STUDY ON PERFORMANCE OF KENAF FIBRE/EPOXY REINFORCED ALUMINIUM LAMINATES (KeRALL) VIA COMPRESSION MOULDING TECHNIQUE

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ABSTRACT: Fibre metal laminates (FML) technology is the best practice for wider usage of natural fibre. It could offer many superior mechanical properties because of the incorporating of metal elements. Therefore, the study is to reveal the findings of kenaf fibre/epoxy reinforced aluminium laminates (KeRALL) through the compression method. In this study, the temperatures of 27°C and 80°C were applied for the compression method. It was found that KeRALL WC yields higher Tg than KeRALL CC based on the DSC analysis. The KeRALL WC showed the highest flexural strength and better impact resistance as compared to KeRALL CC. For water absorption, KeRALL WC absorbed less water absorbed compared to KeRALL WC. For thermal expansion, the trend of the coefficient of thermal expansion (CTE) for KeRALL WC almost equal to the Al sheet with approximately 21% differences. Meanwhile, CTE for KeRALL CC was slightly different from the Al sheet and KeRALL WC. Finally, the fractographic image showed that the KeRALL WC sample had better interfacial bonding between composite (kenaf and epoxy) and Al sheet compared to the KeRALL CC. It was suggested that better bonding affects the overall properties of KeRALL. The empirical evidence presented in the results shows that KeRALL WC has the potential to be commercialized.

KEYWORDS: *Kenaf Fibre/Epoxy Reinforced Aluminium Laminates; Compression Method; Mechanical and Physical properties; Thermal Properties; Fractographic Images*

1.0 INTRODUCTION

Generally, natural fiber composites have a lower strength as compared to the composites reinforced with synthetic fibers such as glass, carbon, and aramid. Also, composite which was involved natural fibers is facing some disadvantages such as easy to faces environmental degradation that caused the mechanical properties reduction. Natural fibre composites may first be exposed to UV radiation, resulting in photo-oxidative degradation, chain scission, cross-linking and consequent debonding of composites [1-2]. For that reason, an alternative way should be explored in order to increase the range of application of natural fiber composite in industries.

For instance, fiber metal laminates (FML) technology is an effective way to solve the disadvantages of natural fiber composite. Basically, FML is a hybrid material, in which it combines some favorable properties of metallic materials and fibre composites. FML has been produced by the combination of synthetic fibres namely aramid, carbon and glass where known as ARALL (Aramid Fibre Reinforced Aluminium Laminate), CARALL (Carbon Fibre Reinforced Aluminium Laminate) and GLARE (Glass Fibre Reinforced Aluminium Laminates) respectively [3-5]. Indeed, FML offer several advantages such as high mechanical strength (tensile and impact) compared with conventional polymer composites and aluminium alloys materials [4].

Beside, in reducing the cost of FML and a pollution-free environment, an attempt has been made in bringing in a natural fiber, a cost effective and eco-friendly fiber into the FML [6]. For example, kenaf bast fibres are attractive because of high specific strength to weight ratio [7]. Furthermore, there is an increasing interest in the utilization of kenaf fibres especially for reinforcement materials in polymer composite technology [8]. Several applications of synthetic polymers reinforced kenaf fibre include automotive industry (wallboards, ceilings, interior lining) and furniture [9]. Additionally, there is no claim or research on FML that involving kenaf fibre as a reinforcement.

Although the FML involving natural fibre has the great potential for future use, the report on their mechanical, physical, and thermal properties are still lacking. Thus, this study aims to characterize the overall performance of the Kenaf Fibre/Epoxy reinforced Aluminium Laminates (KeRALL). In summary, this study is focusing on the KeRALL fabrication process, evaluate mechanical, physical, and thermal properties of KeRALL as well as fractographic observation for the readiness of sustainable KeRALL are set up for various applications.

2.0 EXPERIMENTAL

2.1 Materials

In this study, kenaf bast fiber (KF) in the form of a non-woven mat was used. KF was purchased from Innovative Pultrusion Sdn. Bhd, Malaysia, and received in a form of the non-woven mat with a surface density of 800g/m^2. The KF mat was treated with 5% sodium hydroxide (NaOH) before dried at 70°C for 24 hours. Epoxy resin (EPO DM 15 (F3) – A) and hardener (EPO DM 15 (F3) – B) supplied by CHEMREX Corp. Sdn. Bhd. was used. The epoxy resin acts as matrices for composite parts (kenaf and epoxy) and an adhesive bond between the composite part and Al sheets. The ratio of epoxy to hardener was 5:1. As for the protective layers, aluminum sheets 2024-T3 (Al) with a thickness of 0.5 mm which was supplied by Kird Enterprise were used. Initially, the Al sheets were sanded by using 60-grit sandpaper. Then, the sanded Al sheets underwent a water break test through water spillage to ensure the metal surface was totally clean and uniform.

For KeRALL sample preparation, initially, kenaf was wetted out with epoxy resin and covered by two Al sheets. While a kenaf fiber-reinforced composite (KFRC) was prepared as a reference sample for comparison purposes. Both samples were fabricated via cold compression denoted as CC at 27°C and warm compression denoted as WC at 80°C using a hydraulic press (GOTECH). The pressure of 1000 psi (65kg/cm^2) was applied during the compression process. A square steel mould with a dimension of 150 x 150 x 4 mm was used. The mould was applied with a release agent to ease the demoulding process.

Figure 1 shows the KeRALL fabrication process.

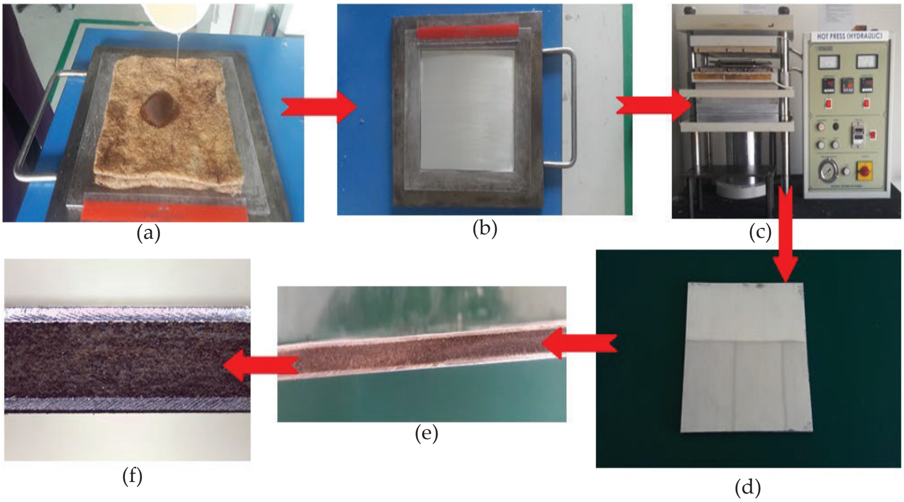


Figure 1: The process flow of (a)-(c) KeRALL fabrication using compression method and (d)-(f) the samples after compression top and side view (cross section area)

For specimen preparation, mechanical cutting equipment was used to cut the specimen according to the ASTM standards. The samples were tested for different behaviors such as mechanical (flexural and impact) and physical (density and water absorption), thermal analysis (DSC and thermal expansion), and morphological observation. The flexural test was carried out by using GOTECH A1-7000-LA 50 kN at 23˚C ± 2˚C and 50% ± 5% relative humidity following ASTM D790. The impact test was performed by Instron-CEAST 9050 Impact Pendulum with pendulum energy of 2.75 J (KeRALL) and 0.5 J (KFRC) following ASTM D256 for edgewise notched Izod impact test. Moreover, a water absorption test (ASTM D 570) was performed at 30˚C for 20 days in a water bath, Yamato-BK610. The density of KeRALL and KFRC was measured by ASTM D 792 by using a laboratory density meter at room temperature. DSC model Q20 (TA Instrument) was used utilized to determine glass transition, also known as Tg. Thermal expansion of KeRALL and KFRC sample was measured using a dilatometer (Series DIL 402 C) by Netzsch. Finally, a scanning electron microscope (SEM) was utilized for fractographic observation.

3.0 RESULTS AND DISCUSSION

3.1 Structural Determination of KeRALL

For structural determination, KeRALL are characterized based on their metal volume fraction (MVF) which is defined in the following equation [10]:

$$\mathrm{MVF} = \frac{\sum_{1}^{n} t_{\mathrm{metal}}}{t_{\mathrm{laminate}}} \tag{1}$$

where t_{metal} = thickness of each metal layer, n = number of the metal layers and t_{laminate} is the thickness of the total laminate.

From Figure 2, the value of MVF for KeRALL is about 0.25, indicating a predominantly composite fraction in KeRALL. An MVF value of zero refers to a full composite, and 1 means an almost monolithic metal. Moreover, the average volume fraction of the composite (kenaf and epoxy) and Al sheets in KeRALL are 77 and 23%, respectively. The result shows that the KeRALL density is 1.4±0.1 g/cm^3. It shows that the density of KeRALL is 50% reduced as compared to the Al sheet. Addition of aluminium sheets to the composite part known as KeRALL sandwich contributed to an increase of 22.8% in density compared to KFRC. The percentage of increase due to aluminium plates is almost like the result reported by Vieira et al. [11], where the researchers found the addition of aluminium contributed to 23.8% of the increase. Besides, it also found that there is no difference in density between KeRALL warm compression (KeRALL WC) and cold compression (KeRALL CC).

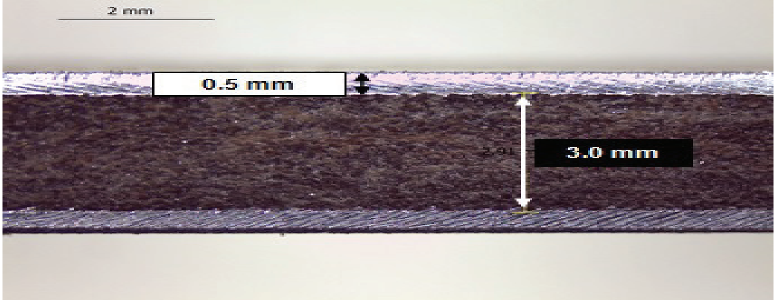


Figure 2: Cross sectional area of KeRALL

3.2 Degree of Curing for KeRALL and KFRC

During the isothermal curing, variations of the heat flow or enthalpy of the epoxy are caused by the cure reaction [12]. The heat flow will change concerning the curing degree of the epoxy. Thus, the determination degree of curing for WC and CC samples is needed. Based on Figure 3, the composite part of KeRALL shows Tg of WC = 65 – 68˚C and CC = 58 – 60˚C. WC shows a higher degree of curing for matrix resin. The heat capacity of the CC sample is larger than the WC sample, thus the heat flow for the CC is lower than WC before the onset temperature of the cure reaction. For WC, the curve becomes almost horizontal after 130 – 140°C while the CC curve after 170 – 180°C (second Tg). This means that the curing reaction for WC and CC is almost complete around this temperature range. There is a difference in heat flow at the end of the test between CC and WC, which resulted from different initial conditions, such as the initial heat given to the sample. For the WC sample, the heat was initially introduced during the compression process; thus, less exothermic toward the end of the temperature program. Therefore, it predictably affected the overall performance of KeRALL. Theoretically, optimum curing results in a perfect cross-linked polymer network, which leads to increase Tg and mechanical properties [13].

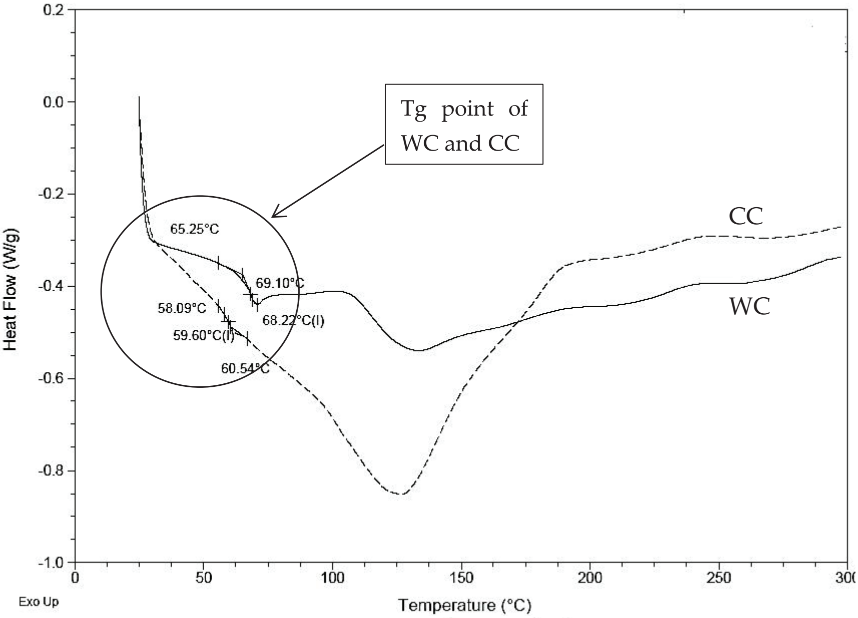


Figure 3: DSC curves of KeRALL composite core

3.3 Flexural Properties

Figure 4 shows the flexural strength of KeRALL and KFRC. The aluminium sheets in KeRALL induce significant flexure strength as compared to KFRC, approximately ~ 400% of the increase. As a comparison, the mean specific flexural strength of the sisal fibre reinforced aluminium laminates (SiRALs) was significantly higher than sisal fibre reinforced composites (SFRCs) revealing increases of 430% [11]. The significant difference of the increment for both KeRALL and SiRAL might be because of the usage of different natural fiber, which is kenaf fibre non-woven mat with a surface density of 800 g/m^2 for KeRALL and SiRAL using sisal fibre in the fabric plain weave form with a surface density of 1300g/m^2. Moreover, KeRALL and KFRC prepared by WC are found to show better flexural properties as compared to CC. This is due to the activation of monomers by an applied temperature that contributes to the cross-linking process [13]. Moreover, thermal curing is the process of temperature-induced chemical change in a material, such as the polymerization of a thermoset resin. This process is relevant, for example, when a precursor resin is heated and hardens during the manufacturing of composites.

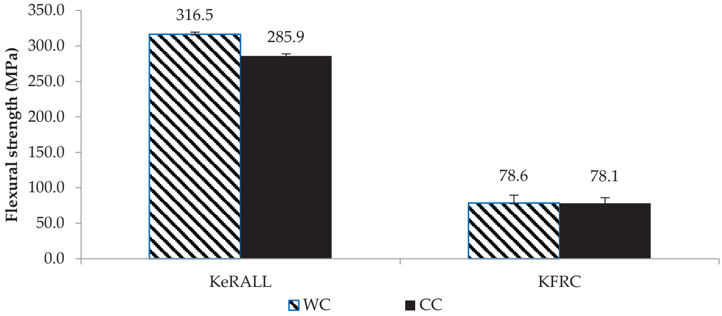


Figure 4: Flexural strength of KeRALL and KFRC

3.4 Impact Properties

Figure 5 shows the Izod impact properties for KeRALL and KFRC. Both samples of warm compression (WC) show better impact strength compared to those prepared using cold compression (CC). The KeRALL WC which has the same materials as well as arrangement with KeRALL CC, but different processing temperatures shows a better impact resistance with approximately 16% increase as shown in Figure 5. It is claimed that better bonding affects the mechanical properties of KeRALL. The same observation has been achieved by Carrillo and Cantwell [14] stated that closer inspection of the cross-sectioned plate indicates that the composite–metal interface has not debonded suggesting that there is a high degree of adhesion across this critical interface. Finally, the laminate was perforated following energy of 8.1 J instead of 6.3 J. In contrast, other researchers found that the delamination occurred can be attributed to the weak bonding between the sisal fibre reinforced composites (SFRCs) and the aluminium plates hence affect the overall mechanical properties [11]. It is claimed that better bonding affects the mechanical properties of KeRALL. The impact resistance of KeRALL is almost more than 14-fold higher as compared to KFRC (Figure 5). Vlot and Gunnink [15] have reported that mechanical properties of the metal alloys can affect the energy absorption of FMLs. The aluminium layers in FMLs contribute significantly to the yielding of the composite at high load, a stable deformation before the break, high residual strength, fatigue performance, excellent blunt notch resistance, and resistance to short cracks [10].

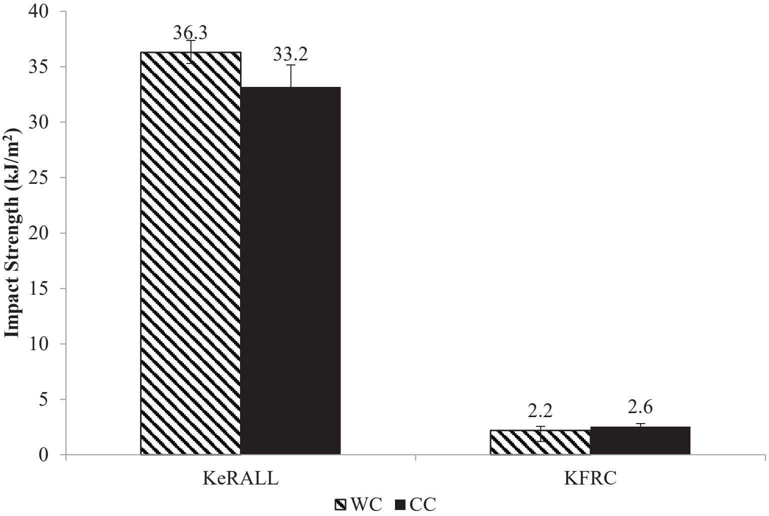


Figure 5: Izod Impact test for KeRALL (WC and CC) and KFRC (WC and CC)

3.5 Water Absorption Behavior

Figure 6 shows water absorption of KeRALL and KFRC prepared by WC and CC processes. For both KeRALL and KFRC, WC shows lower water absorption as compared to CC. The results indicate that epoxy resin with high degree of curing gives a better performance of water resistivity for both KeRALL and KFRC. Moreover, it is observed that the overall amount of water absorbed by KeRALL is less (5 – 10%) compared to KFRC (15 – 20%). The lowest water absorbed was presented by KeRALL WC with 7.9% of water absorbed followed by KeRALL CC with 10.9%. Meanwhile, KFRC WC and CC show 19.0% and 20.6% of water absorbed, respectively. The high water absorption of KFRC is due to the hydrophilic features of the natural fibre that attracts water molecules. This phenomenon can be explained by considering the water absorbing characteristic of kenaf fibre. When KFRC is exposed to moisture, the hydrophilic kenaf fibres swell. As a result of fibre swelling, micro cracking of the brittle thermosetting resin (like epoxy) occurred [16]. Whereas, for the KeRALL, the aluminium as the outer skin provides a barrier against water absorption and only the vulnerable edges section can still absorb the water. According to Botelho et al. [3] the moisture absorption in FML composites is slower than polymer composites even under a relatively harsh conditions due to the barrier of the aluminium outer layers. From WC and CC results, degree of curing epoxy plays an important role in determining the water absorptivity of the materials. Level of epoxy curing degree has given different effect toward KeRALL and KFRC. Hence, it can be concluded that the heat applied during compression causes the improvement in curing degree of KeRALL, thus directly decreases the water absorption of the FML composite.

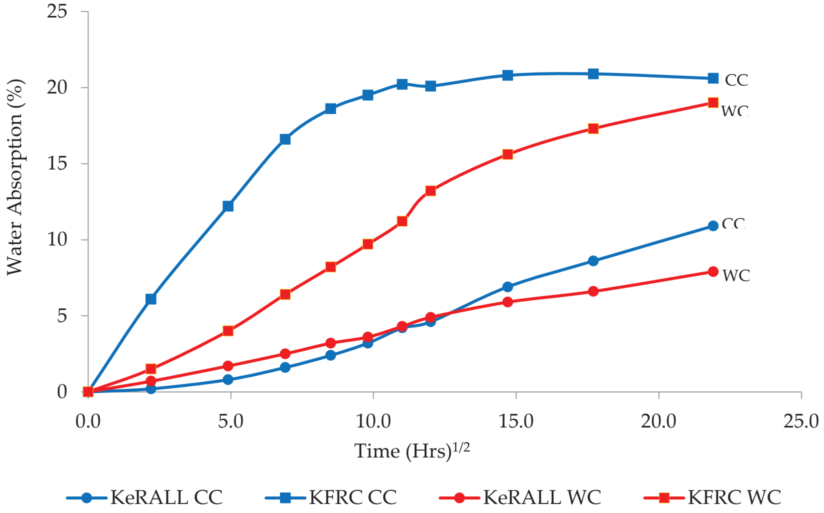


Figure 6: Water absorption of KeRALL and KFRC

3.6 Thermal Expansion Analysis

KeRALL WC and CC underwent thermal expansion analysis via dilatometer instrument to reveal the relationship between the two main components of KeRALL: the composite part (kenaf fibre and epoxy matrix) and the Al sheet. KFRC WC and CC were also tested for comparison. Table 1 presents the coefficient for thermal expansion (CTE) of Al sheet, KeRALL and KFRC. The values of CTE were taken under the temperature range of 40–160°C. It was found that WC sample of KeRALL showed higher CTE compared to CC.

Table 1: Coefficient of thermal expansion (CTE) of various samples

Sample	**Temperature Range (°C)**	**CTE (10^{-6}/°C)**	**% Different (based on Al sheet CTE)**
Al sheet	40–160	22.99	0
KeRALL WC	40–160	18.17	21
KeRALL CC	40–160	12.32	46
KFRC WC	40–160	4.51	80
KFRC CC	40–160	-21.76	194

Figure 7 shows the thermal expansion behaviour of Al sheet and KeRALL (WC and CC). From the figure, CTE of KeRALL WC is almost equal to the Al sheet under the temperature range of 40 to 160°C, with approximately 21% differences as referred to in Table 1. Meanwhile, The CTE of KeRALL CC shows slightly differs from the Al sheet and KeRALL WC with a difference of 39% and 32%, respectively. All the differences are starting at the Tg point of the epoxy.

At above the Tg point, it can be observed that the composite part of KeRALL as well as the matrix of KFRC started to malleable after entering the rubbery region of epoxy. This phenomenon correlates to the intrinsic properties of a thermosetting polymer. In a hot environment, the polymer structure will turn into rubber-like and encourage for post-curing activities. Then, when the heat was forcefully applied above the Tg point, the rigid structure of epoxy polymers will damage because of polymer cross-link chain damages.

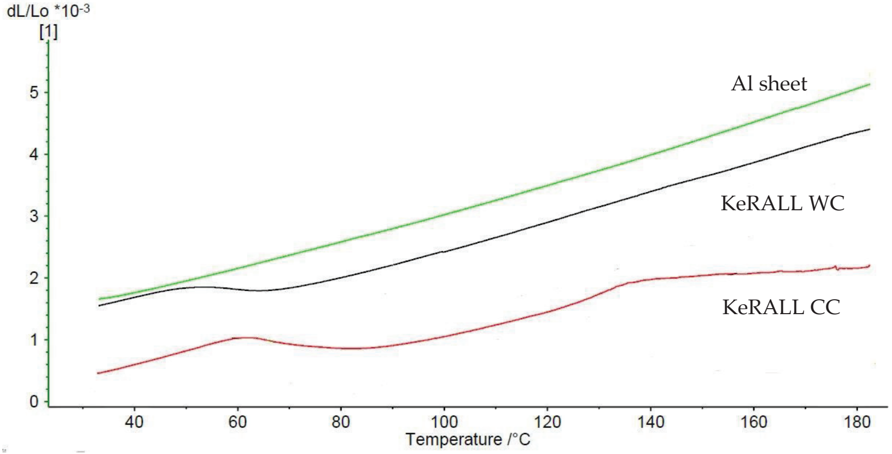


Figure 7: Thermal expansion behaviour of Al sheet and KeRALL (WC and CC)

Figure 8 shows the behaviour of KFRC sample for both processes of WC and CC. It is observed that two peaks occur on both KFRC, but more obvious on KFRC CC. The result suggests that heat plays an important rule for curing stage of epoxy polymer where WC show a better degree of curing as compared to CC. The applied heat during the processing time provides some changes on the degree of curing epoxy KFRC was expanding parallel with the increasing of temperature, especially before the glass transition (Tg) point. After the Tg point, KFRCs expansion suddenly decreases because of epoxy rubberry region and continuously increases after that due to the rigidity of fibre reinforcement (kenaf). Besides KeRALL, the epoxy was slightly going down and going up in parallel to the increasing temperature. This happened due to the rigidity of fibre reinforcement (kenaf) as well as Al sheets of KeRALL. In addition, Al sheet acted as a protective layer for a composite part from the heat effect. It means that the applied temperature is not directly affecting the composite part. In this situation, the Al sheet also functions as a heat absorber for KeRALL. In conclusion, it can be said that Al sheet protects the rubbery-like properties of epoxy on KeRALL and increases the thermal expansion coefficient (CTE). Significant differences in CTEs between the composite parts and aluminium sheets may result in structural failure. Since the metallic substrate is impermeable to moisture, only the polymeric adhesive absorbs moisture and causes a mismatch in hygroscopic strains [17].

Moreover, FMLs would be subjected to failure under a cyclic temperature exposure mainly at the metal/composite interface, due to differences up to 80% in the thermal expansion coefficient of the components [18-19].

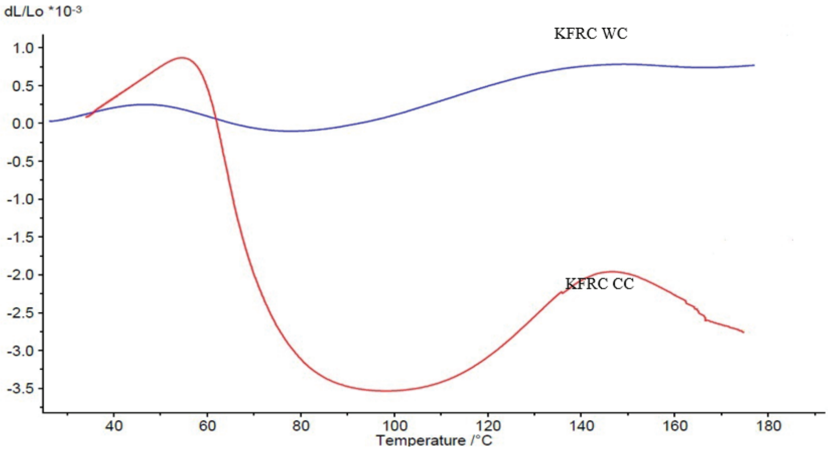
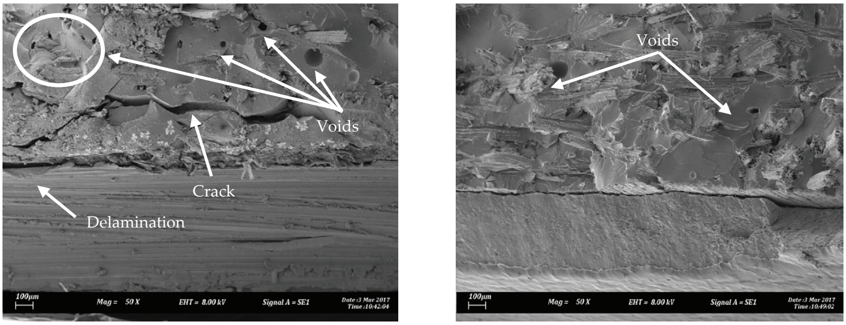


Figure 8: Thermal expansion behaviour of KFRC (CC and WC)

3.7 Fractographic Observation

Figure 9 shows fractographic images of KeRALL samples whereas the KeRALL WC sample shows a better interfacial bonding between composite (kenaf and epoxy) and Al sheet compared to CC as indicated by the arrows. KeRALL CC sample facing a delamination failure between the composite part and the Al sheets component. It might happen because the CC sample did not reach its vitrification stage. The arrow shows resin breakage rather than metal bonding failure. The crack was propagated along with the matrix phase, which caused catastrophic damage to the structure. It is strongly believed that WC increased the interfacial bonding between metal and composite of KeRALL. Furthermore, a high volume of voids was observed in CC. These voids happened because of the trapped gaseous (normally oxygen) and moisture content, especially during the processing time. For thermosetting composites, studies showed that the entrapped air and volatiles generated during the curing process are the major source of the voids, and the voids can be eliminated by introducing resin flow using high pressure, and vacuum in various processing methods [20]. In contrast, the applied temperature in this study, 80°C, has reduced the number of voids as can be seen on KeRALL WC. Heat is essential to break the trapped gaseous and subsequently compressed with high pressure for voids reduction.



(a) (b)

Figure 9: Fractographic images of KeRALL samples: (a) KeRALL CC and (b) KeRALL WC

4.0 CONCLUSION

In conclusion, KeRALL WC showed better mechanical, physical, and thermal properties as compared to KeRALL CC and KFRC. KeRALL WC yields the highest Tg that affects the overall properties of the KeRALL. The fractographic image showed that the KeRALL WC sample had better interfacial bonding between composite (kenaf and epoxy) and Al sheet compared to KeRALL CC. Even though KeRALL WC showed a slightly lower on the flexural strength than SiRALs that studied by the previous researcher, but it remains competitively for further commercialization. It could be enhanced by adding more volume of the fibre in KeRALL's fraction. The finding suggests that KeRALL has high potential as a new sustainable FML composite and can be considered as a promising candidate for future industrial applications.

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