EFFECT OF REINFORCEMEMT PARTICLES PREHEATING ON MECHANICAL AND MICROSTRUCTURAL PROPERTIES OF AMC

Romeo Sephyrin Fono – Tamo[1)], Jen Tien – Chien[1)]*
[1)] *Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg, South Africa, 2006*

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[*]*Corresponding author: e-mail: ftrromeo@gmail.com Tel.: +27739187042, complete postal address: Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg, South Africa, 2006*

Abstract
An investigation into the effect of preheating the powder particles versus not preheating before mixing it with an aluminium slurry was carried out. This was seen as way of overcoming the challenge of wettability which often occurs when powder particles are added to a melted metal for the purpose of developing a metal matrix composite. In this study, non – preheated, 2 w.% preheated and 4 w.% preheated palm kernel shell ash powder was used to develop an aluminium matrix composite (AMC) via stir casting method. Mechanical properties revealed that AMC with 4 w.% pks ash inclusion has the highest Vickers Hardness value. Meanwhile, optical micrographs and scanning electron micrograph show that the pks ash both non – preheated and preheated are homogenously distributed into the matrix. This is further confirmed by the energy dispersive spectroscopy (EDS) mapping of the various samples. Although pks ash particles are only visible on the optical microscope micrographs, the elemental analysis of the various samples through EDS show a strong presence of carbon at various degree proving the presence of pks ash in the composite. Overall, preheating does not significantly affect the surface morphology of the AMCs based on the derived optical and scanning electron micrographs and AMC with higher content of pks ash particles seems to have better mechanical properties.

Keywords: Aluminium Metal Composite, Palm Kernel Shell, Stir Casting, wettability, elemental analysis, Vickers Hardness, Elemental mapping

1 Introduction

The world production of palm oil and palm kernel oil has grown to over 56 million tonnes and the World Bank estimates that world consumption will double by 2020 says a report of the Global Palm Oil Conference [1]. In the process of producing palm oil and palm kernel oil, huge amounts of waste are generated, and this waste include palm frond, empty fruit bunch, palm kernel shell (PKS) and palm trunk. Kong et al. [2] disclosed that most of the waste generated is often disposed of in the open dumping, used as solid fuel in boilers, or even used as fertilizers. In recent years, a number of researches have been conducted on the use of palm kernel shell in building [3]; as fuel [4 and 5] and in polymer composites [6 and 7].
The desire for stronger, lighter and less expensive materials is the actual challenge in engineering especially in automobile where fuel economy and engine performance are of essence. Although metal matrix composites (MMCs) have been identified to offer a broad spectrum of properties suitable for a large number of functional and structural applications

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which monolithic material systems do not offer, its cost disadvantage has triggered a shift towards aluminum matrix composites (AMCs) [8]. AMCs are therefore potential candidate materials in engineering and medicine owing to their strength, machinability, dimension accuracy, and wear resistance report [9]. [8] also noted that three broad groups of reinforcing materials are used in the development of AMCs and these are synthetic ceramic particulates, industrial wastes and agro – waste by-products. So, a new generation of hybrid AMCs is being developed with the use of agro – waste derivatives as replacement to synthetic reinforcement. The advantages offered by the agro – waste derivatives when used in the production of AMCs include low cost, accessibility, low density as well as low environmental pollution. Agro – waste products processed into ashes and their suitability for use as reinforcing phase material in AMCs studied include; bagasse ash [10]; rice husk[11]; bamboo [12],corn cob [13], groundnut [14], eggshells [15], Palm kernel shell [16 and 17]. Agro – waste by-products are viewed as very promising materials for reinforcement in aluminum matrix composites.

Predominant processes for manufacturing AMCs are solid and liquid state processes says [16, 18 and 19]. Methods in solid phase include diffusion bonding (such as cold isostatic pressing), rolling, extrusion, hot isostatic pressing (HIP) while in the liquid phase method, molten metals is involved and examples are squeeze casting, stir casting, rheo casting and various types of infiltration says [19]. The third technique is friction stir processing which they reported is on the rise now. [20] reported that stir casting is one of the liquid methods which is been extensively used for the production of AMCs due to its simplicity and low cost. The entire process they reported, involve melting the entire aluminum matrix and gradually introducing the other ingredients into the molten aluminium while using a mechanical stirrer to create a vortex to facilitate incorporation. To address the challenge of wettability between the molten aluminium matrix and the particles which is a major limitation in stir casting, methods such as the use of wettability agent and fluxes, preheating, and oxidation are employed. Because those techniques to ameliorate the wettability increase the overall production cost, other cheaper techniques such as compocasting or slurry casting are suggested by [21].

Literatures on the uses of palm kernel shell char as reinforcement in AMCs are seldom found in the open. [22] worked on the synthesis and properties analysis of char reinforced AL-13.5Si-2.5Mg alloy composite. Coconut char and palm kernel shell char were used as reinforcement. The powder metallurgy technique was used and there was no mention of PKS powder treatment during the process. It was found that the use of palm kernel shell char at the disperse phase yielded identical result with coconut shell char. [16] studied the physical properties and microstructure of pure aluminium reinforced with palm shell activated carbon. Various mix percentage were used and powder metallurgy technique employed for the compaction of the composites. [17] examined the effect of palm kernel shell ash on the mechanical properties of as-cast aluminium alloy matrix composites. Stir casting technique was used for the development of the aluminium alloy. To achieve their objective, a portion of PKS powder was treated with NaOH solution while the other part was left as untreated before they were introduced into the molten aluminium alloy.

In this work, slurry casting method which is known as an economic technique to develop aluminium matrix is used and at the same time, the PKS powder is preheated prior to its inclusion into the molten aluminium. This process improves the wettability and a more homogenous distribution of the PKS ash particle into the aluminium matrix is achieved. Also, the effect of the reinforcement on the mechanical and microstructural properties of the AMCs is investigated.

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2 Experimental material(s) and methods

2. 1 Product development

The palm kernel shell (PKS) used this study was obtained from a local palm oil processing mill. The PKS was crushed using a hammer mill and then a ball mill to reduce the grains to finer size. The grounded material was then packed in a graphite crucible and fired in electric resistance furnace at temperature of 1300°C for an hour to form palm kernel shell ash and a sieve shaker was used to sieve the palm kernel shell ash to obtain ashes with mesh size under 50µm [13] (**Fig. 1**). Physical and chemical properties of the aluminium ingot are presented in Table 1 and 2. The PKS ash was preheated at a temperature of 250°C to reduce to minimum the moisture content and to improve wettability for 10 minutes. The aluminium ingot (**Fig. 2**) was charged into an electric powered crucible furnace and heated to a temperature of 750°C±30°C. After melting, the PKS ash particles were gradually introduced into the molten aluminium while a mechanical stirrer was used to create a vortex in order to enable better incorporation. An external thermocouple was used to monitor cooling of the liquid alloy to a semi solid state at a temperature of about 600°C. The composite slurry was again superheated to 800°C±30°C and stirred by means of the mechanical stirrer at a speed of 400 rpm for 10 minutes to improve the distribution of the particles in the molten aluminium alloy. After the 10 minutes, the liquid alloy was cast into prepared sand moulds.

Fig. 1 PKS ash particles

Fig. 2 Ingot of A16061

Table 1 Physical properties of A16061

Tensile strength (MPa)	124
Density (g/cm^3)	2.7
Hardness (VHT)	64
Melting point (ºC)	660
Modulus (GPa)	69
% Elongation	8.0

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Table 2 Chemical composition of A16061

Component	Mg	Si	Fe	Cu	Zn	Ti	Mn	Cr	A1
%	0,84	0.62	0,23	0.22	0.1	0.1	0.03	0.22	Rest

2.2 Product Characterisation

Prepared metal composite samples were subdued to Vicker Hardness (VH) measurements through a standard micro-hardness tester HXD-1000TM/LCD at a load of 4.9 N for 15s. These measurements were done with the purpose of understanding how particulate weigh fraction influence the metal matrix mechanical properties.

The cast product surfaces were visualized by means of optical microscope and scanning electron microscope to investigate its microstructure. Cut sections from the developed AMC were grinded then polished using various emery papers grade. Keller‘s solution was used for etching before samples were examined. The scanning electron microscope used was a JEOL 6480 LV doted with an energy dispersive X-ray (EDX) detector. Microscopic studies to examine the particle size, morphology and the AMCs microstructure were done. The secondary electron imaging was used to take the micrographs at suitable accelerating voltages considering the best possible resolution.

3 Results and Discussion

3. 1 Mechanical Properties

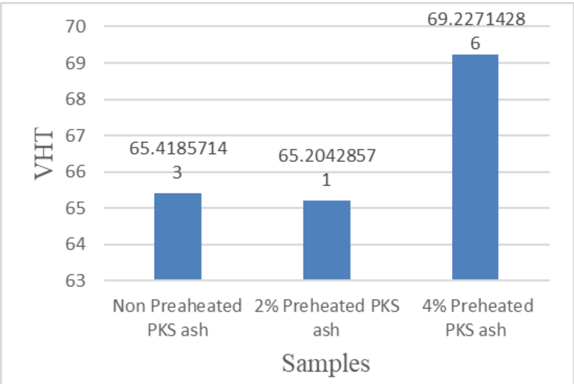

Fig. 3 Vicker hardness values of the AMCs

The developed aluminium matrix composites show an improvement in their mechanical properties. Comparison of the hardness of pure Al sample with cast composites proved that addition of pks ash particles boost hardness of pure Al in general. This can be attributed to the role of enhancement of the density of dislocations by the pks ash particles [23]. Very often, nanoparticles used as reinforcement contribute to the increasing of hardness and this is mainly due to Hall–Petch mechanism, grain refinement and particle strengthening effects which act as obstacles to the motion of dislocations [24]. [25] found that particle distribution significantly affected the mechanical properties of the composites. They also stated that uniform particle distribution often results in good mechanical performance. **Fig. 3** shows that the AMC with non – preheated pks ash displays a hardness value (65.42) a little above that of AMC with 2% preheated pks ash (65.02) while the AMC with 4% preheated pks ash exhibit the highest

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hardness value. The weight percentage mix of the non – preheated pks ash in the composition could have contributed to this slight high in hardness with more pks particles available to strengthen the matrix. When comparing based on the percentage mix of pks ash, it is clear that the AMC with 4% mix is much stronger than the 2% mix with average hardness value of 69.23. The developed AMCs have improved mechanical properties when compared to the pristine aluminium alloy that has a Vickers Hardness value of 64. However, in their work on physical properties and microstructure of green aluminium matrix composite. [26] confirmed that above 5w.%, the hardness of the AMC begins to decrease.

3.2 Surface analysis

Reinforcement grain size is believed to affect miscibility into the matrix with finer grain sizes integrating better in the matrix to create a more homogenous mix. The optical and SEM images indicated in **Figs. 4** and **5** show the microstructures of AL6061 alloy and its composites with non – preheated pks ash, 2% and 4%wt.% pks ash in as cast state. Optical micrograph of the aluminium composite with 2% pks ash inclusion (**Fig. 4. A**) show sparingly distributed pks ash particles. This can be attributed to the percentage to weight ratio of the pks ash added to the molten aluminium which at this level was found not to be too obvious or visible. Nevertheless, appearance of the reinforcement particles. One can notice a more distributed appearance of the particles despite their relatively small size. From these micrographs, it apparent the composites present a homogenous mixture. It is clear that mechanical stirring contributes immensely to the dispersion of pks ash particles in the melt. An investigation by [25] showed that factors such as the particle size and the volume fraction of the particles influence the grain size of the matrix in nanocomposite materials. They also realized that a decrease of the particle size or an increase of the volume fraction of nanoparticles causes a decrease of the grain size of the matrix. This behavior is due to a higher incidence of grain boundary pinning that prevents grain growth [25]. Silicon platelets can be seen in the SEM micrograph of all the sample (**Fig. 5**). This could be due to silicon presence in the initial aluminium ingot. Micro porosities are observed in the inter-grains region. The source of the porosities could be the entrapped gas during casting. Alloyed matrices solidify dendritically in most casting processes [27]. In this case, dendrites grew during the solidification phase producing an eutectic alloy. The microstructure reveals primary α-dendrites embedded in a eutectic matrix [28]. Because of the stirring, the α - particles present in the commercial aluminium took the rosette shape but also the eutectic silicon is broken into platelets as can be seen in **Fig. 5**.

The process of mixing materials to achieve improved properties may come with the creation of additional elements and components in the mixture which will inherently affect the developed composite positively or negatively. While SEM gives elaborated high resolution images of the sample by rastering a focused electron beam across the surface and detecting secondary or backscattered electron signal, energy dispersive X-Ray spectroscope (EDS) provide elemental identification and quantitative compositional information. The SEM-EDS approach used shows the high presence of Al in all the composites. In the composite developed without preheating the pks ash, the presence of carbon element is much higher (24 wt.%) (**Fig. 6. A**) as compared to the other composites 9.5 and 13.5 w.t% for 2% and 4% pks ash inclusion respectively (**Fig. 6 B** and **C**) . This could be attributed to the region of the sample picked for analysis due to the fact that clusters of pks ash might have been present there thus increasing the carbon contain. Clustering of reinforcing particles often occurs when a difference in temperature between the particles and

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the matrix is manifested at the initial stage of mixing. Preheating the reinforcing elements to almost the same temperature with the matrix often contribute to a better distribution of the particles. This phenomenon could have also contributed to the high in Vickers hardness value of the non – preheated pks ash-based AMCs observed earlier in the mechanical properties. For 2% and 4% pks inclusion, the ash was preheated to about 250^{o} C before its transfer into the molten metal thus the homogenous distribution attained. Nevertheless, the carbon content in composite with 2% pks ash being less than that in the 4% can be attributed to the percentage weight of the material added meaning more pks ash more carbon elements in the composite. So, beside the carbon presence in the composite which is an indication of the presence of pks ash, silicon was also detected. Silicone came from the Al substrate mostly.

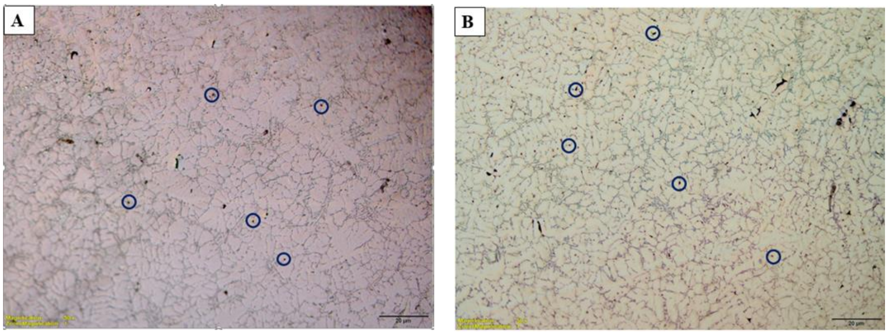

Fig. 4 Optical micrographs of preheated PKS ash at A) 2% and B) 4% homogenously distributed into the aluminium matrix

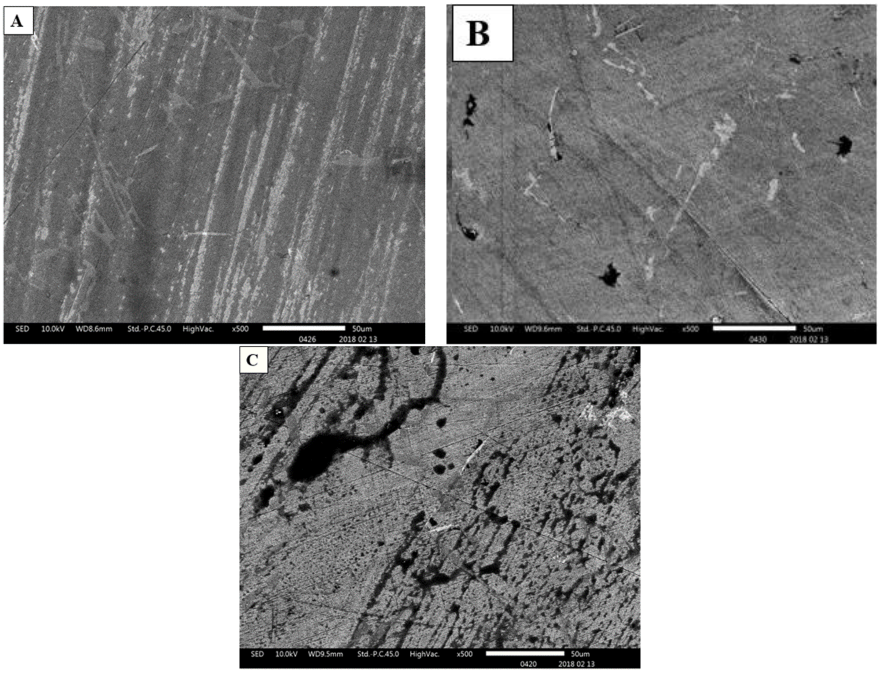

Fig. 5 Scanning electron microscope micrographs of composites with A) No preheated PKS ash particles B) 2% Preheated PKS ash particles C) 4% preheated PKS ash particles

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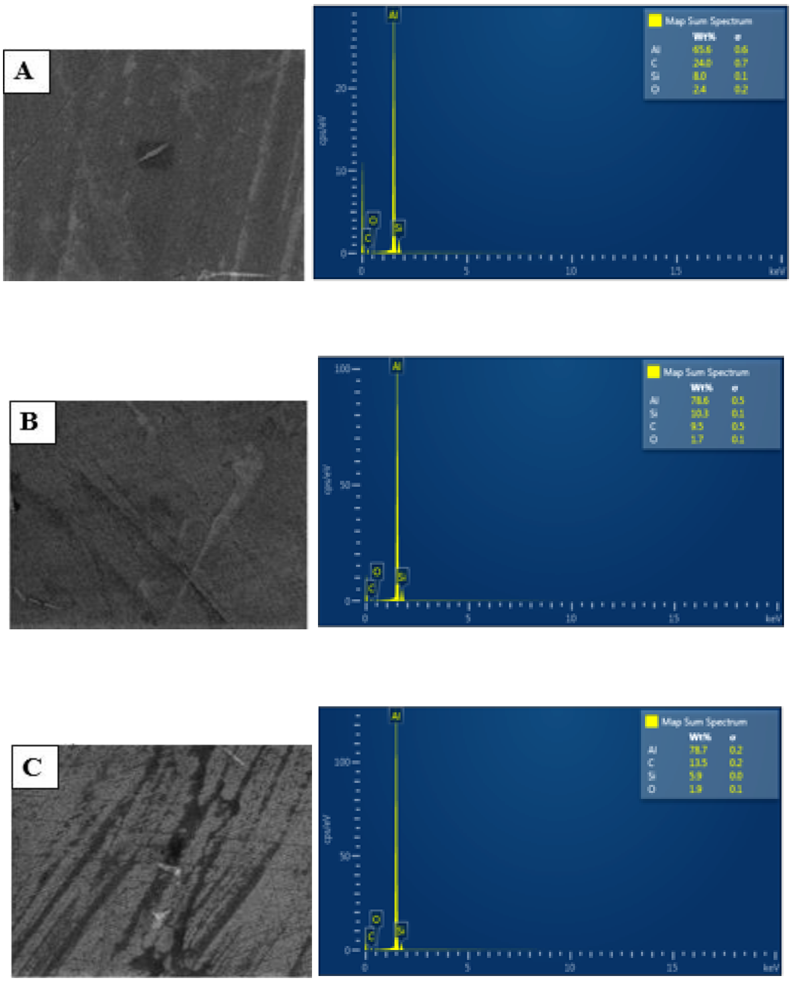

Fig. 6 EDS analysis of the aluminium Matrix with A) Non – reheated pks ash particles B) 2% preheated pks ash C) 4% preheated PKS ash

The elemental mapping of the composites shows the chemical composition as well as the relative position of each element in the composite. The Al, C and O are all homogeneously dispersed in the composites as shown in the EDS mapping images in **Fig. 7**. Si in the form of platelets like clusters is localised and found in some place. Unlike Al, C and O, it is not uniformly dispersed. Thus, the aluminium content is higher than the silicone and carbon amount. These results are in agreement with the EDS spectrum shown in **Fig. 6**. The presence of carbon is an indication of the presence of the pks ash in the composites. These images further confirm that pks ash is homogenously distributed in the composites. It is also observed that the density of carbon element in a a particular aluminium composite varies with the percentage mix of pks ash in the composite. Thus, the composite with 4w.% of pks ash (**Fig. 7. C**) seems to be denser than the others.

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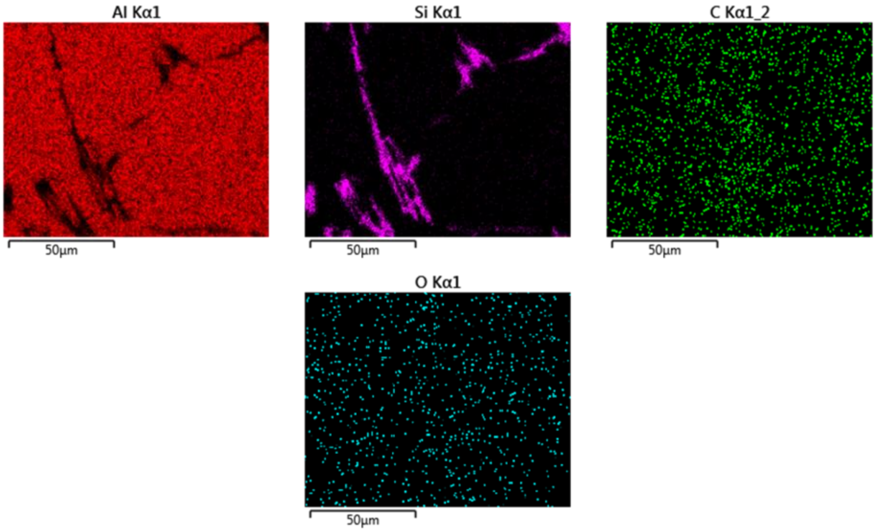

Fig. 7 A. EDS Mapping of the major constituents in PKS aluminium matrix when PKS not preheated

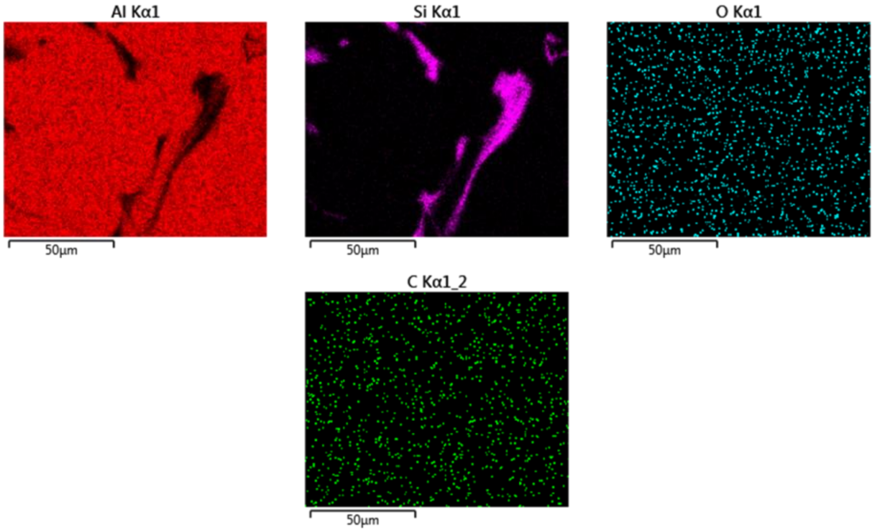

Fig. 7 B. EDS mapping of the major constituents in PKS aluminium matrix with 2% preheated PKS ash particles

4 Conclusion

Development of aluminium matrix composites with palm kernel shell ash as reinforcing particle was achieved through stir casting method. The effect of preheating the pks ash particle before inclusion into the melt as well as the pks percentage mix were investigated. The results showed that there is no obvious influence of preheating the reinforcement particle on it miscibility with the matrix. Mechanical properties show that increase in pks ash particles increases the hardness though it is found in literature that above 5% hardness begins to reduce. The reinforcement

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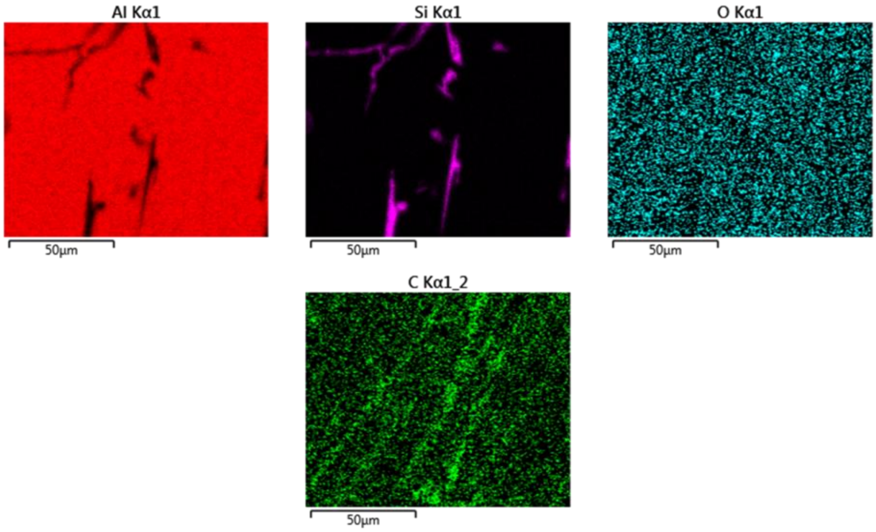

Fig. 7 C. EDS mapping of the major constituents in PKS aluminium matrix with 4% preheated PKS ash particles

particles are homogenously distributed into the matrix for all the AMCs based on SEM-EDS analysis. The developed AMCs could be useful in manufacturing automotive parts, marine vessel such as yacht body as well as aluminium cans where consumption safety is of essence.

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