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SUSCEPTOR-ASSISTED RAPID MICROWAVE SINTERING OF Al-KAOLIN COMPOSITE IN A SINGLE-MODE CAVITY

The present research addresses the low-temperature sintering of 4% kaolin clay reinforced aluminium composite using susceptor-aided microwave sintering at 2.45 GHz frequency. Kaoline clay the naturally available mineral in the north-eastern regions of india. The study aims to convert this kaoline clay into the value added product with enhanced mechanical properties. The Al-x% Kaolin (x = 2, 4, 6, 8, 10) composite was fabricated through the powder metallurgy process by the application of 600 MPa compaction pressure. The composite corresponding to optimum ultimate tensile strength (U.T.S) was subjected to single-mode cavity microwave-assisted sintering by varying the sintering temperatures as 500°C, 550°C and 600°C. The effect of incorporating kaolin clay on the dielectric characteristics of composite powders, as well as the effect of sintering temperature on the microstructural changes and mechanical characteristics of Al-4%Kaolin composites were also examined. Results concluded that the addition of 4 wt% kaolin powder improves the dielectric characteristics of the composite powder. The maximum Hardness. Compression strength and U.T.S of 97 Hv, 202 MPa and 152 MPa respectively achieved for the Al-4% Kaolin composite sintered at 550°C. The higher fracture toughness of 9.56 Ma. $m^{1/2}$ reveals the ductile fracture for the composite sintered at 550°C.

Keywords: kaolin reinforcement; microwave sintering; mechanical properties; powder metallurgy

1. Introduction

In the present era, composites are predominantly used in the automobile sector to develop the components such as brake arms, piston rods and cylinder heads as the composites possess better resistance to corrosion, high ductility and tailorable properties [1,2]. Metal matrix composites can be synthesized by incorporating numerous reinforcements such as TiC, ZrC, ZrO_2 and SiO_2 etc. The high hardness and anti-wear characteristics of these reinforcements make the composite brittle and absence of self-lubricating properties [3]. In addition to this, the higher cost of ceramic reinforcements makes its utility in industrial applications. To eradicate its effect, nowadays metal matrix composites were synthesized by incorporating naturally available particles such as coconut shell particles, bamboo-leaf-ash, rice husk particles and mineral clays [4]. Composite can be fabricated by using liquid-state processing or solid-state processing techniques. The presence of higher porosities and the oxidation of powder particles during the liquid state melting leads to the initiation of agglomerations at the interface regions which leads to composite to fail at the lower intensity of applied loads [5]. However, the powder metallurgy process of composite synthesis eliminates the oxidation phenomenon as the matrix and reinforcements were not undergone the melting process [6]. In the powder metallurgy process, the obtained composites from the compaction process are sintered through various sintering techniques such as conventional sintering, spark plasma sintering (SPS) and microwave-assisted sintering (MAS) techniques [7]. The heat dissipation from the core part of the particle to the outside leads to the initiation of strong bonds between the neighbouring atoms which accelerates the dislocation piling at the grain boundaries and improves the mechanical strength of the MAS composite when compared to conventional sintered composite [8]. K. Ravi Kumar et al., [9] studied the strength analysis of Al-ZrO_2-coconut shell particle composite and the results indicate that the U.T.S of the synthesized composite was found to be 201 N/mm^2 by reinforcing 2 wt% CSA and 8% ZrO_2 particles. Incorporation of ZrO_2 particles of more than 10 wt% leads to decreases in the U.T.S of the composite due to the formation of brittle intermetallics. B. Praveen Kumar et al., [10] analyzed the stir-casted Al-Bamboo leaf ash (BLA) composite. Researcher findings reveal that the mohrs hardness

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and U.T.S of the synthesized composite found to increased up to 104 Mohrs hardness and 176 MPa with the incorporation of 4.5 wt% Cu and 5 wt% BLA particles. Ch. Hima girish [11] investigates the stir casted Al-Aloe vera, Al-Fly ash composite and the obtained results concluded that the an 55.62% enhancement in U.T.S of the Al-Aloe vera composite than the unreinforced aluminium.

Kaolin is an abundantly available mineral in the northeast regions of India. This mineral consists of ceramic compounds such as silicon oxide (SiO_2), aluminium oxide (Al_2O_3), Titanium oxide (TiO_2) and Magnesium oxide (MgO) which processes higher hardness and self-lubricating characteristics. Hence, this study explores the conversion of kaolin clay into a value-added product. The Kaolin particles were reinforced in the aluminium matrix as 2 wt%, 4 wt%, 6 wt% and 8 wt% to investigate the effect of kaolin reinforcement on the mechanical characteristics of the MAS sintered composite. Further, the composite with the optimal mechanical properties was subjected to a single-mode cavity MAS process by varying sintering temperatures to study the sintering temperature impact on the mechanical properties of the synthesized Al-Kaolin composite.

2. Materials and fabrication process

2.1. Preparation of composite powders

The aluminium and kaolin powders with an average particle size (APS) of 40 μm were purchased from Nanoshell Pvt Ltd, Delhi. The constituent elements present in the As-received kaolin powders was shown in TABLE 1. The particle morphology, EDX spectrum and APS of aluminium and kaolin particles were depicted in Fig. 1. The ball milling was performed to the mixture of aluminium and x% kaolin (x = 2, 4, 6, 8) powders by rotating the vial at 300 rpm for 2 h [12]. The powder mixture was surrounded by an Ar gas atmosphere to avoid aluminium powder oxidation during the milling.

2.2. Fabrication of the composite

The milled composite powders were filled in the H-13 steel die and then compacted by applying 600 MPa pressure using the hydraulic-operated pallet press by the application of 600 MPa

TABLE 1

Elemental composition of Kaolin reinforcement

Elemental Constituents	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	K_2O	CaO	MgO	Na_2O	L.O.I.
Weight Percentage	45.6	38.4	1.5	0.4	0.18	0.06	0.05	0.03	13.8

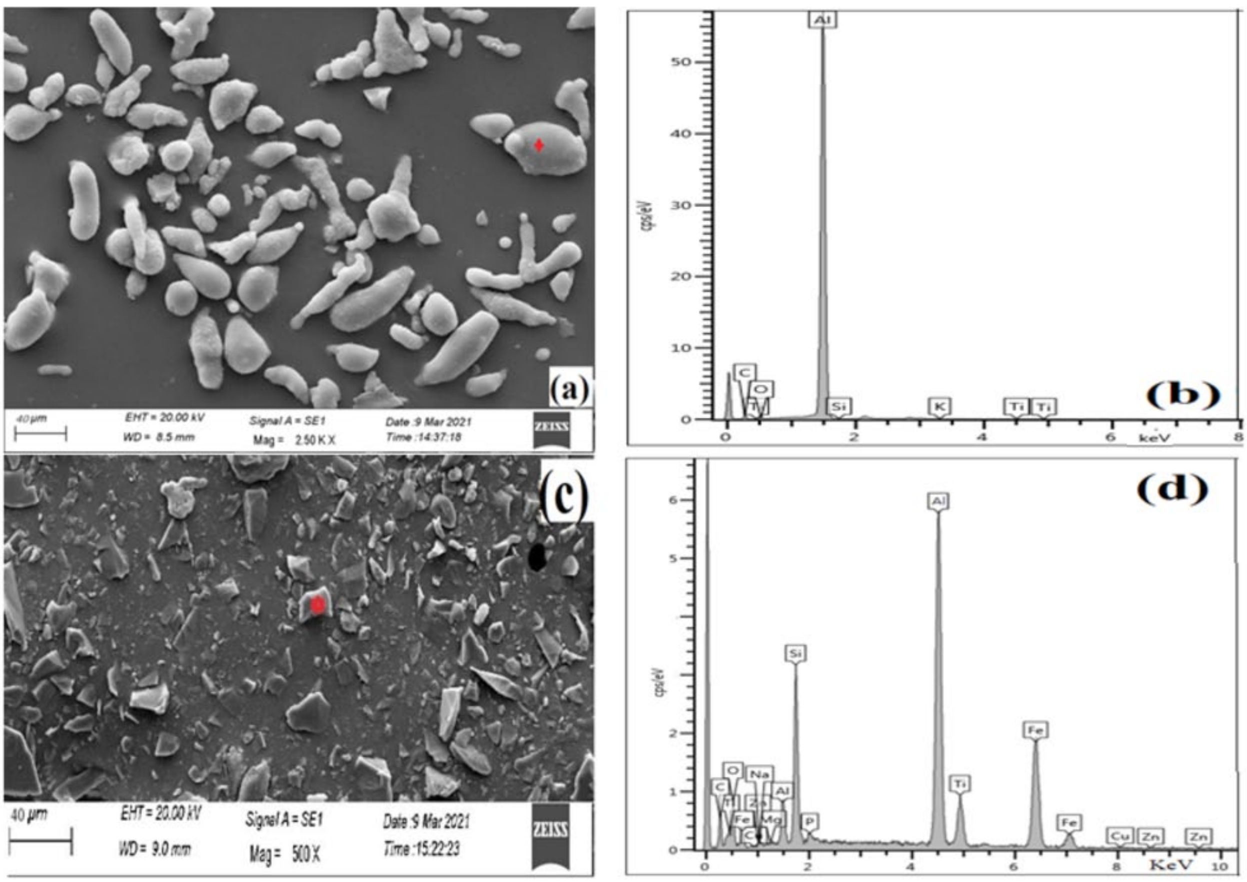

Fig. 1. (a) APS for aluminium (b) EDS Spectra for the aluminium and (c) APS for Kaolin and (d) EDS spectra for Kaolin particles

pressure [13]. The composites are synthesized by reinforcing the 2 wt%, 4 wt%, 6 wt% and 8 wt% kaolin particles. The compacted composites were microwave sintered at 500°C for 30 min with a power input of 1.5 KW and 2.45 GHz frequency to study the influence of wt % of kaolin on the mechanical properties of the composite [14,15]. The composite corresponding to maximum U.T.S was subjected to single-mode cavity microwave sintering (SAIREM, Channai) with WR (Waveguide Rectangular) 340 waveguide by supplying 2 kW power with a frequency of 2.45 GHz. Composite samples were placed in a location where the electric field was presumably the strongest [16]. Croquesel et al., [17] and Cecilia et al., [18] stated the entire process, as well as the conditions for the single-mode cavity sintering of the composites. Fig. 2 depicts the synthesized composites sintered through the MAS technique. The codes assigned in this study are A0K, A2K, A4K, A6K and A8K represent the aluminium composite reinforced with 0 wt%, 2 wt%, 4 wt%, 6 wt% and 8 wt% kaoline particles. A4K500, A4K550, and A4K600 represent Al-4%Kaoline single-mode cavity MAS sinterd at 500°C, 550°C and 600°C respectively.

2.3 Composite characterization methods

The dielectric properties of the as-received aluminium and kaolin powders were measured by using the network analyzer operating at a frequency of 0.5-3 GHz integrated with a dielectric kit probe [19]. Tensile and compression tests were performed as per ASTM E8 and ASTM E9 standards on the M30 model micro universal testing machine [20]. The ECONOMET VH1MD micro Vickers hardness tester was utilised to assess the hardness of the composite as per ASTM E384-16 specifications with the application of a 500 g load [21]. The presence of constituent phases was identified by performing a PANanalytical X-Ray diffraction machine. The microstructures of the composites were identified by using a scanning electron microscope (Carl Zeiss Ltd, U.S.A) integrated with an EDS analyzer by varying the accelerating voltage between 0.2 to 30 kV.

3. Results and discussion

3.1. Permittivity measurement of as-received powders

The dielectric properties of the as-received matrix and reinforcement powders were determined at 2.45 GHz frequency at ambient conditions after constrained tapping for 15 times and the obtained results were shown in TABLE 2 [19]. The addition of 4% kaolin powders to aluminium particles resulted in an enhancement of dielectric characteristics such as real, imaginary and loss tangent values.

TABLE 2

Dielectric properties of as-received powders

Composition	Real (γ)	Imaginary (γ^1)	Loss tangent (tgγ)
Al	1.33 ± 0.01	0.03 ± 0.01	0.004 ± 0.01
Al-4%Kaolin	2.18 ± 0.01	0.21 ± 0.01	0.012 ± 0.01

The loss tangent values represent the microwave absorbing capability of the given substance. From TABLE 2 it was clear that the addition of kaolin to the aluminium significantly improves the microwave absorbing behaviour of the composite powder to be sintered. The presence of aluminium oxide, silicon oxide and magnesium oxide in the kaolin powder makes the composite powder absorb the high intensity of microwaves during the microwave sintering process.

3.2. XRD and microstructural investigation

Fig. 3 depicts the XRD results for the as-received kaolin and aluminium powders. The obtained peaks were compared with JCPDS card numbers. The peaks corresponding to SiO_2 (JCPDS card No: 46-1045 [22,23]), MgO (JCPDS card No: 59-7746 [24,25]), Al_2O_3 (JCPDS card No: 00-046-1212 [14]) and TiO_2 (JCPDS card No: 21-1276 [26]) confirms the as-received powder is kaolin and the peaks other than these con-

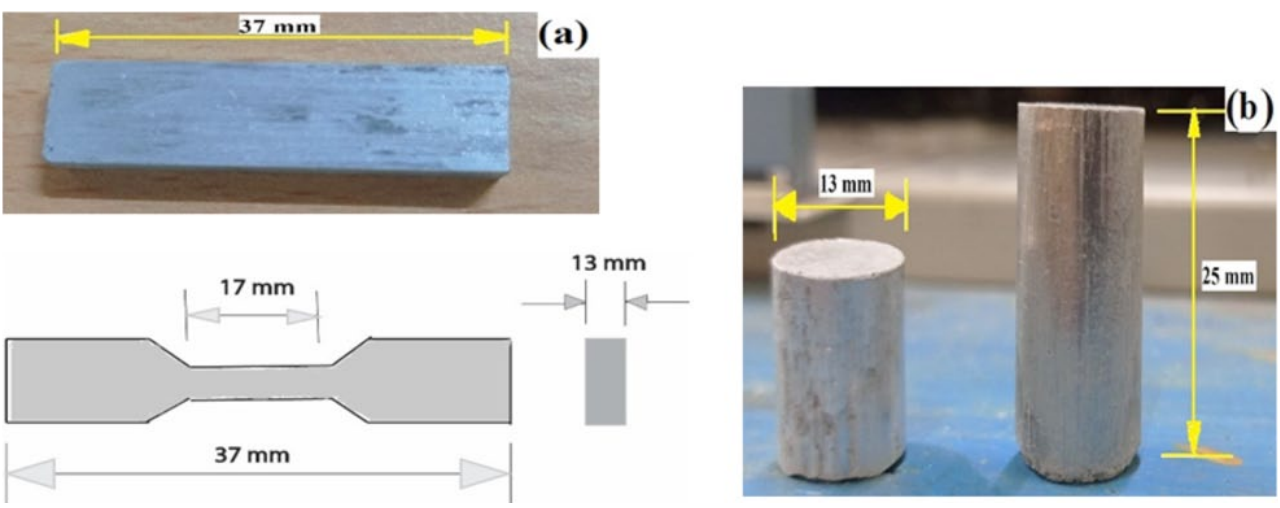

Fig. 2. Synthesized MAS composites for (a) Tensile test, (b) Hardness and Compression test

stituents were not observed, which reveals the kaolin is free from the impurities. The XRD analysis of the single-mode cavity MAS composite at 600°C shows the presence of an Al_2Cu peak as depicted in Fig. 4. The identified Al_2Cu peak (JCPDS card No: 25-0012 [27]) was matched with the peak identified by the researcher Gatea et al., [28]. Increasing the sintering temperature beyond 550°C accelerates the chemical reactions between the kaolin and aluminium powders and prons to the diffusion of atoms among the adjacent particles. This phenomenon predominantly initiates the agglomerations formation at the boundaries of the kaolin and aluminium particles [29]. The generated brittle Al_2Cu agglomeration decreases the load withstanding capability of the composite and causes failure of the specimen at the lower magnitude of applied loads. Despite this, the presence of low MAS temperature (550°C) leads to uniform internal heat dissipation which eliminates the agglomeration formation in the composite.

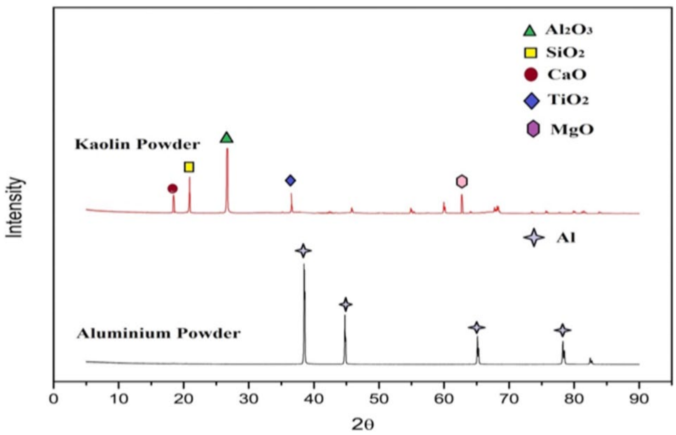

Fig. 3. XRD peaks for the As-Received Aluminium and Kaolin powder

The interface chemical bonding between the kaolin and aluminium particles plays a predominant role in controlling the mechanical characteristics of the composite. To investigate

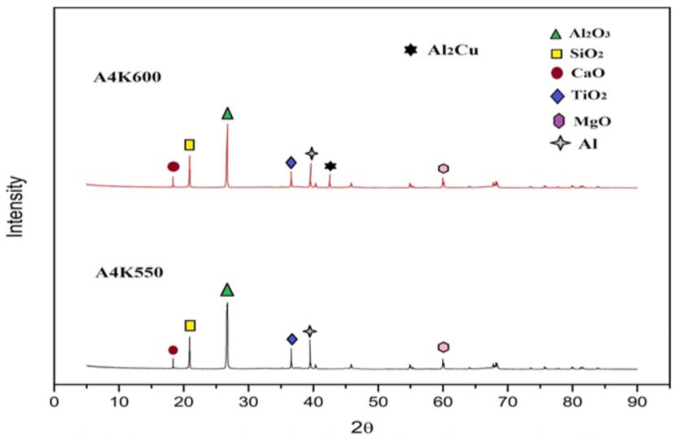

Fig. 4. XRD peaks for the single-mode cavity sintered Al-Kaolin composite at (a) 550°C and (b) 600°C

the kaolin reinforcement distribution in aluminium matrix SEM analysis was performed on the single-mode cavity MAS composite at 550°C and 600°C (Refer Fig. 5.) From Fig. 5, It was observed that the kaolin particles in the aluminium matrix were dispersed uniformly with clean interfaces and no agglomerations were identified, which indicates that the no chemical interaction among the adjacent particles during the microwave sintering. However, Al_2Cu agglomerations were identified in the SEM image for the composite sintered at 600°C due to the presence of accelerated diffusion of atoms and the initiation of chemical interactions at higher temperatures [30,31]. The reinforced kaolin particles absorb the higher intensity of microwaves at elevated temperatures and increase the kinetic energy of the particles located near the grain boundaries [15]. This phenomenon generates the brittle Al_2Cu agglomerations along the grain boundaries as shown in Fig. 5(b). The oxides layers were observed on the surfaces of the MAS composite sintered at 600°C due to the interactions between the agglomerations and the aluminium particle. The oxidized surface of the composite and the SEM image for the oxidized surface was depicted in Fig. 6.

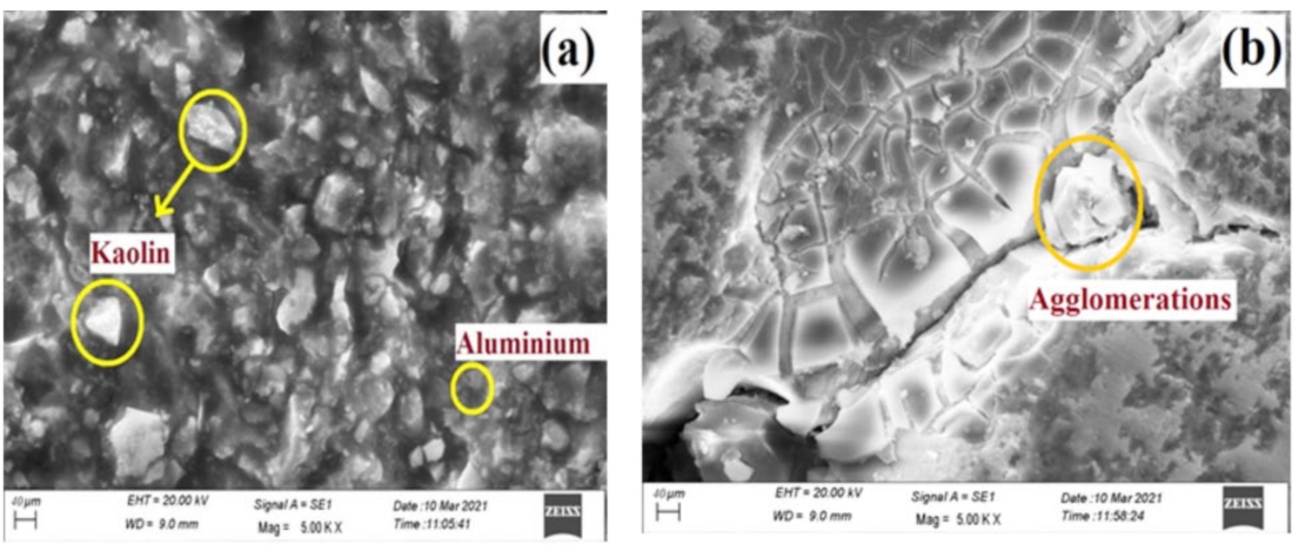

Fig. 5. SEM images for single-mode cavity MAS composite at (a) 550°C and (b) 600°C

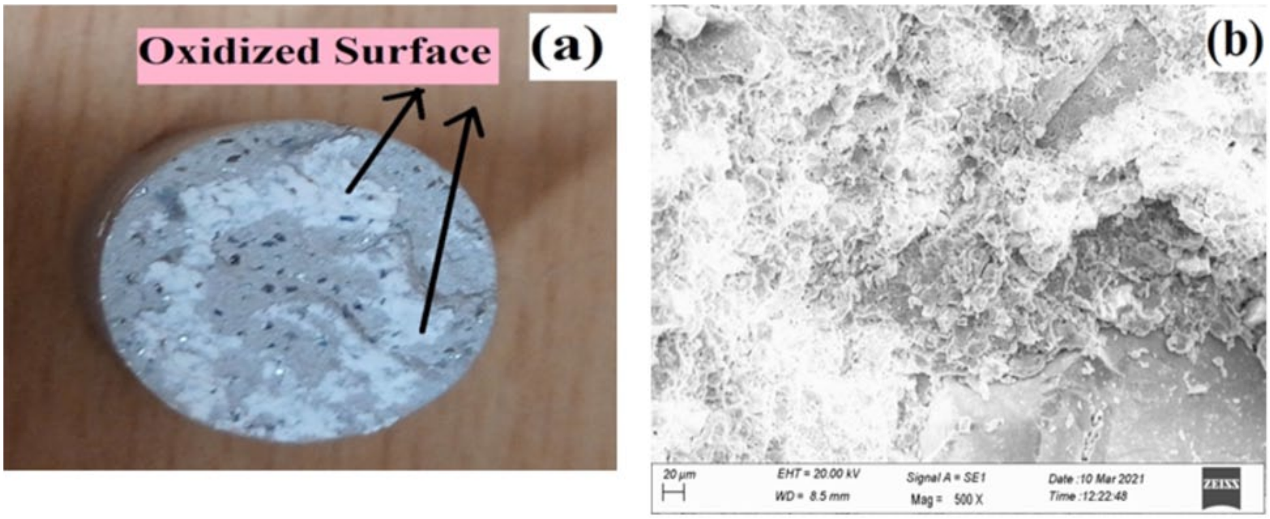

Fig. 6. (a) Oxidized surface of the composite sintered at 600°C, (b) SEM image for the oxidized surface

3.3. Mechanical properties

The plastic strain between the kaolin and aluminium particles affects the hardness and interface strength of the synthesized composite. The U.T.S of the MAS Al-Kaolin composite was shown in Fig. 7. Results reveal that with the incorporation of kaolin particles from 2 wt % to 4 wt %, the U.T.S was improved from 102 MPa to 136 MPa due to the availability of harder SiO_2 and Al_2O_3 compounds in the kaolin reinforcement [25,32]. Beyond the incorporation of 4 wt % kaolin particles leads to decrement in U.T.S due to the formation of agglomerations at the interfacial regions. The composite corresponding to optimal U.T.S (Al-4% Kaolin) was subjected to single-mode microwave sintering at the sintering temperatures of 500°C, 550°C and 600°C and the obtained compression strength and U.T.S results were depicted in Fig 8. From the results, it was clear that an 11.76% enhancement in U.T.S of the single-mode cavity MAS composite at 550°C than the MAS sintered Al-4%kaolin composite. The decrease in trend for the U.T.S was obtained when the sintering temperature was raised beyond 550°C as shown in Fig. 8. This was attributed due to the accelerated chemical interactions at the kaolin and aluminium grain boundaries which in turn generates the brittle agglomerations of Al_2Cu. These Al_2Cu particles were brittle characteristics and processed a lower thermal expansion coefficient compared to the aluminium matrix which leads to uneven expansions during the MAS process [33]. During the application of load crack initiation occurs along the boundaries of Al_2Cu agglomerations and the aluminium particles and makes the composite fail at the lower intensity of externally applied load [20].

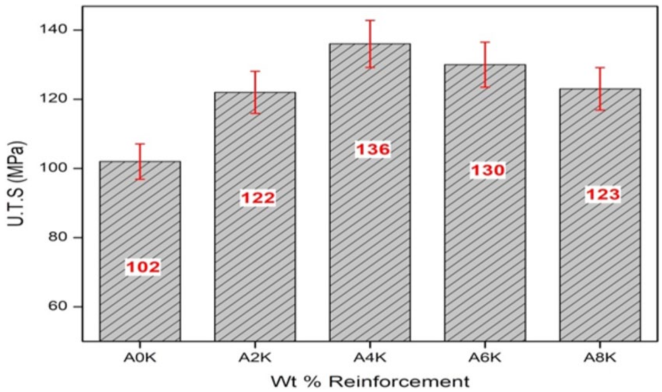

Fig. 7. Variation of U.T.S of MAS composite with wt% of kaolin particles

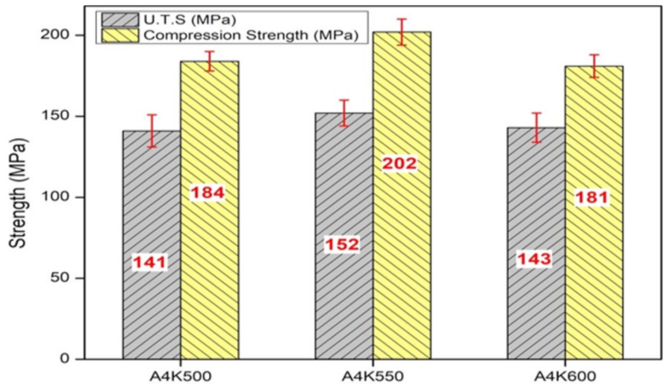

Fig. 8. Variation of Compression strength and U.T.S of the Al-Kaolin composite

The variation of microhardness of the single-mode cavity MAS composite with sintering temperatures was depicted in Fig. 9. Results reveal that the hardness of the Al-4%Kaoline was improved from 83 Hv to 97 Hv with a rise in the sintering temperature from 500°C to 550°C. i,e an enhancement of 16.86% hardness was obtained at 550°C than the composite sintered at 500°C. This enhancement in hardness was due to the reinforcing the stiffer kaolin particles (comprises of harder SiO_2, TiO_2 and CaO) into the ductile aluminium matrix. Despite this, the added kaolin particles pile at the grain boundaries and obstruct the movement of dislocations from one grain to another grain during the indentation test which improves the hardness of the composite [34]. However, increasing the sintering temperature beyond 550°C is prone to decrement in hardness from 97 Hv to 85 Hv. The presence of difference in linear thermal expansion coefficient among the generated agglomerations and aluminium matrix leads to uneven expansions of the interface particles and leads to void generation along the grain boundaries and reduces the hardness of the composite at the higher sintering temperatures [35,36].

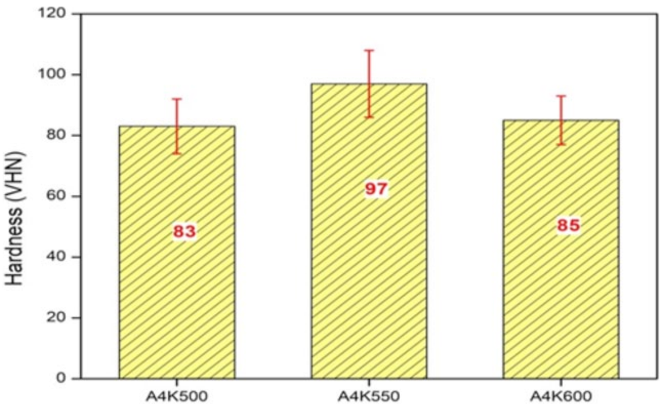

Fig. 9. Variation of Microhardness of the composite with different sintering temperatures

3.4. Toughness of the synthesized composites

The energy absorbing capacity of the synthesized composite was assessed by performing the Charpy test and the obtained results were shown in Fig. 10. There was a 45.7% increment in Toughness of the composite sintered at 550°C than the composite sintered at 500°C. The Magnesium constituent present in the kaolin clay enhances the wettability among the neighbouring particles and creates the strong interfacial bond between adjacent particles, thereby, the toughness of the composite was improved from 6.56 MPa.m$^{1/2}$ to 9.56 MPa.m$^{1/2}$ with increasing the MAS temperature from 500°C to 550°C. However, the generated intermetallics make the composite brittle and reduce the energy-absorbing capability by 31.4% at 550°C sintering temperature than the composite sintered at 500°C. For each wt% of kaolin reinforcement, the experiment was performed on four samples to obtain accurate results. The error bars shown in Fig. 10 lie within the ±5% acceptable deviation range.

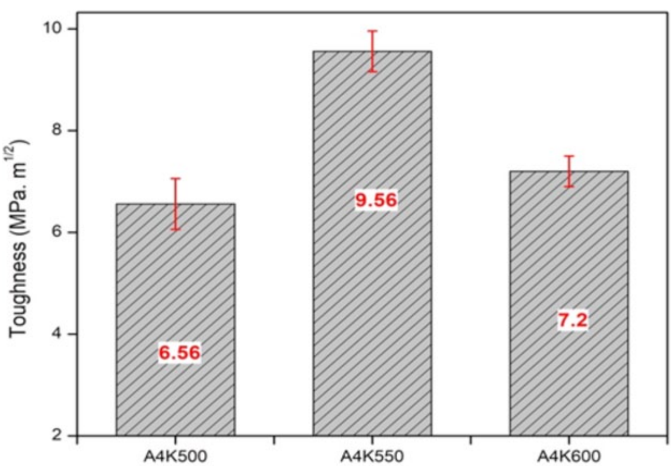

Fig. 10. Toughness of the single-mode cavity MAS sintered composite at different sintering temperatures

3.5. Fractography investigation

Fractography is a failure assessment technique used to examine the fracture surface of materials. In this study, Fractography was performed on the tensile fractured Al-Kaolin composites to identify the mode of fracture for the tensile specimens. Fig. 11 represents the fractography images for the composites sintered at 550°C and 600°C respectively. Dimples were identified on the composite sintered at 550°C which confirms the ductile fracture of the composite [37]. However, the presence of Al_2Cu agglomerations in the composite sintered at 600°C leads to cleavage facts on the fractured surface. These cleavage facts initiate the intergranular crack initiation and make the brittle fracture in the sample [2]. The ductile fracture in the composite sintered at 550°C makes the better utilization of the composite in automobile and industrial applications.

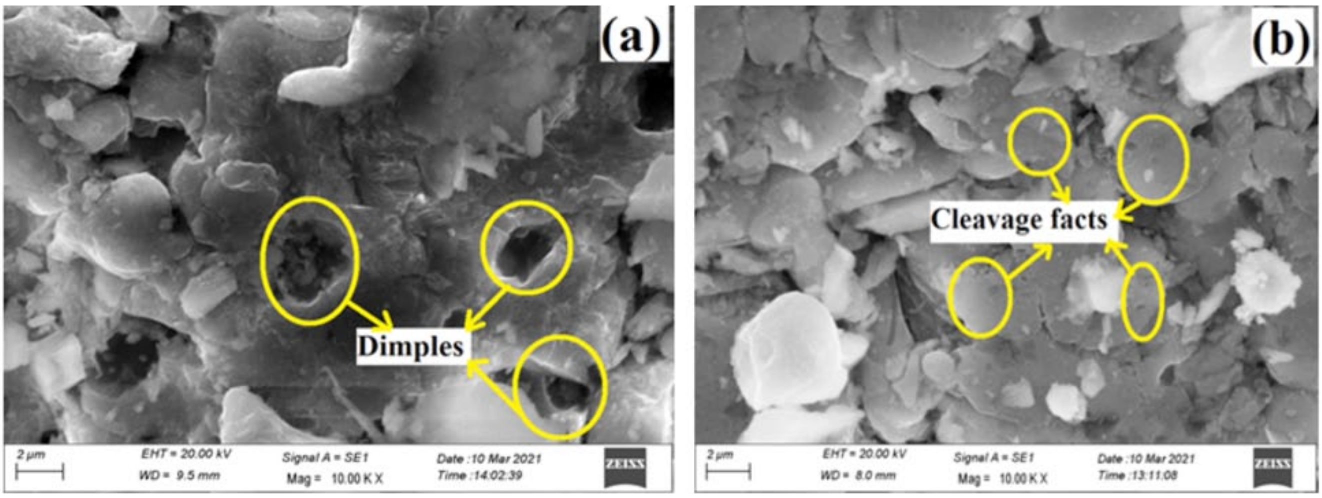

Fig. 11. SEM images for the tensile fractured Al-Kaolin composite at (a) 550°C and (b) 600°C

4. Conclusions

In this research, Al-Kaolin composite was sintered through single-mode cavity microwave-assisted sintering operating at a microwave frequency of 2.45 GHz with 600 W input power. The obtained results were summarized below.

- The permittivity analysis results concluded that the incorporation of 4 wt% kaolin improved the dielectric loss factor of the composite powder (Al-4%Kaolin) which suggests that the composite can be microwave sintered at different sintering temperatures.
- The maximum U.T.S of 136 MPa has been obtained for the microwave sintered 4 wt% kaolin reinforced aluminium composite.
- With increasing the single-mode cavity sintered microwave sintering temperature from 500°C to 550°C, the compression strength and U.T.S was found to be 202 MPa and 152 MPa respectively due to the absorption of microwaves and the uniform kaolin particles dispersion in the aluminium matrix.
- The Al_2Cu agglomerations generated at the grain boundaries of adjacent particles lead to decreases in the compression and U.T.S of the composite when the sintering temperature increases beyond 550°C.
- The fracture toughness of the composite sintered at 550°C was increased to 45.73% compared to the composite sintered at 500°C due to the absence of agglomerations at the grain boundaries.
- Finally, The Al-4%Kaolin composite sintered through single-mode cavity microwave sintering at 550°C exhibits superior properties compared to the composite sintered at 500°C and 600°C sintering temperatures.

REFERENCES

[1] V. Shrivastava, G.K. Gupta, I.B. Singh, Heat treatment effect on the microstructure and corrosion behavior of Al-6061 alloy with influence of α-nanoalumina reinforcement in 3.5% NaCl solution, J. Alloys Compd. **775**, 628-638 (2019). DOI: https://doi.org/10.1016/j.jallcom.2018.10.111

[2] A. Baradeswaran, A. Elayaperumal, R. Franklin Issac, A statistical analysis of optimization of wear behaviour of Al- Al 2O3 composites using taguchi technique, Procedia Eng. **64**, 973-982 (2013). DOI: https://doi.org/10.1016/j.proeng.2013.09.174

[3] V.S.S. Venkatesh, A.B. Deoghare, Fabrication and mechanical behaviour of Al-Kaoline metal matrix composite fabricated through powder metallurgy technique. Mater. Today Proc. **38**, 3291-3296 (2020). DOI: https://doi.org/10.1016/j.matpr.2020.10.021

[4] K. Ravi Kumar, K. Kiran, V.S. Sreebalaji, Micro structural characteristics and mechanical behaviour of aluminium matrix composites reinforced with titanium carbide, J. Alloys Compd. **723**, 795-801 (2017). DOI: https://doi.org/10.1016/j.jallcom.2017.06.309

[5] C.S. Kim, K. Cho, M.H. Manjili, M. Nezafati, Mechanical performance of particulate-reinforced Al metal-matrix composites (MMCs) and Al metal-matrix nano-composites (MMNCs), J. Mater. Sci. **52**, 13319-13349 (2017). DOI: https://doi.org/10.1007/s10853-017-1378-x

[6] A. Pakdel, A. Witecka, G. Rydzek, D.N. Awang Shri, A comprehensive microstructural analysis of Al–WC micro- and nano-composites prepared by spark plasma sintering, Mater. Des. **119**, 225-234 (2017). DOI: https://doi.org/10.1016/j.matdes.2017.01.064

[7] N. Saheb, Spark plasma and microwave sintering of Al6061 and Al2124 alloys, Int. J. Miner. Metall. Mater. **20**, 152-159 (2013). DOI: https://doi.org/10.1007/s12613-013-0707-6

[8] G. Manohar, K.M. Pandey, S.R. Maity, Effect of sintering mechanisms on mechanical properties of AA7075/B4C composite fabricated by powder metallurgy techniques, Ceram. Int. **47**, 15147-15154 (2021). DOI: https://doi.org/10.1016/j.ceramint.2021.02.073

[9] K. Ravi Kumar, T. Pridhar, V.S. Sree Balaji, Mechanical properties and characterization of zirconium oxide (ZrO2) and coconut shell ash (CSA) reinforced aluminium (Al 6082) matrix hybrid composite, J. Alloys Compd. **765**, 171-179 (2018). DOI: https://doi.org/10.1016/j.jallcom.2018.06.177

[10] B.P. Kumar, A.K. Birru, Microstructure and mechanical properties of aluminium metal matrix composites with addition of bamboo leaf ash by stir casting method, Trans. Nonferrous Met. Soc. China. **27**, 2555-2572 (2017). DOI: https://doi.org/10.1016/S1003-6326(17)60284-X

[11] C. Hima Gireesh, K.G. Durga Prasad, K. Ramji, P.V. Vinay, Mechanical Characterization of Aluminium Metal Matrix Composite Reinforced with Aloe vera powder, Mater. Today Proc. **5**, 3289-3297 (2018). DOI: https://doi.org/10.1016/j.matpr.2017.11.571

[12] G. Manohar, K.M. Pandey, S.R. Maity, Effect of microwave sintering on the microstructure and mechanical properties of AA7075/B4C/ZrC hybrid nano composite fabricated by powder metallurgy techniques, Ceram. Int. **47**, 32610-32618 (2021). DOI: https://doi.org/10.1016/j.ceramint.2021.08.156

[13] S. Ozkaya, A. Canakci, Effect of the B4C content and the milling time on the synthesis, consolidation and mechanical properties of AlCuMg-B4C nanocomposites synthesized by mechanical milling, Powder Technol. **297**, 8-16 (2016). DOI: https://doi.org/10.1016/j.powtec.2016.04.004

[14] V.S.S. Venkatesh, A.B. Deoghare, Effect of Sintering Mechanisms on the Mechanical Behaviour of SiC and Kaoline Reinforced Hybrid Aluminium Metal Matrix Composite Fabricated through Powder Metallurgy Technique, Silicon **14**, 5481-5493 (2022). DOI: https://doi.org/10.1007/s12633-021-01333-8

[15] P. Ashwath, M. Anthony Xavior, The effect of ball milling & reinforcement percentage on sintered samples of aluminium alloy metal matrix composites, Procedia Eng. **97**, 1027-1032 (2014). DOI: https://doi.org/10.1016/j.proeng.2014.12.380

[16] J. Croquesel, C.P. Carry, J.M. Chaix, D. Bouvard, S. Saunier, Direct microwave sintering of alumina in a single mode cavity: Magnesium doping effects, J. Eur. Ceram. Soc. **38**, 1841-1845 (2018). DOI: https://doi.org/10.1016/j.jeurceramsoc.2017.12.010

[17] J. Croquesel, D. Bouvard, J.M. Chaix, C.P. Carry, S. Saunier, Development of an instrumented and automated single mode cavity for ceramic microwave sintering: Application to an alpha pure alumina powder, Mater. Des. **88**, 98-105 (2015). DOI: https://doi.org/10.1016/j.matdes.2015.08.122

[18] C. Mortalò, R. Rosa, P. Veronesi, S. Fasolin, V. Zin, S.M. Deambrosis, E. Miorin, G. Dimitrakis, M. Fabrizio, C. Leonelli, Microwave assisted sintering of Na-β''-Al2O3 in single mode cavities: Insights in the use of 2450 MHz frequency and preliminary experiments at 5800 MHz, Ceram. Int. **46**, 28767-28777 (2020). DOI: https://doi.org/10.1016/j.ceramint.2020.08.039

[19] Ö.S. Canarslan, L. Koroglu, E. Ayas, N.S. Canarslan, A. Kara, P. Veronesi, Susceptor-assisted fast microwave sintering of TiN reinforced SiAlON composites in a single mode cavity, Ceram. Int. **47**, 828-835 (2021). DOI: https://doi.org/10.1016/j.ceramint.2020.08.194

[20] G. Manohar, K.M. Pandey, S.R. Maity, Effect of Variations in Microwave Processing Temperatures on Microstructural and Mechanical Properties of AA7075/SiC/Graphite Hybrid Composite Fabricated by Powder Metallurgy Techniques, Silicon. **14** (13):1-17 (2022). DOI: https://doi.org/10.1007/s12633-021-01554

[21] F. Toptan, A. Kilicarslan, A. Karaaslan, M. Cigdem, I. Kerti, Processing and microstructural characterisation of AA 1070 and AA 6063 matrix B4Cp reinforced composites, Mater. Des. **31**, S87-S91 (2010). DOI: https://doi.org/10.1016/j.matdes.2009.11.064

[22] N.N.A. Mohamed Abdul Ghani, M.A. Saeed, I.H. Hashim, Thermoluminescence (TL) response of silica nanoparticles subjected to 50 Gy gamma irradiation, Malaysian J. Fundam. Appl. Sci. **13**, 178-180 (2017). DOI: https://doi.org/10.11113/mjfas.v13n3.593

[23] N. Bajpai, A. Tiwari, S.A. Khan, R.S. Kher, N. Bramhe, S.J. Dhoble, Effects of rare earth ions (Tb, Ce, Eu, Dy) on the thermoluminescence characteristics of sol-gel derived and γ-irradiated SiO2 nanoparticles, Luminescence **29**, 669-673 (2014). DOI: https://doi.org/10.1002/bio.2604

[24] D. Bharali, R. Devi, P. Bharali, R.C. Deka, Synthesis of high surface area mixed metal oxide from the NiMgAl LDH precursor for nitro-aldol condensation reaction, New J. Chem. **39**, 172-178 (2015). DOI: https://doi.org/10.1039/c4nj01332h

[25] V.S.S. Venkatesh, A.B. Deoghare, Effect of Particulate Type Reinforcements on Mechanical and Tribological Behavior of Aluminium Metal Matrix Composites: A Review, Recent Adv. Mech. Eng., 2021 Springer Singapore, pp. 295-303.

[26] S. Phromma, T. Wutikhun, P. Kasamechonchung, T. Eksangsri, C. Sapcharoenkun, Effect of calcination temperature on photocatalytic activity of synthesized TiO2 nanoparticles via wet ball milling sol-gel method, Appl. Sci. **10** (3), 993 (2020). DOI: https://doi.org/10.3390/app10030993

[27] H. Ma, B. Zhao, K. Ding, Y. Zhang, G. Wu, Y. Gao, Influence of dealloying solution on the microstructure of nanoporous copper through chemical dealloying of Al75Cu25ribbons, J. Mater. Res. **35**, 2610-2619 (2020). DOI: https://doi.org/10.1557/jmr.2020.69

[28] S. Gatea, H. Ou, G. McCartney, Deformation and fracture characteristics of Al6092/SiC/17.5p metal matrix composite sheets due to heat treatments, Mater. Charact. **142**, 365-376 (2018). DOI: https://doi.org/10.1016/j.matchar.2018.05.050

[29] R. Liu, C. Wu, J. Zhang, G. Luo, Q. Shen, L. Zhang, Microstructure and mechanical behaviors of the ultrafine grained AA7075/B4C composites synthesized via one-step consolidation, J. Alloys Compd. **748**, 737-744 (2018). DOI: https://doi.org/10.1016/j.jallcom.2018.03.152

[30] N. Kumar Bhoi, H. Singh, S. Pratap, Synthesis and characterization of zinc oxide reinforced aluminum metal matrix composite produced by microwave sintering, J. Compos. Mater. **54**, 3625-3636 (2020). DOI: https://doi.org/10.1177/0021998320918646

[31] V.S.S. Venkatesh, A.B. Deoghare, Effect of microwave sintering on the mechanical characteristics of Al / kaoline / SiC hybrid composite fabricated through powder metallurgy techniques MAS, Mater. Chem. Phys. **287**, 126276 (2022). DOI: https://doi.org/10.1016/j.matchemphys.2022.126276

[32] V.S.S. Venkatesh, A.B. Deoghare, Effect of controllable parameters on the tribological behavior of ceramic particulate reinforced aluminium metal matrix composites: A review, J. Phys. Conf. Ser. **1451** (2020). DOI: https://doi.org/10.1088/1742-6596/1451/1/012025

[33] A.D. Akinwekomi, Microstructural characterisation and corrosion behaviour of microwave-sintered magnesium alloy AZ61/fly ash microspheres syntactic foams, Heliyon **5**, 4, e01531 (2019). DOI: https://doi.org/10.1016/j.heliyon.2019.e01531

[34] X. Zhang, Z. Zhang, Y. Liu, A. Wang, S. Tian, W. Wang, J. Wang, High-performance B 4 C–TiB 2 –SiC composites with tuneable properties fabricated by reactive hot pressing, J. Eur. Ceram. Soc. **39**, 2995-3002 (2019). DOI: https://doi.org/10.1016/j.jeurceramsoc.2019.04.001

[35] M. Oghbaei, O. Mirzaee, Microwave versus conventional sintering: A review of fundamentals, advantages and applications, J. Alloys Compd. **494**, 175-189 (2010). DOI: https://doi.org/10.1016/j.jallcom.2010.01.068

[36] V.S.S. Venkatesh, A.B. Deoghare, Modelling and Optimisation of Wear Parameters for Spark Plasma Sintered Al – SiC – Kaoline Hybrid Composite Modelling and Optimisation of Wear Parameters for Spark Plasma Sintered Al – SiC – Kaoline Hybrid Composite, Adv. Mater. Process. Technol. **08**, 1286-1304 (2021). DOI: https://doi.org/10.1080/2374068X.2021.1939561

[37] A. Bhowmik, D. Dey, A. Biswas, Comparative Study of Microstructure, Physical and Mechanical Characterization of SiC/TiB2 Reinforced Aluminium Matrix Composite, Silicon **13**, 2003-2010 (2021). DOI: https://doi.org/10.1007/s12633-020-00591-2