is extensively investigated on the static mechanical properties. However, the investigation on the high strain-rates effect is less reported due to the difficulty of the experimental set-up as well as the limitation of dynamic testing apparatus. The split Hopkinson pressure bar (SHPB) was utilised in this present study to characterise the dynamic mechanical properties of the hybrid composite between E-glass with jute fibres at three different strain rates of 755, 1363, and 2214 s^{-1}. Results showed that the dynamic compression stress and strain of the tested samples significantly influenced by the value of strain rates applied. The E-glass/jute sample exhibited the strain-rate dependent behaviour, whereby the higher dynamic mechanical properties were recorded when the higher strain rates were imposed. The difference between maximum dynamic stress was 12.1 and 23.9% when the strain rates were increased from 755 to 1363 s^{-1} and 1363 to 2214 s^{-1}, respectively. In terms of compressive strain, the maximum compressive strain was recorded when the lower strain rates were imposed during testing.

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hybrid composite;
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INTRODUCTION

The strain-rate effect is widely recognised as a crucial factor influencing the mechanical properties of material [1]. However, there are very little works focusing on understanding the correlation between the factor and the sensitivity of the polymers, particularly in terms of the relevant mechanical properties. Jute fibre has many advantages such as acceptable specific properties, less abrasive during processing, less harmful, lower density in comparison with almost of synthetic fibres and has good dimension stability [2]. The hybridisation of composite materials with synthetic or natural fibre and petroleum-based polymers, such as thermoset or thermoplastic matrices would produce alternative engineering materials which are environmentally friendly, biodegradable, economic and potentially recyclable. The use of such materials will also reduce our dependence on non-renewable material sources. Subsequently, this will contribute to lower pollutant level and greenhouse gas emission, enhanced energy recovery and increase of biodegradable components at the end of a product's lifecycle [3].

Hybridization between jute and glass fibres has been investigated on the impact resistance, water resistance and life cycle assessment (LCA) [4], the effect of stacking sequence between jute and glass position on the tensile properties [5], pultruded jute and glass fibres on the tensile and flexural properties [6] and low velocity impact loading at different energy level [7]. On the dynamic properties, natural fibres of pultruded jute and kenaf reinforced composites were investigated experimentally using SHPB at strain rates of 1021, 1150, and 1340 s^{-1}. It was found that the higher of dynamic compression properties were recorded when the higher strain rates were imposed on the tested samples [8]. Strain rate effects of the composite materials are highly correlated with materials hardening factors that are highly influenced with the types of materials used, manufacturing process, surficial adhesion between fibre and matrix, fibre architecture, loading direction, and the range of applied strain rates. These factors have been discovered after testing the hybrid composite of carbon/glass at strain rates of 200, 600, and 1000 s^{-1} [9]. The investigation on the mechanical properties of glass fibre composites extensively done by previous researchers on the stress-strain profiles due to the temperature effect [10]. For high performance application, E-glass was utilized in the fabrication of pressure vessels and rocket motor cases [11]. The usage of natural resources of pineapple leaf/PLA was investigated on the mechanical performance on the effect of hydrophilic in nature [12] and coir fibre was also used with different treatment solution in resisting tensile stress [13].

The used of nano fibrillated kenaf cellulose (NFKC)) fibre as reinforcement in polylactic acid (PLA) bio composites was investigated on the tensile properties. The evaluation of the mechanical properties of the PLA and its nanocomposite showed a trend that the tensile strength and modulus were improved with increased blending speed and time. The modulus of the PLA was increased from 4.2 GPa to 10.21 GPa with the addition of 5 wt.% fibrillated kenaf fibers. The maximum increase in tensile strength of 59.32% and elongation of 100% were observed for NFKC-PLA composite with NFKC yielded at a blending speed and time of 15000 rpm and 15 minutes as compared to pure PLA. The tensile properties indicated that the strength and modulus were improved with increased nanofiber contents [14]. The development of green composite materials using high density polyethylene (HDPE) with date palm fibre (DPF) at different loading rate of DPF

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was investigated on the thermal properties. From the differential scanning calorimetry (DSC) analysis results revealed that the addition of the DPF into the HDPE matrix has increased the crystallization temperature. However, the crystallinity index of the composites at all DPF loadings was lower than the neat HDPE, which could be related to the hindered movement of the HDPE molecular chains by the presence of the fibres [15]. The comparison study of using extracted fibre from waste and residue of Malaysian's palm oil (OPF) with Japanese type cedar thinned wood fibre on the tensile and impact properties reinforced PP was investigated. It was found that the OPF/PP exhibited the equality properties about 95% and 93% of the tensile and impact properties as wood/PP, respectively [16]. The usage of thermoset matrix was investigated on the 2.5 D carbon fabric toughened epoxy at the different angle of tensile test at 0°, 45° and 90°. It was found that FE simulation shows a good agreement with experimental result on the tensile properties. From author point of view, this study significantly contributes in cost and time saving because the failure mode of the investigated material can be predicted using a multiscale simulation approach and potentially being applied to other composite materials [17].

Natural source from pineapples was used for the development of helmet based on Indonesia National Standard (SNI). Result of this research showed there was improvement about composite strength in 10% of fibre volume fraction of pineapple leaves with the value of absorbed energy and impact strength of 0.5375 Joules and 0.01657/mm^2, respectively. The emergence of pineapple leaves able to increase the existing properties of SNI helmet which previously only amounted to 0.3125 Joules and 0.00972 J/mm^2. Hence, it can be concluded that pineapple leaves fibre composites can be used as an alternative material for making SNI helmet [18]. The application of carbon black was investigated by previous literature on the physical and mechanical properties of natural rubber/starch composites. Results showed that the optimum tensile properties were achieved at a carbon black loading of 50 phr and glycerol content of 7%. This new formulation between rubber starch-filled carbon black composites are potential material for natural rubber-based products with acceptable mechanical properties [19].

The split Hopkinson pressure bar SHPB was invented by Kolsky [20] to characterize the dynamic mechanical properties of engineering materials such as alloys, ceramics, metals, rubber and foams. Apart from that, the high strain rates response of fibre reinforced plastics (FRP) was previously investigated on the effect of specimen's geometry [21] through-thickness stitching effect [22] fibre orientation [23] and, fibre areal density and architecture [24]. Natural fibre of hemp, glass, and hybrid composite of hemp/glass reinforced vinyl ester was characterised using SHPB. It was found that the hemp/glass composite recorded the intermediate dynamic properties between glass and hemp laminates [25]. The SHPB test was applied on the rice husk/linear low-density PE with the strain rates of 650, 900, and 1100 s^{-1}, and the higher of dynamic compression strength and modulus were recorded when the higher strain rates were applied [26]. The objectives of the present work are to investigate the dynamic compressive properties of E-glass/jute on the effect of stacking sequence, the effect of high strain rates and the effect of hybridisation between hybrid and pure composites using SHPB apparatus.

MATERIALS AND METHODS

The hybrid composite samples were fabricated from natural fibre of jute with synthetic fibre of E-glass. Both reinforcements are in the form of plain weave. Details of the materials used as shown in Table 1. Jute fibre was supplied by Easy Composite Ltd., United Kingdom while the synthetic fibre of E-glass and epoxy resin were supplied by Chemrex Corporation Sdn. Bhd. Selangor, Malaysia. The epoxy resin DM15F3 (A) cured with hardener DM15F3 (B) in the ratio of 5:1 was used as matrix.

Table 1. Material properties

	Arial weight (g/m^2)	Density (g/cm^3)	Tensile strength (MPa)	Tensile modulus (GPa)
Jute	200	1.46	400 ± 120	40 ± 10
E-glass	600	2.50	3200 ± 300	63 ± 5
Epoxy	-	1.17	85 ± 10	10.5 ± 4

The hybrid and pure composite were prepared using vacuum infusion process (VIP). In this process, a stack of dry reinforcements is laid onto the glass mould which are then sealed with vacuum bag. The applied vacuum creates a pressure differential which is used to literally sucked resin into the dry fabric lay-up via carefully placing of spiral tubing as illustrated in Figure 1.

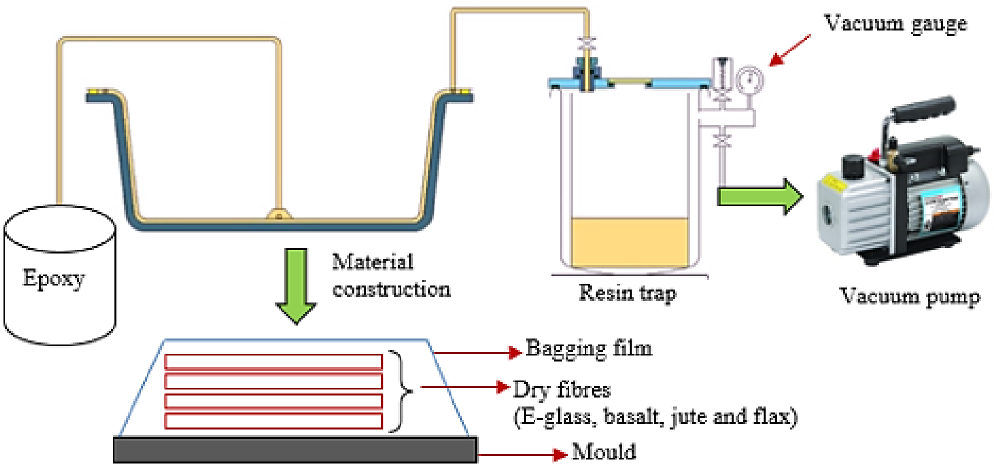

Figure 1. Schematic diagram of vacuum infusion process (VIP)

During infusion stage, vacuum pressure was maintained at 78 ± 10 KPa using vacuum pump model ECVP425 provided by Easy Composite, United Kingdom. Laminates were cured at room temperature for 24 hours, then post-cured in an oven at 60 °C for 3 hours. For this study, two types of stacking sequences were considered during sample preparation, namely sandwich-like (SL) and intercalation (IC) sequences with the total of seven plies which consist four layers of E-glass and three layers of jute fibres. Details of the hybrid configuration as shown in Table 2.

Table 2. The hybrid composite of E-glass/jute with SL and IC sequences

Sandwich-like (SL)	Intercalation (IC)
E-glass	E-glass
E-glass	Jute
Jute	E-glass
Jute	Jute
Jute	E-glass
E-glass	Jute
E-glass	E-glass

For dynamic compression properties characterisation, the SHPB test was performed at the strain rates of 755, 1363 and 2214 s^{-1}. Basically, the SHPB equipment consists of a gun barrel, a striker bar, an incident bar and a transmitter bar which maintain their elasticity throughout the test. The arrangement of SHPB apparatus as shown in Figure 2.

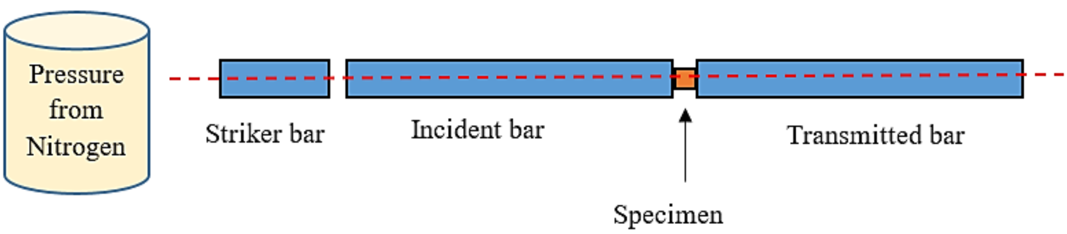

Figure 2. Schematic diagram of SHPB

Typically, there are three types of waves that occur when dealing with SHPB compression - incident wave, transmitted wave and reflected wave. Initially, the generated pressure from nitrogen tank was transferred to the striker bar and the applied pressure would accelerate the striker bar and collide with the incident bars. As a result of the collision, the compression wave was generated and travelled down along the incident bar and is known as incident wave (ε_i). Meanwhile, at the sample interface, the wave was partially transmitted into the sample and referred to as the transmitted wave (ε_t), the remaining wave was reflected and known as reflected wave (ε_r) due to the impedance mismatch between the incident bar and the sample. A relatively uniform stress condition would be reached after a series of passages waves passed through the sample. Figure 3 presents the propagation behaviour of the elastic stress waves via Lagrangian x-t diagram as suggested from a previous literature [8].

Prior to test, the piezoelectric strain gages were mounted between the incident bar and the transmitter bar to capture the incident, reflected and transmitted pulse during collision. Due to the resistance change in the piezoelectric strain gages, the signals measured from piezoelectric strain gages were converted into voltage signals by using the Wheatstone bridge circuits. Then, the voltages were transferred and amplified using a transducer amplifier. The amplified signals were then captured by a digital oscilloscope with 12.5 MHz before being transferred to a computer for data processing.

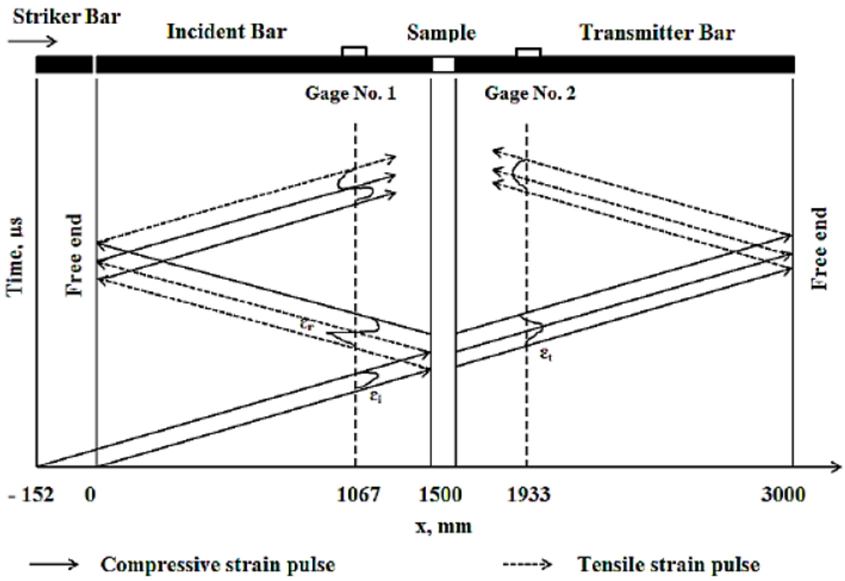

Figure 3. Lagrangian x-t diagram [8]

RESULTS AND DISCUSSION

Effect of Stacking Sequences between SL and IC sample

In terms of the stacking sequence effects, the E-glass/jute with SL sample exhibits the higher of maximum compressive stress for all tested strain rates compare to IC sequence as shown in Figure 4. At the strain rate of 755 s^{-1}, the hybrid composites of E-glass/jute with SL and IC sequences exhibited the compressive stress of 156 and 134 MPa, respectively at fixed strain of 0.06. This mean that SL sample able to withstand the dynamic compression loadings about 14.2% higher than its IC sample with the similar volume fraction of synthetic and natural fibres used. The increment about 14.8% of dynamic compressive stress was observed for E-glass/jute with SL sequence compare to its IC when the applied strain rates increased from 755 to 1363 s^{-1}. Nevertheless, when the strain rates increased to 2214 s^{-1}, it was observed that the difference on the dynamic compressive properties dominated by SL sequence is only 8.3%.

This suggests that the presence of a higher number of interfaces in IC sequence may consequently be detrimental to the overall properties of the laminates especially in their stiffness. This can be explained by referring to the Table 2 of the IC configuration, whereby there are four steps of bonding created between E-glass and jute fibres instead of only two steps of bonding occurred in the SL. These findings concur with a previous study regarding the effect of lay-up architecture on plain-weave flax laminates [27].

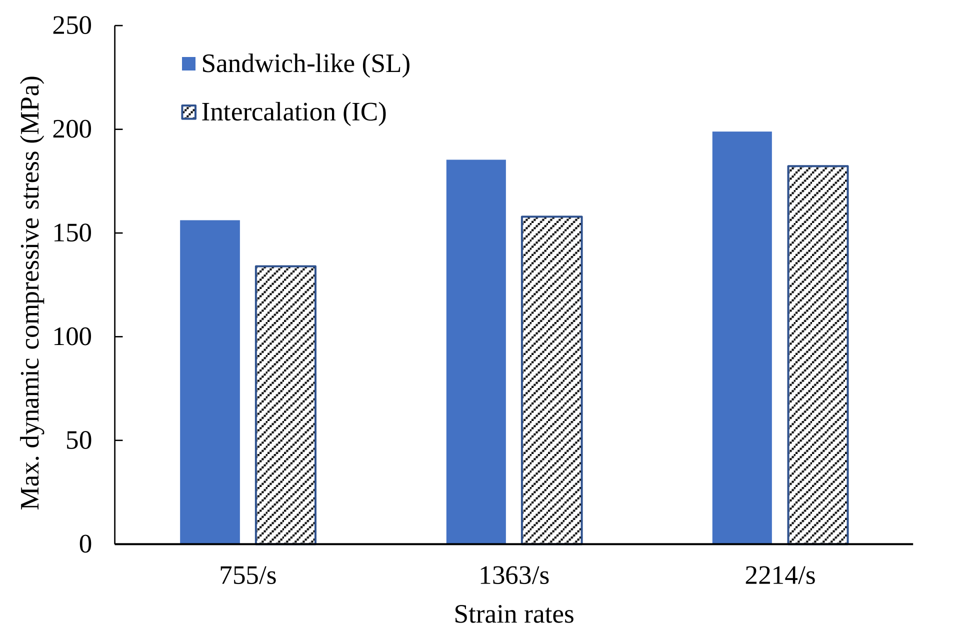

Figure 4. Graph of maximum dynamic compressive stress for SL and IC sequences of E-glass/jute at different strain rate

Effect of Different High Strain Rates

Generally, the compressive stress-strain diagram is generally presenting several mechanical properties of the material such as compressive strength, compressive modulus, strain rate sensitivity and failure modes. Strain rate can be estimated by dividing the velocity of the deformation with the initial length of the sample as depicted in Eq. (1).

$$\dot{\varepsilon} = \frac{d\varepsilon}{dt} = \frac{d}{dt}\left(\frac{l - l_0}{l_0}\right) = \frac{l}{l_0}\frac{dl}{dt} = \frac{V}{l_0} \tag{1}$$

where;
$\dot{\varepsilon}$ - strain rate
V - velocity of the deformation
l_0 - initial length of the sample
l - final length of the sample

Due to the difficulties to precisely control the same strain rates accurately applied to all tested samples, the analogous range was considered in this present study as recommended by Kim and Argento [28]. As shown in Figure 5, the stress-strain curves of E-glass/jute composite had been dominated by the strain rate effect. The higher the strain rates imposed, the higher the maximum stress exhibited by the tested samples. Tested samples recorded the maximum compressive stress of 230, 202, and 175 MPa at the strain rates of 2214, 1363, and 755 s^{-1}, respectively. Similar findings were also reported by the previous literatures [8], [26], [29]–[31] and the increment is attributed by the strengthening effect of the material towards the strain rate applied as suggested by Omar et al. [30].

Conversely, the dynamic failure strain decreases with the increasing strain rates. At the fixed dynamic stress of 150 MPa, the maximum dynamic strains were approximately 0.053, 0.037, and 0.021 with the applied strain rates of 755, 1363, and 2214 s^{-1}, respectively. This suggests that the rapid crack propagation and fibre's failure occurred within a very short time which caused the total failure of the samples, as stipulated in previous literature [1].

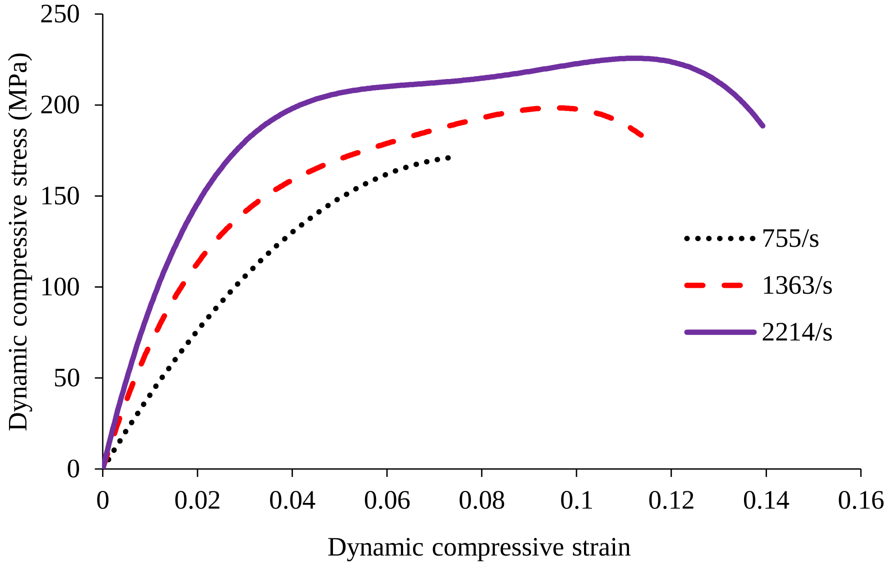

Figure 5. Graph of effect of strain rates on the stress-strain curves of E-glass/jute

Effect of Hybridisation between Hybrid and Pure Composites

The effects of hybridisation on the high strain rate loadings of the E-glass/jute with the pure composites of E-glass and jute reinforced epoxy is presented in Figure 6. As can be seen in Figure 6, the hybridisation of E-glass with jute fibres have positive significant impact on the stress-strain curves. As predicted, the E-glass composite exhibits the highest maximum stress, followed by hybrid composite of E-glass/jute, then pure jute laminate. At the strain of 0.05, the difference between the maximum compressive stress of E-glass/jute with pure jute is 118 MPa.

The pure jute laminate exhibits the lowest of dynamic compressive stress with the value of 109 MPa. As a result, the formation of E-glass/jute had increased the dynamic maximum compressive stress by 143% compared to pure jute. These findings can be explained relate to the fibre volume fraction, V_f as suggested in the previous literatures on sisal fibre epoxy composites [32] as well as the impact strength of bamboo/glass reinforced epoxy [33], whereby the volume fraction significantly influences on the mechanical properties of the tested samples. As shown in Figure 7, pure laminate of jute recorded the lowest of the fibre volume fraction and consume more resin for wettability compare to E-glass/jute. By embedding E-glass with jute, significantly improve the fibre volume fraction from 28 to 42%. This finding show that natural resources are viable and could potentially utilised in composite industries as alternative for man-made fibres.

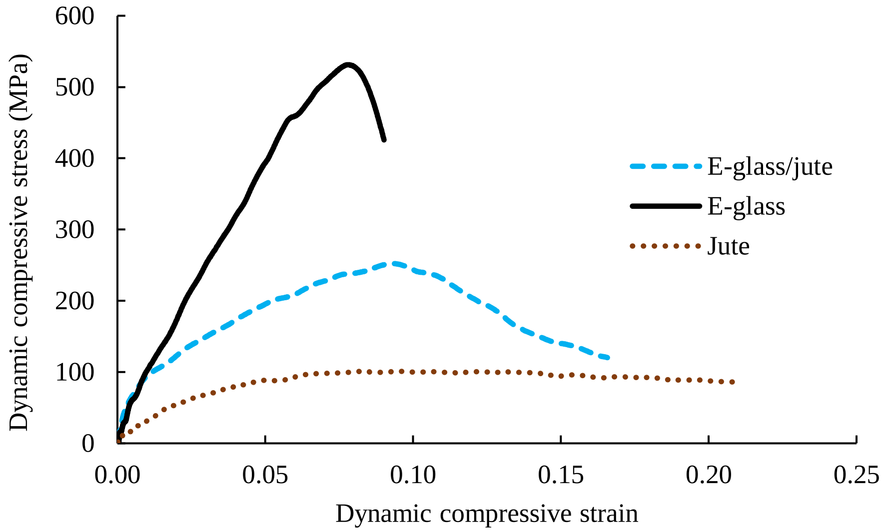

Figure 6. Graph of Stress versus Strain curves between E-glass/jute, E-glass and jute laminates at the strain rate of 2000 s^{-1}

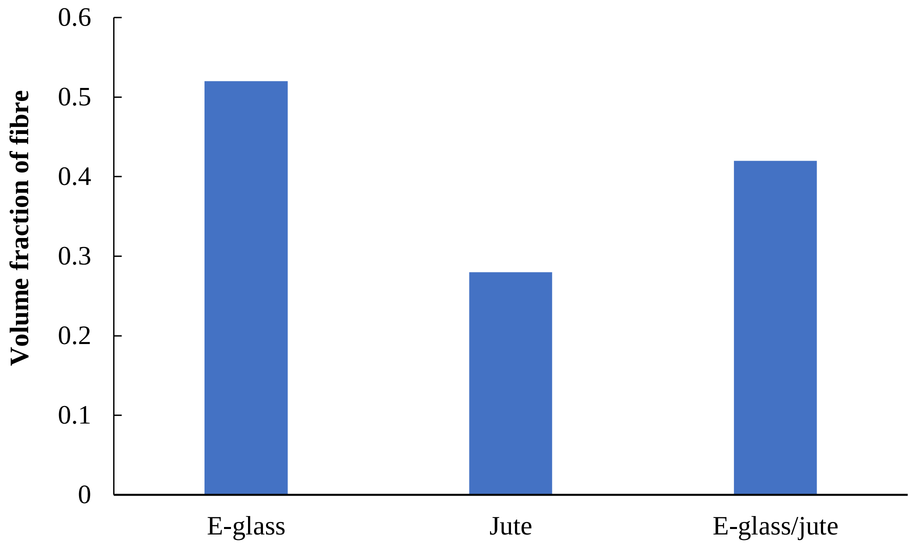

Figure 7. Graph comparison of volume fraction of fibre between pure and hybrid composites

CONCLUSION

This study explored the effect of stacking sequences, the effect of high strain rates and the effect of hybridisation on the dynamic compression properties of E-glass/jute reinforced epoxy at the strain rates of 755, 1363, and 2214 s^{-1}. It was observed that the tested samples with SL sequences recorded the higher value of the maximum dynamic compressive properties compare to their IC sequences for all the ranges of applied strain rates discuss presently. It is noticeable that both hybrid and pure laminates recorded the strain rate dependent behaviour with the increases of dynamic compressive stress upon increasing the applied strain rates. However, the dynamic strain recorded the contrary pattern. The formation of E-glass/jute can compensate the weakness of pure jute composite and this kind of natural resources potentially to be utilized in the composite industry. Hence, it will indirectly reduce the number of non-biodegradable materials on the planet towards environmentally friendly and as part of the green technology development.

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REFERENCES

[1] Z. Song, Z. Wang, H. Ma, and H. Xuan, "Mechanical behavior and failure mode of woven carbon/epoxy laminate composites under dynamic compressive loading," *Compos. Part B Eng.*, vol. 60, pp. 531–536, Apr. 2014.

[2] S. Nahar, R. A. Khan, K. Dey, B. Sarker, A. K. Das, and S. Ghoshal, "Comparative studies of mechanical and interfacial properties between jute and bamboo fiber-reinforced polypropylene-based composites," *Journal of Thermoplastic Composite Materials*, vol. 25, no. 1. pp. 15–32, 2012.

[3] M. Jawaid, H. P. S. Abdul Khalil, and A. Abu Bakar, "Woven hybrid composites: Tensile and flexural properties of oil palm-woven jute fibres based epoxy composites," *Mater. Sci. Eng. A*, vol. 528, no. 15, pp. 5190–5195, 2011.

[4] S. D. Pandita, X. Yuan, M. A. Manan, C. H. Lau, A. S. Subramanian, and J. Wei, "Evaluation of jute/glass hybrid composite sandwich: Water resistance, impact properties and life cycle assessment," *J. Reinf. Plast. Compos.*, vol. 33, no. 1, pp. 14–25, Nov. 2013.

[5] K. S. Ahmed and S. Vijayarangan, "Tensile, flexural and interlaminar shear properties of woven jute and jute-glass fabric reinforced polyester composites," *J. Mater. Process. Technol.*, vol. 207, no. 1–3, pp. 330–335, Oct. 2008.

[6] H. M. Akil, C. Santulli, F. Sarasini, J. Tirillò, and T. Valente, "Environmental effects on the mechanical behaviour of pultruded jute/glass fibre-reinforced polyester hybrid composites," *Compos. Sci. Technol.*, vol. 94, pp. 62–70, Apr. 2014.

[7] K. S. Ahmed, S. Vijayarangan, and A. Kumar, "Low velocity impact damage characterization of woven jute glass fabric reinforced isothalic polyester hybrid composites," *J. Reinf. Plast. Compos.*, vol. 26, no. 10, pp. 959–976, 2007.

[8] M. Firdaus, H. Akil, Z. Arifin, A. A. M. Mazuki, and T. Yokoyama, "Dynamic properties of pultruded natural fibre reinforced composites using Split Hopkinson Pressure Bar technique," *Mater. Des.*, vol. 31, pp. 4209–4218, 2010.

[9] P. Zhu, J. Lu, Q. Ji, and Z. Cheng, "Experimental study of in-plane mechanical performance of carbon/glass hybrid woven composite at different strain rates," *Int. J. Crashworthiness*, pp. 1–13, 2016.

[10] Z. Chow, Z. Ahmad, and K. Wong, "Experimental study on the mechanical properties of glass fibre reinforced epoxy at elevated temperature," *Int. J. Autom. Mech. Eng.*, vol. 16, no. 3, pp. 7108–7120, 2019.

[11] H. Hansmann and H. Wismar, *ASM Handbook*, Volume 21. United state: ASM International Handbook Committee, 2001.

[12] C. T. and J. J. E. H. Agung, M. H. M. Hamdan, J. P. Siregar, D. Bachtiar, "Water Absorption Behaviour and Mechanical Performance of Pineapple Leaf Fibre Reinforced Polylactic Acid Composites," *Int. J. Automot. Mech. Eng.*, vol. 15, no. 4, pp. 5760–5774, 2018.

[13] I. R. and H. A. B. Bakri, A. E. E. Putra, A. A. Mochtar, "Sodium Bicarbonate Treatment on Mechanical and Morphological Properties of Coir Fibres," *Int. J. Automot. Mech. Eng.*, vol. 15, no. 3, pp. 5562–5572, 2018.

[14] Q. Ahsan, T. S. S. Carron, and Z. Mustafa, "On the use of nano fibrillated kenaf cellulose fiber as reinforcement in polylactic acid biocomposites," *J. Mech. Eng. Sci.*, vol. 13, no. 2, pp. 4970–4988, 2019.

[15] A. Chafidz, M. Rizal, R. M. Faisal, M. Kaavessina, D. Hartanto, and S. M. AlZahrani, "Processing and properties of high density polyethylene/date palm fiber composites prepared by a laboratory mixing extruder," *J. Mech. Eng. Sci.*, vol. 12, no. 3, pp. 3771–3785, 2018.

[16] M. N. A. Nordin *et al.*, "Tensile and impact properties of pulverized oil palm fiber reinforced polypropylene composites: A comparison study with wood fiber reinforced polypropylene composites," *J. Mech. Eng. Sci.*, vol. 12, no. 4, pp. 4191–4202, 2018.

[17] A. Gherissi, "Failure study of the woven composite material: 2.5 D carbon fabric/ resin epoxy," *J. Mech. Eng. Sci.*, vol. 13, no. 3, pp. 5390–5406, 2019.

[18] B. T. Mulyo and H. Yudiono, "Toughness analysis of pineapple leaves fiber composite as alternative material for SNI helmet," *J. Mech. Eng. Sci.*, vol. 13, no. 4, pp. 5961–5972, 2019.

[19] M. Mazliah *et al.*, "Optimization of physical and mechanical properties of glycerol - modified natural rubber/starch - filled carbon black composites using two level factorial design," *J. Mech. Eng. Sci.*, vol. 13, no. 2, pp. 4989–5005, 2019.

[20] H. Kolsky, "An investigation of the mechanical properties of materials at very high rates of loading.," *IOP Sci.*, pp. 676–700, 1949.

[21] J. R. Woldesenbet, E. and Vinson, "Specimen geometry effects on high-strain-rate testing of graphite/epoxy composites," *AIAA J.*, vol. 37, pp. 1102–1106, 1999.

[22] B. Dee, A.T., Vinson, J.R. and Sankar, "Through-thickness stitching effects on graphite/epoxy high-strain-rate compressive properties," *AIAA J.*, vol. 39, no. 1, pp. 126–133, 2001.

[23] A. B. Kumar P, Garg A, "Dynamic compressive behaviour of unidirectional GFRP for various fibre orientations," *Mater. Lett.*, vol. 4, pp. 111–116, 1986.

[24] K. Shaker, A. Jabbar, M. Karahan, N. Karahan, and Y. Nawab, "Study of dynamic compressive behaviour of aramid and ultrahigh molecular weight polyethylene composites using Split Hopkinson Pressure Bar," *J. Compos. Mater.*, pp. 1–14, 2016.

[25] D. Kim, W., Argento, A., Lee, E., Flanigan, C., Houston, "High strain-rate behavior of natural fiber-reinforced polymer composites.," *J. Compos. Mater.*, vol. 46, pp. 1056–1065, 2011.

[26] N. S. Abdul Wahab, M. F. Omar, H. Md Akil, Z. A. Ahmad, and N. N. Zulkepli, "Effect of surface modification on rice husk (RH)/linear low density polyethylene (LLDPE) composites under various loading rates," *Mater. Sci. Forum*, vol. 840, pp. 3–7, 2016.

[27] B. A. Muralidhar, "Tensile and compressive properties of flax-plain weave preform reinforced epoxy composites," *J. Reinf. Plast. Compos.*, vol. 32, no. 3, pp. 207–213, Nov. 2012.

[28] W. Kim and A. Argento, High strain rate testing of natural fiber composites, no. 2000. *Woodhead Publishing Limited*, 2013.

[29] H. Akil, Z. Arifin, M. Firdaus, O. Hui, and D. Hui, "Measurement on the dynamic properties of nanosilica/polypropylene composite using split hopkinson pressure bar technique," *Composite Material Research Laboratory, University of New Orleans*. pp. 1–3, 2010.

[30] M. F. Omar, H. M. Akil, and Z. A. Ahmad, "Measurement and prediction of compressive properties of polymers at high strain rate loading," *Mater. Des.*, vol. 32, pp. 4207–4215, 2011.

[31] N. S. Suharty, H. Ismail, K. Diharjo, D. S. Handayani, and M. Firdaus, "Effect of kenaf fiber as a reinforcement on the tensile, flexural strength and impact toughness properties of recycled polypropylene/halloysite composites," in *5th International Conference on Recent Advances in Materials, Minerals and Environment (RAMM) & 2nd International Postgraduate Conference on Materials, Mineral and Polymer (MAMIP)*, 2016, vol. 19, pp. 253–258.

[32] T. Padmavathi, S. V. Naidu, and R. Rao, "Studies on mechanical behavior of surface modified sisal fibre - epoxy composites," *J. Reinf. Plast. Compos.*, vol. 31, no. 8, pp. 519–532, Feb. 2012.

[33] H. R. Rao, M. A. Kumar, and G. R. Reddy, "Hybrid composites : Effect of fibers on mechanical properties," *Int. J. Macromol. Sci.*, vol. 1, no. 1, pp. 9–14, 2011.